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An Integrated Fuzzy AHP-TOPSIS for Open-Source ERP Selection: A Case Study in Indonesia

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Abstract

Enterprise Resource Planning (ERP) system is a system that can integrate the company's business processes to be effective and efficient. However, implementing licensed ERP systems that are pretty expensive results in Small and Medium Enterprises (SMEs) that cannot use this system. Therefore, open-source ERP systems are needed by SMEs. This research aims to select an open-source ERP system by integrating the Fuzzy Analytic Hierarchy Process (AHP)- Fuzzy Technique for Order Preference by Similarities to Ideal Solution (TOPSIS) procedure. 5 criteria and 19 criteria are used in the selection of open-source ERP systems. A case study is presented on a Transportation Service provider SME in Indonesia with 11 alternative open-source ERP systems selected for this problem. The results revealed that Package criteria are the most important for selecting open-source ERP systems. Meanwhile, based on the 11 alternative open-source ERP systems selected, the open-source ERP system alternative 10 is the first-ranked open-source ERP system. Furthermore, this study's results can help decision-makers determine the best open-source ERP system that leads to improved SME performance.

Keywords: Selecting, Enterprise resource planning, ERP, Fuzzy AHP, Fuzzy TOPSIS

1. Introduction

One of the most important developments in information technology (IT) in the 1990s was enterprise resource planning (ERP) systems (Deb et al., 2022). ERP has become one of the most widely used business systems that shifts a company's focus from functionality to procedure-driven infrastructure (Al-Mashari, 2002; Utama & Yulianto, 2014). Inventory control, one of the first significant activities of modern production systems, was established in the 1960s, followed by "materials requirement planning" in the 1970s and "manufacturing resources planning II" in the 1980s (Velcu, 2007). ERP-based IT systems had a positive impact in the late 1990s (Umble et al., 2003). Thus, enterprise processes increasingly rely on computer information systems and related applications (Fernando et al., 2021). Due to global market competition and ever-changing customer demands, enterprise operations are becoming more complex, and ERP is becoming a cutting-edge response to the complexity of modern business (Karsak & Özogul, 2009). ERP is software that organizes and integrates related enterprise resources (Shukla et al., 2016). In other words, the main reason for implementing ERP is to organize data across the enterprise (Botta-Genoulaz et al., 2005; May et al., 2013). Automation

of business processes and improved supply chain management through e-commerce are benefits that can be derived from a well-implemented ERP (Liao et al., 2007).

In addition, ERP systems encourage improvements to business processes in an organization by reducing redundancy (Alaskari et al., 2021). ERP can also improve productivity and quality of work (Maditinos et al., 2012). Due to these advantages, ERP is becoming increasingly popular among businesses to become and remain competitive (Deep et al., 2008). ERP has three phases that involve selection, execution, and usage. ERP selection involves problem identification, requirements specification, evaluation of alternatives, and system selection. ERP selection is the most crucial step in ERP installation (Forslund & Jonsson, 2010). Selecting an enterprise ERP has been done in various ways. Priority-based models, optimization, and multi-criteria decision-making (MCDM) are popularly used in ERP selection (Tan et al., 2012). Recently, multi-criteria decision-making (MCDM) models have become one of the popular methods for selecting the best ERP system (Kilic et al., 2014). Since ERP is essential for companies today, choosing the right system that fits their goals and capabilities is crucial and complex (Kilic et al., 2015). Therefore, choosing the right ERP system is vital to minimize the risk of failure and ensure successful implementation (Alaskari et al., 2019; Kilic et al., 2014; Svensson & Thoss, 2021).

The multi-criteria decision-making model has been utilized in ERP selection. Using the MCDM Model, Gürbüz et al. (2012) assessed ERP based on integrated Measuring Attractiveness with a Categorical-Based Evaluation Technique, Analytic Network Process (ANP), and Choquet integral. Park and Jeong (2013) integrated QoS and MCDM Models to select ERP applications with Social Networks. This study provides a guide for selecting the best SaaS ERP system based on criteria. Using the hybrid fuzzy MCDM Model with DEMATEL, ANP, and Analytical Hierarchy Process (AHP) models, Hinduja and Pandey (2019) selected a cloud-based ERP system for businesses. The fuzzy MCDM Model effectively addresses the ERP selection issue. Kazancoglu and Burmaoglu (2013) selected ERP software for a steel forming and hot-dip galvanizing company using TODIM. Some other procedures have also been proposed, such as DEMATEL and fuzzy AHP (Jafarnejad et al., 2012), AHP (Rouyendegh & Erkan, 2011), Intuitionistic Fuzzy Information(Deb et al., 2022), fuzzy SWARA-COPRAS (Garg et al., 2022), Fuzzy AHP dan TOPSIS (Dalyan et al., 2022), and AHP-TOPSIS (Amirkabiri & Rostamiyan, 2018) (Hansen et al., 2023) (Uddin et al., 2021). Ayağ and Yücekaya (2019) evaluated the ERP system using the MCDM Model and grey relational analysis based on fuzzy ANP. The authors utilized the fuzzy extension of the ANP method to reflect the uncertainty and ambiguity of decision-makers in order to find more trustworthy solutions. Recently, considering fuzzy information, Thanh (2022) proposed the Fuzzy Analytic Hierarchy Process model (FAHP) and the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS).

Based on previous research, various procedures have been proposed for ERP selection. Unfortunately, the criteria that have been used focus on ERP selection criteria for licensed and paid ERP systems. Most previous research also states that adopting ERP selection methods is used in large-scale companies with high investment costs. It causes small and medium industries (SMEs) not to have sufficient costs to invest in licensed ERP systems. Currently, many open-source ERP systems can be used by SMEs (Adriana & Amalia-Elena, 2022). Open-source ERP generally comes with a free license but with limited modules and customization (Joseph Christianto, 2022). Many open-source ERP systems can be used, but each has advantages and disadvantages. An open-source ERP system that can provide a suitable package that meets the information needs and needs of the company is a supporting factor to generate better competitiveness. The cost of implementation is recognized as a fundamental aspect that influences ERP adoption decisions in enterprises, especially SMEs. Therefore, open-source ERP systems that have many features and ease of use are potentially chosen by SMEs. Although

previous studies have discussed ERP system selection, the selection of open-source ERP systems is still lacking.

In selecting open-source ERP systems, The criteria and subcriteria for selecting open-source ERP systems differ from licensed and paid ERP systems (Adriana & Amalia-Elena, 20[11] Bhatt et al., 2021). Thus, new criteria and subcriteria must be identified under the nature of open-source ERP systems. Since it involves many criteria and subcriteria, selecting an open-source ERP system is a complex and critical decision-making problem. Therefore, this research aims to select an open-source ERP system by proposing an MCDM methodology that integrates Fuzzy AHP-TOPSIS. Fuzzy AHP is proposed to determine the weights of criteria and subcriteria in a structured manner based on pairwise comparisons. At the same time, Fuzzy TOPSIS is proposed to determine the preference ranking of open-source ERP system selection. Integrating these two MCDM methods aims to overcome the complexity of open-source ERP selection that involves unclear or vague information. Both methods have been used individually or in combination with other methods in previous ERP selection studies. However, the combination of Fuzzy AHP and Fuzzy TOPSIS was not found in the open-source ERP system selection problem. Therefore, this research makes a real contribution to the literature, especially in selecting open-source ERP systems based on the integration of Fuzzy AHP and Fuzzy TOPSIS. This research also contributes new criteria and sub-criteria in selecting open-source ERP systems. On the other hand, the proposed framework is applied to the transportation service provider industry. Therefore, this research recommends an excellent open-source ERP system to improve the company's operations and economic performance.

2. Methods

2.1 Proposed Integrated Method

This section presents the proposed integrated method of selecting an open-source ERP system. The proposed method of selecting an open-source ERP system is shown in Figure 1. In selecting an open-source ERP system, there are four main stages. These stages include identifying criteria and sub-criteria for open-source ERP selection, weighting them using fuzzy AHP, identifying alternatives and assessing their performance using a fuzzy rating scale, and ranking them using fuzzy TOPSIS.

Integrating Fuzzy AHP and Fuzzy TOPSIS MCDM procedures is based on vague decision data information. With fuzzy procedures, the effect of incomplete information can be reduced in decision-making. The fuzzy AHP procedure is proposed for the Weight assessment of criteria and sub-criteria for open-source ERP selection using fuzzy AHP. The weight of criteria and sub-criteria from fuzzy AHP is used Fuzzy TOPSIS method to assess the preference of alternatives. Fuzzy TOPSIS is a frequently used preference assessment and ranking method. Previous studies have also seen its application in various sectors. Details of each stage of the Proposed Integrated Method in open-source ERP selection are presented in the following subsections.

2.1.1 Identification Criteria and Sub-criteria open-source ERP selection

Identification Criteria and Sub-criteria open-source ERP selection are based on a literature review in this first stage. It is done to find a set of criteria and sub-criteria to select an open-source ERP system. To get a broader picture of the criteria and sub-criteria used, the collection of a list of criteria and sub-criteria is not limited to open-source ERP systems. Criteria and sub-criteria were also collected from licensed and paid ERP systems. Furthermore, a group of experts was involved in a focus group discussion to determine the appropriate criteria and sub-criteria for selecting an open-source ERP system. Through the expert discussion and

literature review results, new criteria and sub-criteria were used in selecting an open-source ERP system. Furthermore, the selected criteria and sub-criteria are weighted with the Fuzzy AHP procedure, described in detail in the next section.

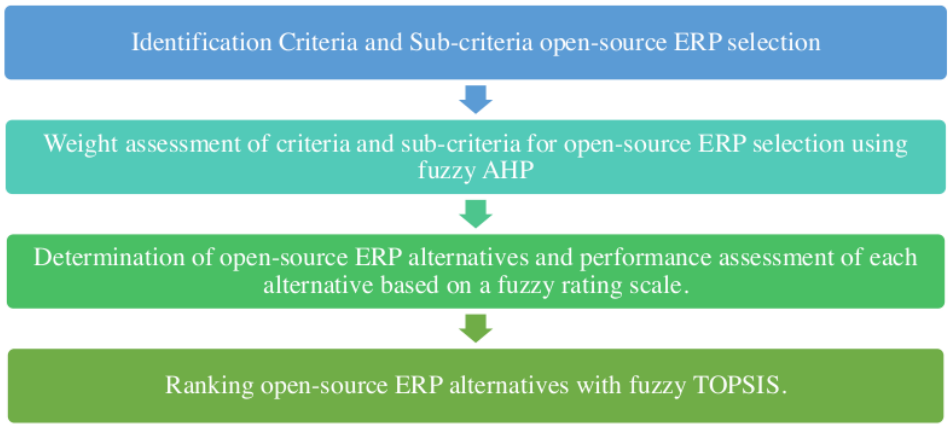

Figure 1 Proposed method of selecting an open-source ERP system

2.1.2 Weight assessment of criteria and sub-criteria using fuzzy AHP

This section presents the weighting based on the selected criteria and sub-criteria. The weighting of criteria and sub-criteria is carried out using the Fuzzy AHP method. Fuzzy AHP is a procedure to overcome the shortcomings of the classic AHP procedure (Baroto et al., 2022; Utama, 2021; Utama et al., 2021). According to Liu et al. (2020), the fundamental difference between AHP and Fuzzy AHP is replacing crisp values with fuzzy sets. In previous research, Fuzzy AHP has been used to solve various problems, such as software selection performance analysis (Afolayan et al., 2020; Che et al., 2020), and supplier selection (Amallynda et al., 2022; Djunaidi et al., 2019; Ho et al., 2021; Kar, 2015; Kilincci & Onal, 2011; Wijaya & Widodo, 2022). The proposed Fuzzy AHP procedure is adopted from the Fuzzy AHP procedure proposed by Kilic et al. (2014). The weighting stages based on criteria and sub-criteria with fuzzy AHP are described as follows:

Step 1: Define fuzzy pairwise comparison matrix

Define fuzzy pairwise comparison matrix with $F = [\tilde{c}_{ij}]_{n\times n}$ as a matrix for several n criteria compared to goals. $\tilde{c}_{ij}$ is a fuzzy set representing the relative importance of criterion i over j. Vice versa $1/\tilde{c}_{ij}$ equal to the relative importance of Criterion j over i or $\tilde{c}_{ji}$. Pairwise comparisons on criteria and sub-criteria are based on focus group discussions with experts. The pairwise comparison assessment is based on a triangular fuzzy number scale, as presented in Table 1. For example, if the assessment results of the relative importance of criteria 1 over criteria 2 are described by a triangular fuzzy number (4,5,6). So, criteria 2 over criteria 1 will be worth (1/6, 1/5, 1/4).

Step 2: Calculate the fuzzy weights of the criteria

At this stage, a fuzzy set will be obtained that describes the weight of importance of each criterion. One method to get the fuzzy weight of each criterion is the geometric mean method proposed by Buckley (1985). Equation (1) computes the geometric mean of the fuzzy comparison value of criterion i for each criterion. Furthermore, the fuzzy weight of the i-th criterion, represented by a triangular fuzzy number, is found in Equations (2) and (3).

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

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

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

Table 1 Variable Linguistic and Triangular Fuzzynumber AHP Importance

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
ExI	Extremely Importance	9,9,9	One element is absolutely more important than the other
IV	Intermediate Values	1,2,3; 3,4,5; 5,6,7; 7,8,9	When a compromise between two elements is required

Step 3: Defuzzify the fuzzy weights

At this stage, the weights in fuzzy sets will be converted into crisp weights for further comparison. It is necessary because fuzzy sets will be difficult to compare directly. According to Liu et al. (2020), and The Center of Area (COA) method, or the centroid method, is one of the most common defuzzification methods. Nonfuzzy value M_i from fuzzy number $\tilde{w}_i$ can be calculated using Equation (4).

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

M_i is a nonfuzzy number, normalized weight N_i obtained by normalization. After getting each N_i, global weight of all criteria M_i obtained by multiplying the locally normalized criterion weights by the normalized weights of the related dimensions.

2.1.3 Determination alternatives and performance assessment based on a fuzzy scale

The next stage is the determination of alternatives and performance assessment based on a fuzzy scale. Managers and decision-makers determine alternative open-source ERP systems that can be implemented in the company. The open-source ERP system alternatives must be selected based on the organization's requirements. Experts also evaluate each criterion and sub-criterion of alternative open-source ERP systems through focus group discussions. Table 2 displays the linguistic variables and Triangular Fuzzy number performance evaluation of the open-source ERP stem.

Table 2 Variabel Linguistic and Triangular Fuzzy number 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

2.1.4 Ranking open-source ERP alternatives using fuzzy TOPSIS

The last stage in the selection of open-source ERP systems is the ranking of alternatives using fuzzy TOPSIS. TOPSIS requires that chosen alternatives have the shortest Euclidean distance from the positive ideal solution, which minimizes cost and maximizes benefit criteria. (Natalia et al., 2020). This study uses the fuzzy TOPSIS to determine the alternatives' ranking in open-source ERP system selection. This research adopts the fuzzy TOPSIS procedure proposed by Nădăban et al. (2016). The detail procedures of fuzzy TOPSIS are as follows:

Step 1. Specify a rating for alternatives

Assume there is a decision group with K members, the fuzzy rating of the k^{th} decision-maker about alternative A_i concerning the criterion C_j is denoted in Equation (5).

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

Step 2. Compute the aggregated fuzzy ratings for alternatives

The aggregated fuzzy rating $\tilde{x}_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right)$ of i^{th} alternative w.r.t. j^{th}. The criterion is obtained in Equation (6).

$$a_{ij} = \min_{k}\{a_{ij}^{k}\}, b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ij}^{k}, c_{ij} = \max_{k}\{c_{ij}^{k}\} \quad (6)$$

Step 3. Compute the normalized fuzzy decision matrix

The normalized fuzzy decision matrix is $\tilde{R} = [\tilde{r}_{ij}]$ can be seen in Equations (7) and (8).

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

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

Step 4. Compute the weighted normalized fuzzy decision matrix

The weighted normalized fuzzy decision matrix is $\tilde{V} = \left(\tilde{v}_{ij}\right)$ can be formulated in Equation (9). This weight w_j is generated from the fuzzy AHP weighting described in the previous section.

$$\tilde{v}_{ij} = \tilde{r}_{ij} \times w_j \quad (9)$$

Step 5. Compute the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS)

Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) can be calculated based on Equation (10) and (11).

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

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

Step 6. Compute the distance from each alternative to the FPIS and the FNIS

The computation of the distance from each alternative can be formulated on Equation (12). Let be the distance from each alternative A_i to the FPIS and the FNIS, respectively.

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

Step 7. Compute the closeness coefficient CC_i for each alternative

For each alternative (A_i), we can calculate the Closeness Coefficient (CC_i) based on Equation (13).

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*} \quad (13)$$

Step 8. Rank the alternatives

The alternative with the highest closeness coefficient represents the best alternative.

2.2 Case Study

This research presents an open-source ERP system selection case study at an SME Transportation Service Provider in Indonesia. This research involves eight experts in identifying criteria and sub-criteria, pairwise comparison assessment of criteria and sub-criteria, and performance assessment of each alternative open-source ERP system.

In identifying criteria and sub-criteria, an in-depth literature study was conducted to obtain a list of criteria often used in ERP system selection problems. The literature used is research that discusses ERP system selection in general. The criteria and sub-criteria used are decided through focus group discussions with experts in selecting an open-source ERP system. The focus group discussion Criteria and sub-criteria results are classified into five aspects, and 19 criteria are determined, presented in Table 3.

Table 3 Criteria and sub-criteria for selecting open-source ERP systems

Main Criteria	ID	Sub Criteria
Cost	C1	Consultant and implementation cost
	C2	Support and maintenance cost
	C3	Hosting cost
Reputation	C4	Brand image
	C5	Update availability history
	C6	Sustainability
Package	C7	Number of free modules
	C8	Availability of 3rd party modules
	C9	Accommodating logistics service business processes
	C10	Integration with satellite-based navigation system
	C11	Integration level between modules
Operation and Technical	C12	Implementation time
	C13	User friendliness
	C14	Online help and tutorials
	C15	Ease of data migration
	C16	Ease of maintenance
Flexibility	C17	Ease to customization
	C18	Upgradeability
	C19	Potential for future strategy

Through focus group discussions, the experts also conducted pairwise comparison assessments of criteria and sub-criteria. Meanwhile, the experts also managed to identify 11

alternative open-source ERP systems that were considered for selection. The performance assessment of each alternative open-source ERP system was also carried out through focus group discussions.

3 Results and Discussion

3.1 Criteria and sub-criteria weight

This section presents the weighting criteria and sub-criteria results based on Fuzzy AHP. The results of the weighting of criteria and sub-criteria for selecting open-source ERP systems are presented in Table 4. The results show that the Package criteria have a weight value of 0.342. This weight is the largest among other open-source ERP system selection criteria. Criteria with weights ranked two to five in a row are Cost, Reputation, Operation & Technical, and Flexibility. Flexibility criteria are in the lowest position with the lowest importance weight of 0.085. Furthermore, the Package criteria are critical because open-source ERP systems generally provide limited free modules in the installation package. Therefore, SMEs need an open-source ERP system with a package accommodating business needs. On the other hand, not all open-source ERP systems have modules that suit business needs, especially for SMEs that provide transportation services. For example, in the Transportation Services business, this company needs a fleet management module that is needed to manage the company's transportation fleet. Therefore, with the package as the most crucial criterion, implementing an open-source ERP system is more about long-term goals.

Meanwhile, the cost criterion occupies the second position, which indicates that cost is an essential criterion after the package criterion. In open-source ERP systems, the installation package of the open-source ERP system is indeed provided free of charge. However, it does not mean the company does not need any costs. Some costs must be invested in the implementation process, such as consulting fees, maintenance, and hosting rental. Not only that, but companies also need to invest in supporting facilities and conduct training on the use of open-source ERP systems. Companies also need to incur costs if they use additional modules that are not free but are needed to accommodate the company's business processes.

Based on the weighting of criteria, this study's results indicate differences in the level of importance of aspects in selecting paid and open-source ERP systems. In previous research investigated by Kilic et al. (2015), the research findings show that the selection of ERP systems for SMEs shows the cost aspect as the aspect with the highest weight on the paid ERP system. However, this study found that the package criteria became fundamental in open-source ERP systems because the features provided by open-source ERP systems were limited (Joseph Christianto, 2022).. In contrast to paid ERP systems, the cost aspect becomes very significant because the modules are tailored to the business needs of the vendor. Therefore, SMEs adopting open-source ERP systems must ensure that the system has a package accommodating the company's business processes.

Interestingly, reputation was revealed as the third most crucial aspect that needs to be prioritized. Choosing an Open-source ERP system should not be haphazard. It is essential to pay attention to the provider's track record. It can minimize losses if there is a change in policy from a vendor that provides a system for free.

Based on the weighting of sub-criteria with Fuzzy AHP, the sub-criteria Accommodating logistics service business processes (C9), Support and maintenance cost (C2), and Consultant and implementation cost (C1) are the three sub-criteria with the most significant weight. Accommodating logistics service business processes (C9) have the highest weight. This result is very reasonable because the case study of this research is on SME logistics service providers that require logistics features. The limited number of modules offered by open-source

ERP systems makes analyzing the free modules provided from the start essential. The modules provided must accommodate the company's business processes, such as a module for the vehicle assignment process in a logistics service business. The adopted open-source ERP system must have modules accommodating the business process. Meanwhile, the sub-criteria Implementation time (C12) and Online help and tutorials (C14) are ranked 18-19 with a weight of 0.011.

Table 4 Weighting criteria and sub-criteria for ERP system selection

Criteria	Weight	Sub-Criteria		Local Weight	Global Weight
Cost	0.248	C1	Consultant and implementation cost	0.297	0.074
		C2	Support and maintenance cost	0.617	0.153
		C3	Hosting cost	0.086	0.021
Reputation	0.180	C4	Brand image	0.426	0.077
		C5	Update availability history	0.148	0.027
		C6	Sustainability	0.426	0.077
Package	0.342	C7	Number of free modules	0.176	0.060
		C8	Availability of 3rd party modules	0.102	0.035
		C9	Accommodating logistics service business processes	0.467	0.160
		C10	Integration with satellite-based navigation system	0.061	0.021
		C11	Integration level between modules	0.195	0.067
Operation & Technical	0.146	C12	Implementation time	0.075	0.011
		C13	User friendliness	0.373	0.054
		C14	Online help and tutorials	0.075	0.011
		C15	Ease of data migration	0.141	0.021
		C16	Ease of maintenance	0.337	0.049
Flexibility	0.085	C17	Ease to customization	0.225	0.019
		C18	Upgradeability	0.457	0.039
		C19	Potential for future strategy	0.319	0.027

3.2 Alternatives ERP Score

The score for each alternative is obtained by normalizing the closeness coefficient value presented in Table 5. It shows that the scores for each alternative are not significantly different and have a competitive score. However, alternative 10 has the highest score. Previously, it has been found that the package criterion has the highest weight. In addition, there are accommodating logistics service business processes as a criterion with the highest local weight. The analysis shows that the alternative 10 Open-source ERP system has modules to accommodate SMEs of Transportation Services Provider business processes. For example, apart from other basic modules, a fleet management module allows transportation companies to attain specific tasks relating to a company's fleet of vehicles. In addition, many third-party modules can be used for free.

3.2 Managerial implication

An ERP system is designed to increase business productivity by coordinating parts of an organization's operations through an integrated database and software applications. Many

SMEs need help implementing an ERP system even though the benefits are evident because of the prohibitive investment costs. However, many ERP system vendors lately provide open-source systems to implement in the company's business operations. Experts and practitioners estimate that about two-thirds of ERP system implementations fail due to incompatibility of business procedures and expensive implementation costs. Therefore, selecting an ERP system in the ERP adoption/implementation process is necessary, especially for open-source systems.

The selection of a scientifically sound open-source ERP system is essential in the ERP adoption/implementation process due to the large variety of open-source ERP system offerings. Each open-source ERP system has strengths and weaknesses. Therefore, to increase the chances of success, all available open-source ERP system selection criteria and sub-criteria options must be carefully considered. MCDM decision-making tools are widely used to assist the ERP system selection process because there are many criteria and sub-criteria to be considered. This procedure was chosen because it can accommodate the trade-offs of the criteria and sub-criteria used in the ERP system selection.

Table 5 Rank of alternatives based on TOPSIS

	d*	d-	Cj	Normalized	Ranking
Alt1	0.511	0.367	0.417	7.73%	10
Alt2	0.390	0.495	0.558	10.34%	2
Alt3	0.426	0.461	0.519	9.61%	3
Alt4	0.485	0.400	0.452	8.37%	8
Alt5	0.481	0.411	0.460	8.52%	7
Alt6	0.469	0.411	0.466	8.64%	6
Alt7	0.495	0.383	0.436	8.07%	9
Alt8	0.448	0.441	0.495	9.18%	4
Alt9	0.520	0.372	0.417	7.72%	11
Alt10	0.259	0.616	0.703	13.03%	1
Alt11	0.464	0.420	0.475	8.80%	5

This study aims to select an open-source ERP system faced by an SME transportation service provider in Indonesia. The criteria for selecting an open-source ERP system are determined based on the needs and desires of the company's top management. After the criteria and sub-criteria are determined, a fuzzy AHP methodology is proposed to weight the criteria and sub-criteria. Furthermore, the assessment of each alternative open-source ERP system offered. Fuzzy TOPSIS is used by utilizing the weights of the criteria and sub-criteria of the fuzzy AHP methodology to determine the preference for open-source ERP systems.

The selection of open-source ERP systems is evaluated based on several criteria Cost, Reputation, Package, Operation & Technical, and Flexibility. These five criteria are translated into 19 sub-criteria. The results show that the Package criteria have a weight value more significant than the other criteria, followed by the cost criteria. Based on the weighting of sub-criteria with Fuzzy AHP, the three sub-criteria with the most weight are Accommodating logistics service business processes (C9), Support and maintenance costs (C2), and Consultant and implementation costs (C1). This finding shows how SMEs consider package and cost criteria in selecting an open-source ERP system. The most critical to consider is the sub-criteria of features that are by the company's problems, such as the Accommodating logistics service business processes (C9) sub-criteria.

Meanwhile, cost needs to be considered, such as the Support and maintenance costs (C2) and Consultant and implementation costs (C1) sub-criteria. Although open source, SMEs

also require support and maintenance costs (C2) and Consultant and implementation costs (C1). Therefore, the cost is also essential when selecting an ERP system.

Based on the proposed method that integrates Fuzzy AHP and Fuzzy TOPSIS, the results show that the proposed procedure is technically sound and acceptable to the organization. When the ambiguity and complexity of the decision situation are addressed by combining the benefits of two decision support methods, decision makers can feel confident in their choice. The fuzzy AHP method can help managers and decision-makers weight the criteria and sub-criteria for selecting an open-source ERP system. This procedure can easily weight the criteria and sub-criteria. Meanwhile, fuzzy TOPSIS is proven to efficiently rank the preferences of open-source ERP system alternatives based on vague information.

4. Conclusion

The research aims to select an open-source ERP system for SME transportation service providers. Five criteria and 19 sub-criteria are proposed to solve the problem of selecting an open-source ERP system. This research proposes an MCDM methodology integrating fuzzy AHP and TOPSIS in ERP system selection. Fuzzy AHP is applied to determine the weight of each criterion and sub-criteria. Fuzzy TOPSIS method is used to determine the score and ranking of each alternative ERP system. The results of this study show that package criteria are the most important criteria that need to be prioritized to select an open-source ERP system. In addition, cost and reputation criteria are the criteria that rank second and third. In addition, the ERP system in alternative ten is stated as the open-source ERP system with the highest preference, especially for transportation service provider SMEs. This ERP system in alternative 10 has advantages in the packages offered, especially having modules that can be configured according to the business processes of Transportation Service Provider SMEs.

However, there are still limitations in this study. The completeness of the proposed framework may be limited because the attributes proposed in this study were obtained from the literature and assessed by eight experts. It is recommended for future research to expand and deepen the proposed attributes to improve the discussion and ERP system selection framework. In addition, due to the specific knowledge, experience, and understanding of ERP systems and the transportation service provider industry, the limited number of experts involved as respondents of this study may cause bias in interpreting the results. Therefore, to address this issue, increasing the number of expert respondents is essential for future studies. Furthermore, future research should include other industries besides SMEs and the transportation service provider industry to understand ERP system selection better. Meanwhile, this study also ignored the relationship between criteria. Therefore, future research must consider the relationship between criteria in selecting open-source ERP systems.

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- **Submission email**

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Dana Marsetiya Utama, ST., MT. . <dana@umm.ac.id> Mon, Apr 24, 2023 at 6:15 PM
To: editor@sc-press.com

Dear Editor.

We submitted a manuscript with the title " An Integrated Fuzzy AHP-TOPSIS for Open-Source ERP Selection: A Case Study in Indonesia" to be processed in the Journal of Logistics, Informatics and Service Science. we believe this article has a contribution in ERP Selection. In addition, an integrated method based on Fuzzy AHP-TOPSIS was proposed to solve real case in Indonesia. Therefore, this article has the ability to make a real contribution to ERP Selection. Here we attach our article and similarity check (14%).

Regards

Dana Marsetiya Utama

Best Regards
Dana Marsetiya Utama
Department of Industrial Engineering University Of Muhammadiyah Malang (UMM), Indonesia.
Address: Jl. Tlogomas No 246 Malang, Jawa Timur, Indonesia.
Email: dana@umm.ac.id

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3. First revision: Revision Required Decision (1 Mei 2023)

- **Decision email**
- **Reviewer comments**

JLISS DECISION: REVISION REQUIRED
2 messages

Mincong <tang12290@gmail.com> Mon, May 1, 2023 at 8:54 AM
To: "Dana Marsetiya Utama, ST., MT. ." <dana@umm.ac.id>

Dear Author,
Please check the reviewer comments, you MUST return the revised version before May 21, 2023. When you submit the revised version, please DO remember to provide a response to reviewers with details. THIS IS A MUST. THIS IS A MUST. THIS IS A MUST.
In addition, please strictly format your paper according to the template of the journal. Thank you very much.
Best regards,
Mincong

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REVIEWER'S REPORT

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Manuscript Title	An Integrated Fuzzy AHP-TOPSIS for Open-Source ERP Selection: A Case Study in Indonesia
Authors	

Please provide your comments and suggestions considering the following points for ´publication in Journal.

Is the topic of the article suitable for publication?	√☐Yes	☐ No
Is the article **original** with **new** and **important** results?	√☐Yes	☐ No
Is the title of the article appropriate?	√☐ Yes	☐ No
Are the abstract and keywords appropriate?	☐Yes	√☐No
Is the quality of the illustrations and tables appropriate?	√☐Yes	☐ No
Are the references up-to-date and adequate with journal style?	√☐Yes	☐ No
Is the article well organized and clearly written?	√☐Yes	☐ No
Is the English language satisfactory?	☐Yes	√☐ No
Are the conclusions sound and justified?	√☐Yes	☐ No
Did the author confuse the summary with conclusion?	☐Yes	√☐ No

What is your overall grading of the manuscript?

At least 3 to consider publication after revision ☐ 0 (worst) ☐ 1 ☐ 2 ☐3 √☐ 4 ☐ 5 (best)

COMMENTS:

The paper presents an integrated Fuzzy Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) for open-source ERP selection. The authors have conducted a case study in Indonesia to demonstrate the applicability of their proposed approach. Overall, the paper is well-written and organized, and the research work is of high quality. However, some minor revisions are needed to improve the clarity and presentation of the research.

Specific Comments:

1. The introduction of the paper should be improved to provide a more comprehensive overview of the study. The authors should provide more background information on open-source ERP and the challenges faced in the selection process. Additionally, the research questions and objectives of the study should be clearly stated in the introduction section.
2. In Section 2, The authors should provide more information about the selection criteria used in the study and how they were derived. Additionally, the authors should provide more details about the open-source ERP options considered in the study, such as the features and functionalities of each option.
3. In Section 3, the results of the study should be presented more clearly. The authors should provide a summary of the results obtained from the Fuzzy AHP and TOPSIS analyses, including the weights and scores of each criterion and alternative.
4. In the discussion section, the authors should provide more insights into the findings of the study. The authors should discuss the strengths and weaknesses of the selected open-source ERP and compare it with other options. Additionally, the authors should provide some recommendations for future research.
5. The conclusion section is brief and could be improved. The authors should provide a more comprehensive summary of the study's findings and their implications. Additionally, the authors should emphasize the contribution of the study to the existing literature.
6. The paper's language and grammar need to be improved. There are some grammatical errors and

awkward sentences throughout the paper that need to be corrected.

7. The paper's formatting should be improved. The authors should ensure that the paper adheres to the formatting guidelines of the journal.

Overall, the paper has the potential to make a valuable contribution to the field of open-source ERP selection. However, the authors should make some revisions to improve the clarity and presentation of the research.

RECOMMENDATION REGARDING THIS MANUSCRIPT:

√Minor Revisions ☐ Major Revisions ☐ Reject☐ Another Conference/Journal ☐

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Manuscript No.	
Manuscript Title	An Integrated Fuzzy AHP-TOPSIS for Open-Source ERP Selection: A Case Study in Indonesia
Authors	

Please provide your comments and suggestions considering the following points for ´publication in Journal.

Is the topic of the article suitable for publication?	√☐Yes	☐ No
Is the article **original** with **new** and **important** results?	√☐Yes	☐ No
Is the title of the article appropriate?	√☐ Yes	☐ No
Are the abstract and keywords appropriate?	☐Yes	√☐No
Is the quality of the illustrations and tables appropriate?	☐Yes	√☐No
Are the references up-to-date and adequate with journal style?	√☐Yes	☐ No
Is the article well organized and clearly written?	√☐Yes	☐ No
Is the English language satisfactory?	☐Yes	√☐No
Are the conclusions sound and justified?	√☐Yes	☐ No
Did the author confuse the summary with conclusion?	☐Yes	√☐No

What is your overall grading of the manuscript?

At least 3 to consider publication after revision ☐ 0 (worst) ☐ 1 ☐ 2 ☐3 √☐ 4 ☐ 5 (best)

COMMENTS:

The paper is well written and has some merits to the field. I have some minor comments for you to improve:

1. The title is not good, WHY A CASE IN INDONESIA COULD BE ATTRACTIVE?
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4. Please make sure that sufficient details about the methodology be provided, otherwise people cannot replicate your method.
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   Please check carefully about the subtitles of each section.
   Please include some references from JSMS and JLISS.
   Format your paper according to the template of the journal.

RECOMMENDATION REGARDING THIS MANUSCRIPT:

Minor Revisions √ ☐ Major Revisions ☐ Reject☐ Another Conference/Journal ☐

4. Revision submitted (20 Mei 2023)

- **Revised version submission email**
- **Reviewer comments response**
- **Revised version with highlights**

JLISS DECISION: REVISION REQUIRED
2 messages

Dana Marsetiya Utama, ST., MT. . <dana@umm.ac.id> Sat, May 20, 2023 at 10:49 AM
To: Mincong <tang12290@gmail.com>

Dear Editor,

Here we attach the revised article with 3-word files, namely the response to the reviewer's comments, the revised article with highlights, and the revised article that has been adjusted to the template (clean version).

Best Regards
Dana Marsetiya Utama
Department of Industrial Engineering University Of Muhammadiyah Malang (UMM), Indonesia.
Address: Jl. Tlogomas No 246 Malang, Jawa Timur, Indonesia.
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Responses of Reviewers Comments

Title: An Integrated Fuzzy AHP-TOPSIS for Open-Source ERP Selection: A Case Study in Indonesia

Dear Editor and Reviewers;
Greetings
Thank you very much for your comments.
Regards;

Reviewer 1:

The paper presents an integrated Fuzzy Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) for open-source ERP selection. The authors have conducted a case study in Indonesia to demonstrate the applicability of their proposed approach. Overall, the paper is well-written and organized, and the research work is of high quality. However, some minor revisions are needed to improve the clarity and presentation of the research.	**Thank you very much for your comments.** **The quality of this manuscript is improved thanks to editors and reviewers 'comments.**
1. The introduction of the paper should be improved to provide a more comprehensive overview of the study. The authors should provide more background information on open-source ERP and the challenges faced in the selection process. Additionally, the research questions and objectives of the study should be clearly stated in the introduction section.	**Thank you very much for your comments.** **Improved** **The authors have revised the manuscript.** **Please see section 1. Introduction.** Various ERP selection procedures have been suggested in prior studies. Nevertheless, the utilized criteria are predominantly centered on selecting licensed and fee-based ERP systems, primarily catering to large organizations with substantial investment costs. This approach neglects the needs of small and medium enterprises (SMEs) that lack the financial resources to invest in licensed ERP systems. Thus, this study posited a need for discourse on ERP systems, particularly open-source ERP systems suitable to enhance SMEs. Currently, SMEs can utilize various open-source ERP systems (Adriana & Amalia-Elena, 2022). Open-source ERP systems refer to ERP systems that have publicly accessible source code. It implies that developers and programmers can scrutinize and modify it at their discretion. Subsequently, individuals can distribute updated iterations or alternative versions that integrate their modifications. Open-source ERP generally has a free license but limited modules and customization (Joseph Christianto, 2022). Several open-source ERP systems exist, but each system possesses its own set of merits and demerits. Utilizing an open-source ERP system can serve as a valuable tool in meeting a company's information and operational requirements, thereby contributing to enhanced competitiveness. The cost of implementation is recognized as a

	fundamental aspect that influences ERP adoption decisions in enterprises, especially SMEs. Therefore, open-source ERP systems that have many features and ease of use are potentially chosen by SMEs. Although prior studies have addressed the selection of ERP systems, the selection of open-source ERP systems remains limited. Additionally, the discussion and implementation of ERP systems for SMEs are frequently overlooked. Therefore, this study strives to identify the primary selection criteria for open-source ERP systems for SMEs. **Regarding the study's objectives please see section 1. Introduction paragraph 5.** To address this issue, this study aims to achieve the following objectives: (1) To identify the essential criteria and sub-criteria required to be prioritized for the selection of open-source ERP systems based on qualitative data; (2) To determine an ideal alternative among open-source ERP systems; (3) To provide practical guidance to SMEs for enhancing their operations.
2. In Section 2, The authors should provide more information about the selection criteria used in the study and how they were derived. Additionally, the authors should provide more details about the open-source ERP options considered in the study, such as the features and functionalities of each option.	**Thank you very much for your comments.** We have revised it in section 2. "Identification Criteria and Sub-criteria open-source ERP selection are based on a literature review in this first stage. It is done to find a set of criteria and sub-criteria to select an open-source ERP system. To get a broader of the criteria and sub-criteria used, the collection of a list of criteria and sub-criteria is not limited to open-source ERP systems. Criteria and sub-criteria were also collected from licensed and paid ERP systems. Furthermore, a group of experts was involved in a focus group discussion to determine the appropriate criteria and sub-criteria for selecting an open-source ERP system. Through the expert discussion and literature review results, new criteria and sub-criteria were used in selecting an open-source ERP system."
3. In Section 3, the results of the study should be presented more clearly. The authors should provide a summary of the results obtained from the Fuzzy AHP and TOPSIS analyses, including the weights and scores of each criterion and alternative.	**Thank you very much for your comments.** **Improved** **The authors have revised the manuscript.** **Please see section 3. Results and Discussion, sub-section 3.1. Criteria and sub-criteria weight.** The fuzzy AHP findings indicate that the package criteria, with a weight of 0.342, is the most crucial factor to consider when choosing an open-source ERP system. It is highlighted that how the open-source ERP system is packaged has the potential to affect both the cost and complexity of its implementation. Additionally, the remaining criteria are prioritized as follows: Cost holds a weight of 0.248, reputation holds a weight of 0.180, Operation and Technical hold a weight of 0.180, and flexibility

	holds a weight of 0.085. On the other hand, the outcomes of the fuzzy AHP analysis also denote that the sub-criteria Accommodating logistics service business processes (weighted at 0.160), Support and maintenance cost (weighted at 0.153), and consultant and implementation cost (weighted at 0.074) are the three sub-criteria that carry the most substantial weight and needed to be prioritized in selecting an open-source ERP system. **Please see section 3. Results and Discussion, sub-section 3.2. Alternatives ERP Score.** The normalization of the closeness coefficient value presented in Table 5 is utilized to derive the score for each alternative. The results indicate that the scores attributed to each alternative do not exhibit a significant difference and are characterized by a comparable level of competitiveness. Nevertheless, it is noteworthy that Alternative 10 demonstrates the highest score, as evidenced by the normalized percentage of 13.03%.
4. In the discussion section, the authors should provide more insights into the findings of the study. The authors should discuss the strengths and weaknesses of the selected open-source ERP and compare it with other options. Additionally, the authors should provide some recommendations for future research.	**Thank you very much for your fruitful comments.** **The authors have revised the manuscript.** **Please see section 3. Results and Discussion, sub-section 3.1. Criteria and sub-criteria weight.** Based on the findings, the criteria of the ERP package play a crucial role as they significantly impact the successful implementation and adoption of the system within a business. It has been emphasized that the packaging of open-source ERP systems can affect the system's cost and complexity. This research is in line with the research findings presented by Zhang et al. (2005) and Ngai et al. (2008) which found that in the selection of ERP systems, the criteria for the ERP model package provided have an essential meaning in the adoption of ERP systems. It can ensure that the selected system fits business needs and can be integrated with existing information technology infrastructure. For example, some ERP systems offer a simplified installation process with limited customization options. In contrast, others provide a wide range of modules and customization possibilities that require substantial resources for implementation. Furthermore, it is essential for a package of an open-source ERP system to include adequate support and maintenance guidelines to ensure smooth system operation and alignment with the organization's needs, particularly for small and medium-sized enterprises (SMEs) (Amado & Belfo, 2021). As a result, SMEs should choose an open-source ERP system that offers a comprehensive suite of tools tailored to their specific business requirements. However, it should be noted that open-source ERP systems often have limited complementary modules included in the installation package. In particular, SMEs in the transportation services industry may face challenges as these systems may not offer modules that cater specifically to their needs. For example, implementing a fleet management module is crucial for effectively managing the transportation fleet in the transportation services industry. Therefore, the package of an open-source ERP system holds significant importance in the selection process as it can impact the costs, complexity, and

	effectiveness of implementing and integrating the system within an enterprise (Benlian & Hess, 2011). **Regarding the future research, please see section 4. Conclusion.** The completeness of the proposed framework may be limited because the attributes proposed in this study were obtained from the literature and assessed by eight experts. It is recommended for future research to expand and deepen the proposed attributes to improve the discussion and ERP system selection framework. **Please see section 4. Conclusion.** In addition, due to the specific knowledge, experience, and understanding of ERP systems and the transportation service provider industry, the limited number of experts involved as respondents of this study may cause bias in interpreting the results. Therefore, to address this issue, increasing the number of expert respondents is essential for future studies. **Please see section 4. Conclusion.** Furthermore, future research should include other industries besides SMEs and the transportation service provider industry to understand ERP system selection better. Meanwhile, this study also ignored the relationship between criteria. Therefore, future research must consider the relationship between criteria in selecting open-source ERP systems.
5. The conclusion section is brief and could be improved. The authors should provide a more comprehensive summary of the study's findings and their implications. Additionally, the authors should emphasize the contribution of the study to the existing literature.	**Thank you very much for your fruitful comments.** **Improved** **The authors have revised the conclusion.** **Please see section 4. Conclusion.** This study makes a valuable contribution to the existing literature on open-source ERP systems by identifying key factors crucial in selecting these systems and identifying the most suitable open-source ERP system alternative for SMEs. The findings of this study have practical implications and can guide businesses to improve their efficiency and financial outcomes. The study reveals that the selection of an open-source ERP system should prioritize package criteria as essential factors. The packaging of the open-source ERP system significantly impacts implementation costs and complexity, potentially affecting the effectiveness of the installation process and system integration within an enterprise. Additionally, cost is ranked as the second most crucial criterion, given the financial conditions of SMEs. It is essential to consider expenses incurred during the implementation process, including consulting fees, maintenance, hosting rental, training, and supporting facilities, as these can be seen as investments toward enhancing the economic performance of the business. Furthermore, the study highlights specific important sub-criteria, including accommodating logistics service business processes, support and maintenance costs, and consultant and implementation costs. These findings are highly relevant, considering the focus of the study on logistics attributes that are

	essential for SMEs in the logistics service provider industry. It is crucial to carefully analyze the initially provided free modules due to the limited number of modules available in open-source ERP systems. The selected open-source ERP system should include modules that align with the operational workflows of the business, such as a module for vehicle allocation in a logistics enterprise.
6. The paper's language and grammar need to be improved. There are some grammatical errors and awkward sentences throughout the paper that need to be corrected.	**Thank you very much for your fruitful comments.** **We have revised it.**
7. The paper's formatting should be improved. The authors should ensure that the paper adheres to the formatting guidelines of the journal.	**Thank you very much for your fruitful comments.** **We have revised it.**
Overall, the paper has the potential to make a valuable contribution to the field of open-source ERP selection. However, the authors should make some revisions to improve the clarity and presentation of the research.	**Thank you very much** **The authors have revised the manuscript.**

Reviewer 2:

The paper is well written and has some merits to the field. I have some minor comments for you to improve:	**Thank you very much for your fruitful comments.** **The quality of this manuscript is improved thanks to editors and reviewers 'comments.**
1. The title is not good, WHY A CASE IN INDONESIA COULD BE ATTRACTIVE?	**Thank you very much for your fruitful comments.** **The authors have revised the title into:** Open-Source ERP Systems Selection: An Integrated Method based on Fuzzy AHP -TOPSIS
2. Please make sure you have presented the following contents in the abstract: the purpose of your study, why you did this research? the method you used in this study, what method did you use to solve your research problem? The results of your study, what have you got from this study? the implication of your study, what are the practical and theoretical implications of your study? I mean how can the results be applied to theory and practices. the values of your study, what's your contribution to theory or/practice? Through this way, readers (including me) could have a whole picture of your work.	**Thank you very much for your fruitful comments.** **Improved** **The authors have revised the abstract accordingly.** **Please see the abstract.** The Enterprise Resource Planning (ERP) system is a software solution that facilitates the integration of a company's business processes to enhance its efficiency. The utilization of licensed ERP systems, which entail significant costs, excludes Small and Medium Enterprises (SMEs) from accessing such systems. Consequently, SMEs require open-source ERP systems. This study aims to identify the essential criteria and sub-criteria that must be prioritized in the selection of open-source ERP systems. This study also aims to determine the ideal open-source ERP system alternatives for SMEs by incorporating the Fuzzy Analytic Hierarchy Process (AHP)- Fuzzy Technique for Order Preference by Similarities to Ideal Solution (TOPSIS) methodology. Five criteria and 19 sub-criteria are used to select open-source ERP systems. A case study is presented on a Transportation Service provider SME in Indonesia with 11 alternative open-source ERP systems selected for this problem. The findings indicate that the Package criteria hold the most significant importance in selecting open-source ERP systems,

	owing to their potential influence on the associated costs and complexities during implementation. Moreover, the crucial sub-criteria for selecting an open-source ERP system are the accommodating logistics service business processes, support and maintenance cost, and consultant and implementation cost. Meanwhile, according to the analysis conducted on the 11 open-source ERP systems, it has been determined that the 10th alternative open-source ERP system is the top-ranked option. This study contributes significantly to the existing literature on open-source ERP systems by identifying the most suitable open-source ERP system alternative for SMEs and highlighting the critical selection criteria for such systems. Additionally, the findings provide practical recommendations and instructions for enterprises aiming to enhance their financial and operational performance.
3. In the introduction section, you should summarize the gap of research as well. Where do you contribute?	**Thank you very much for your fruitful comments.** **Improved** **The authors have revised the manuscript.** **Regarding the research gap, please see section 1. Introduction paragraph 4.** Although prior studies have addressed the selection of ERP systems, the selection of open-source ERP systems remains limited. Additionally, the discussion and implementation of ERP systems for SMEs are frequently overlooked. Therefore, this study strives to identify the primary selection criteria for open-source ERP systems for SMEs. **Regarding the study's contributions, please see section 1. Introduction, paragraph 6.** Subsequently, the contribution of this study are as follows: (1) It identifies the criteria and sub-criteria in selecting open-source ERP systems; (2) The hierarchical framework for selecting open-source ERP systems, which is based on the integrated Fuzzy AHP and Fuzzy TOPSIS, contributes to and enriches the existing literature. Additionally, it helps decision-makers determine the best possible open-source ERP system alternatives.; (3) The industrial recommendations in this study can be the guidelines for enterprises to attain enhanced operations and economic performance.
4. Please make sure that sufficient details about the methodology be provided, otherwise people cannot replicate your method.	**Thank you very much for your fruitful comments.** **We have revised it in section 2.**
5. What is the limitation/shortcoming of your study?	**Thank you very much for your fruitful comments.** **Regarding the study's limitations, please see section 4. Conclusion, paragraph 4.** However, there are still limitations in this study. The completeness of the proposed framework may be limited because the attributes proposed in this study were obtained from the literature and assessed by eight experts. It is recommended for

	future research to expand and deepen the proposed attributes to improve the discussion and ERP system selection framework. In addition, due to the specific knowledge, experience, and understanding of ERP systems and the transportation service provider industry, the limited number of experts involved as respondents of this study may cause bias in interpreting the results. Therefore, to address this issue, increasing the number of expert respondents is essential for future studies. Furthermore, future research should include other industries besides SMEs and the transportation service provider industry to understand ERP system selection better. Meanwhile, this study also ignored the relationship between criteria. Therefore, future research must consider the relationship between criteria in selecting open-source ERP systems..
6. Other comments include: Please proofread and correct some of the language errors. Please check carefully about the subtitles of each section. Please include some references from JSMS and JLISS. Format your paper according to the template of the journal.	**We have revised for** proofread and correct some of the language errors**.** **We have added references** Sethi, N. A., & Karnawat, S. N. (2018). Real time reporting of inventory: An innovation in inventory management. Journal of Logistics, Informatics and Service Science, 5(2), 1-10. Park, W., & Seo, K. K. (2020). A study on cloud-based software marketing strategies using cloud marketplace. Journal of Logistics, Informatics and Service Science, 7(2), 1-13.

Open-Source ERP Systems Selection: An Integrated Method based on Fuzzy AHP -TOPSIS

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Abstract. The Enterprise Resource Planning (ERP) system is a software solution that facilitates the integration of a company's business processes to enhance its efficiency. The utilization of licensed ERP systems, which entail significant costs, excludes Small and Medium Enterprises (SMEs) from accessing such systems. Consequently, SMEs require open-source ERP systems. This study aims to identify the essential criteria and sub-criteria that must be prioritized in the selection of open-source ERP systems. This study also aims to determine the ideal open-source ERP system alternatives for SMEs by incorporating the Fuzzy Analytic Hierarchy Process (AHP)- Fuzzy Technique for Order Preference by Similarities to Ideal Solution (TOPSIS) methodology. Five criteria and 19 sub-criteria are used to select open-source ERP systems. A case study is presented on a Transportation Service provider SME in Indonesia with 11 alternative open-source ERP systems selected for this problem. The findings indicate that the Package criteria hold the most significant importance in selecting open-source ERP systems, owing to their potential influence on the associated costs and complexities during implementation. Moreover, the crucial sub-criteria for selecting an open-source ERP system are the accommodating logistics service business processes, support and maintenance cost, and consultant and implementation cost. Meanwhile, according to the analysis conducted on the 11 open-source ERP systems, it has been determined that the 10th alternative open-source ERP system is the top-ranked option. This study contributes significantly to the existing literature on open-source ERP systems by identifying the most suitable open-source ERP system alternative for SMEs and highlighting the critical selection criteria for such systems. Additionally, the findings provide practical recommendations and instructions for enterprises aiming to enhance their financial and operational performance.

Keywords: Selection, Enterprise resource planning, ERP, Fuzzy AHP, Fuzzy TOPSIS

1. Introduction

One of the most important developments in information technology (IT) in the 1990s was enterprise resource planning (ERP) systems (Deb et al., 2022). ERP has become one of the most widely used business systems that shifts a company's focus from functionality to procedure-driven infrastructure (Al-Mashari, 2002; Sethi & Karnawat, 2018; Utama & Yulianto, 2014). Inventory control, one of the first significant activities of modern production systems, was established in the 1960s, followed by "materials requirement planning" in the 1970s and "manufacturing resources planning II" in the 1980s (Velcu, 2007). ERP-based IT

systems had a positive impact in the late 1990s (Umble et al., 2003). Thus, enterprise processes increasingly rely on computer information systems and related applications (Fernando et al., 2021; Park & Seo, 2020). Due to global market competition and ever-changing customer demands, enterprise operations are becoming more complex, and ERP is becoming a cutting-edge response to the complexity of modern business (Karsak & Özogul, 2009). ERP is software that organizes and integrates related enterprise resources (Shukla et al., 2016). In other words, the main reason for implementing ERP is to organize data across the enterprise (Botta-Genoulaz et al., 2005; May et al., 2013). Automation of business processes and improved supply chain management through e-commerce are benefits that can be derived from a well-implemented ERP (Liao et al., 2007).

In addition, ERP systems encourage improvements to business processes in an organization by reducing redundancy (Alaskari et al., 2021). ERP can also improve productivity and quality of work (Maditinos et al., 2012). Due to these advantages, ERP is becoming increasingly popular among businesses to become and remain competitive (Deep et al., 2008). ERP has three phases that involve selection, execution, and usage. ERP selection involves problem identification, requirements specification, evaluation of alternatives, and system selection. ERP selection is the most crucial step in ERP installation (Forslund & Jonsson, 2010). Selecting an enterprise ERP has been done in various ways. Priority-based models, optimization, and multi-criteria decision-making (MCDM) are popularly used in ERP selection (Tan et al., 2012). Recently, multi-criteria decision-making (MCDM) models have become one of the popular methods for selecting the best ERP system (Kilic et al., 2014). Since ERP is essential for companies today, choosing the right system that fits their goals and capabilities is crucial and complex (Kilic et al., 2015). Therefore, choosing the right ERP system is vital to minimize the risk of failure and ensure successful implementation (Alaskari et al., 2019; Kilic et al., 2014; Svensson & Thoss, 2021).

The multi-criteria decision-making model has been utilized in ERP selection. Using the MCDM Model, Gürbüz et al. (2012) assessed ERP based on integrated Measuring Attractiveness with a Categorical-Based Evaluation Technique, Analytic Network Process (ANP), and Choquet integral. Park and Jeong (2013) integrated QoS and MCDM Models to select ERP applications with Social Networks. This study provides a guide for selecting the best SaaS ERP system based on criteria. Using the hybrid fuzzy MCDM Model with DEMATEL, ANP, and Analytical Hierarchy Process (AHP) models, Hinduja and Pandey (2019) selected a cloud-based ERP system for businesses. The fuzzy MCDM Model effectively addresses the ERP selection issue. Kazancoglu and Burmaoglu (2013) selected ERP software for a steel forming and hot-dip galvanizing company using TODIM. Some other procedures have also been proposed, such as DEMATEL and fuzzy AHP (Jafarnejad et al., 2012), AHP (Rouyendegh & Erkan, 2011), Intuitionistic Fuzzy Information(Deb et al., 2022), fuzzy SWARA-COPRAS (Garg et al., 2022), Fuzzy AHP dan TOPSIS (Dalyan et al., 2022), and AHP-TOPSIS (Amirkabiri & Rostamiyan, 2018) (Hansen et al., 2023) (Uddin et al., 2021). Ayağ and Yücekaya (2019) evaluated the ERP system using the MCDM Model and grey relational analysis based on fuzzy ANP. The authors utilized the fuzzy extension of the ANP method to reflect the uncertainty and ambiguity of decision-makers in order to find more trustworthy solutions. Recently, considering fuzzy information, Thanh (2022) proposed the Fuzzy Analytic Hierarchy Process model (FAHP) and the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS).

Various ERP selection procedures have been suggested in prior studies. Nevertheless, the utilized criteria are predominantly centered on selecting licensed and fee-based ERP systems, primarily catering to large organizations with substantial investment costs. This approach neglects the needs of small and medium enterprises (SMEs) that lack the financial resources to invest in licensed ERP systems. Thus, this study posited a need for discourse on

ERP systems, particularly open-source ERP systems suitable to enhance SMEs. Currently, SMEs can utilize various open-source ERP systems (Adriana & Amalia-Elena, 2022). Open-source ERP systems refer to ERP systems that have publicly accessible source code. It implies that developers and programmers can scrutinize and modify it at their discretion. Subsequently, individuals can distribute updated iterations or alternative versions that integrate their modifications. Open-source ERP generally has a free license but limited modules and customization (Joseph Christianto, 2022). Several open-source ERP systems exist, but each system possesses its own set of merits and demerits. Utilizing an open-source ERP system can serve as a valuable tool in meeting a company's information and operational requirements, thereby contributing to enhanced competitiveness. The cost of implementation is recognized as a fundamental aspect that influences ERP adoption decisions in enterprises, especially SMEs. Therefore, open-source ERP systems that have many features and ease of use are potentially chosen by SMEs. Although prior studies have addressed the selection of ERP systems, the selection of open-source ERP systems remains limited. Additionally, the discussion and implementation of ERP systems for SMEs are frequently overlooked. Therefore, this study strives to identify the primary selection criteria for open-source ERP systems for SMEs.

In selecting open-source ERP systems, The criteria and subcriteria for selecting open-source ERP systems differ from licensed and paid ERP systems (Adriana & Amalia-Elena, 2022; Bhatt et al., 2021). Thus, new criteria and sub-criteria must be identified under the nature of open-source ERP systems. Since it involves many criteria and subcriteria, selecting an open-source ERP system is a complex and critical decision-making problem. Therefore, this study aims to select an open-source ERP system by proposing an MCDM methodology that integrates Fuzzy AHP-TOPSIS. Fuzzy AHP is proposed to determine the weights of criteria and sub-criteria in a structured manner based on pairwise comparisons. At the same time, Fuzzy TOPSIS is proposed to determine the preference ranking of open-source ERP system selection. Integrating these two MCDM methods aims to overcome the complexity of open-source ERP selection that involves unclear or vague information. Both methods have been used individually or in combination with other methods in previous ERP selection studies. However, the combination of Fuzzy AHP and Fuzzy TOPSIS was not found in the open-source ERP system selection problem. To address this issue, this study aims to achieve the following objectives:

(1) To identify the essential criteria and sub-criteria required to be prioritized for the selection of open-source ERP systems based on qualitative data;
(2) To determine an ideal alternative among open-source ERP systems;
(3) To provide practical guidance to SMEs for enhancing their operations.

Subsequently, the contribution of this study are as follows: (1) It identifies the criteria and sub-criteria in selecting open-source ERP systems; (2) The hierarchical framework for selecting open-source ERP systems, which is based on the integrated Fuzzy AHP and Fuzzy TOPSIS, contributes to and enriches the existing literature. Additionally, it helps decision-makers determine the best possible open-source ERP system alternatives.; (3) The industrial recommendations in this study can be the guidelines for enterprises to attain enhanced operations and economic performance.

The remaining sections of this study will be organized as follows. Methods are described in Section 2. In Section 3, the results and discussion are presented in detail. Finally, the conclusion is provided in Section 4.

2. Methods

2.1. Proposed Integrated Method

This section presents the proposed integrated method of selecting an open-source ERP system. The proposed method of selecting an open-source ERP system is shown in Figure 1. In selecting an open-source ERP system, there are four main stages. These stages include identifying criteria and sub-criteria for open-source ERP selection, weighting them using fuzzy AHP, identifying alternatives and assessing their performance using a fuzzy rating scale, and ranking them using fuzzy TOPSIS.

Integrating Fuzzy AHP and Fuzzy TOPSIS MCDM procedures is based on vague decision data information. With fuzzy procedures, the effect of incomplete information can be reduced in decision-making. The fuzzy AHP procedure is proposed for the Weight assessment of criteria and sub-criteria for open-source ERP selection using fuzzy AHP. The weight of criteria and sub-criteria from fuzzy AHP is used Fuzzy TOPSIS method to assess the preference of alternatives. Fuzzy TOPSIS is a frequently used preference assessment and ranking method. Previous studies have also seen its application in various sectors. Details of each stage of the Proposed Integrated Method in open-source ERP selection are presented in the following subsections.

2.1.1. Identification Criteria and Sub-criteria Open-source ERP selection

Identification Criteria and Sub-criteria open-source ERP selection are based on a literature review in this first stage. It is done to find a set of criteria and sub-criteria to select an open-source ERP system. To get a broader of the criteria and sub-criteria used, the collection of a list of criteria and sub-criteria is not limited to open-source ERP systems. Criteria and sub-criteria were also collected from licensed and paid ERP systems. Furthermore, a group of experts was involved in a focus group discussion to determine the appropriate criteria and sub-criteria for selecting an open-source ERP system. Through the expert discussion and literature review results, new criteria and sub-criteria were used in selecting an open-source ERP system. Furthermore, the selected criteria and sub-criteria are weighted with the Fuzzy AHP procedure, described in detail in the next section.

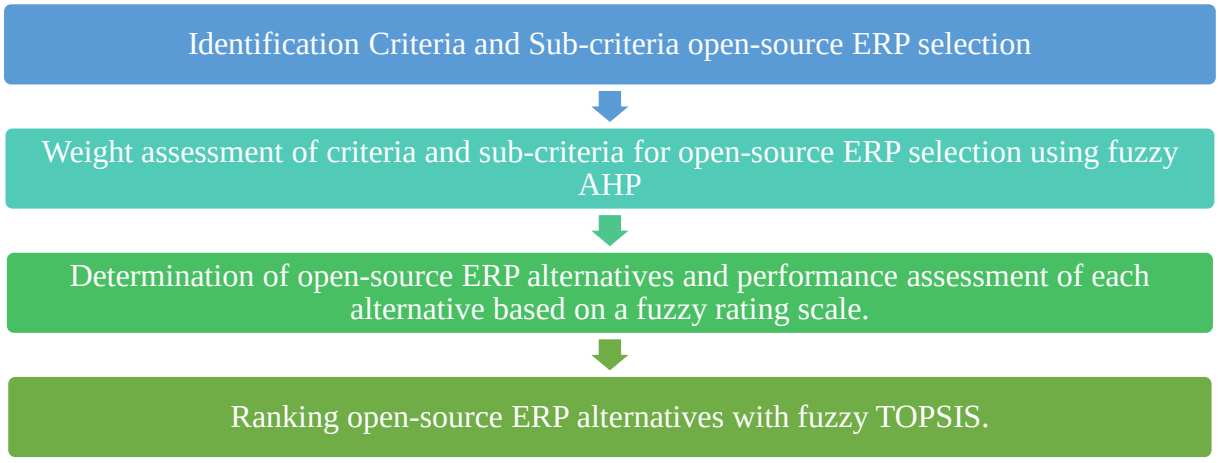

Figure 1 Proposed method of selecting an open-source ERP system

2.1.2. Weight assessment of criteria and sub-criteria using fuzzy AHP

This section presents the weighting based on the selected criteria and sub-criteria. The weighting of criteria and sub-criteria is carried out using the fuzzy AHP method. Fuzzy AHP is a procedure to overcome the shortcomings of the classic AHP procedure (Baroto et al., 2022; Ibrahim et al., 2021; Utama, 2021; Utama et al., 2021). According to Liu et al. (2020), the fundamental difference between AHP and fuzzy AHP is replacing crisp values with fuzzy sets. In previous research, fuzzy AHP has been used to solve various problems, such as software selection performance analysis (Afolayan et al., 2020; Che et al., 2020) and supplier selection (Amallynda et al., 2022; Djunaidi et al., 2019; Ho et al., 2021; Kar, 2015; Kilincci & Onal, 2011; Wijaya & Widodo, 2022). The proposed fuzzy AHP procedure is adopted from the fuzzy AHP procedure proposed by Kilic et al. (2014). The weighting stages based on criteria and sub-criteria with fuzzy AHP are described as follows:

Step 1: Define fuzzy pairwise comparison matrix

Define fuzzy pairwise comparison matrix with $F = \left[\tilde{c}_{ij}\right]_{n\times n}$ as a matrix for several n criteria compared to goals. $\tilde{c}_{ij}$ is a fuzzy set representing the relative importance of criterion i over j. Vice versa $1/\tilde{c}_{ij}$ equal to the relative importance of Criterion j over i or $\tilde{c}_{ji}$. Pairwise comparisons of criteria and sub-criteria are based on focus group discussions with experts. The pairwise comparison assessment is based on a triangular fuzzy number scale, as presented in Table 1. For example, if the assessment results of the relative importance of criteria 1 over criteria 2 are described by a triangular fuzzy number (4,5,6). So, criteria 2 over criteria 1 will be worth (1/6, 1/5, 1/4).

Step 2: Calculate the fuzzy weights of the criteria

At this stage, a fuzzy set will be obtained that describes the weight of importance of each criterion. One method to get the fuzzy weight of each criterion is the geometric mean method proposed by Buckley (1985). Equation (1) computes the geometric mean of the fuzzy comparison value of criterion i for each criterion. Furthermore, the fuzzy weight of the i-th criterion, represented by a triangular fuzzy number, is found in Equations (2) and (3).

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

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

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

Table 1 Variable Linguistic and Triangular Fuzzynumber AHP Importance

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
ExI	Extremely Importance	9,9,9	One element is absolutely more important than the other

IV	Intermediate Values	1,2,3; 3,4,5; 5,6,7; 7,8,9	When a compromise between two elements is required

Step 3: Defuzzify the fuzzy weights

At this stage, the weights in fuzzy sets will be converted into crisp weights for further comparison. It is necessary because fuzzy sets will be difficult to compare directly. According to Liu et al. (2020), and The Center of Area (COA) method, or the centroid method, is one of the most common defuzzification methods. Nonfuzzy value M_i from fuzzy number $\widetilde{w}_i$ can be calculated using Equation (4).

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

M_i is a nonfuzzy number, normalized weight N_i obtained by normalization. After getting each N_i, global weight of all criteria M_i obtained by multiplying the locally normalized criterion weights by the normalized weights of the related dimensions.

2.1.3. Determination alternatives and performance assessment based on a fuzzy scale

The next stage is the determination of alternatives and performance assessment based on a fuzzy scale. Managers and decision-makers determine alternative open-source ERP systems that can be implemented in the company. The open-source ERP system alternatives must be selected based on the organization's requirements. Experts also evaluate each criterion and sub-criterion of alternative open-source ERP systems through focus group discussions. Table 2 displays the linguistic variables and Triangular fuzzy number performance evaluation of the open-source ERP stem.

Table 2 Variabel Linguistic and Triangular fuzzy number performance assessment

		Triangular Fuzzy Number		
Variable Linguistic	Code	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

2.1.4. Ranking open-source ERP alternatives using fuzzy TOPSIS

The last stage in the selection of open-source ERP systems is the ranking of alternatives using fuzzy TOPSIS. TOPSIS requires that chosen alternatives have the shortest Euclidean distance from the positive ideal solution, which minimizes cost and maximizes benefit criteria. (Natalia et al., 2020). This study uses the fuzzy TOPSIS to determine the alternatives' ranking in open-source ERP system selection. This research adopts the fuzzy TOPSIS procedure proposed by Nădăban et al. (2016). The detailed procedures of fuzzy TOPSIS are as follows:

Step 1. Specify a rating for alternatives

Assume there is a decision group with K members, the fuzzy rating of the k^{th} decision-maker about alternative A_i concerning the criterion C_j is denoted in Equation (5).

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

Step 2. Compute the aggregated fuzzy ratings for alternatives

The aggregated fuzzy rating $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ of i^{th} alternative w.r.t. j^{th}. The criterion is obtained in Equation (6).

$$a_{ij} = \min_k\{a_{ij}^k\}, b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ij}^k, c_{ij} = \max_k\{c_{ij}^k\} \quad (6)$$

Step 3. Compute the normalized fuzzy decision matrix

The normalized fuzzy decision matrix is $\tilde{R} = [\tilde{r}_{ij}]$ can be seen in Equations (7) and (8).

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

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

Step 4. Compute the weighted normalized fuzzy decision matrix

The weighted normalized fuzzy decision matrix is $\tilde{V} = (\tilde{v}_{ij})$ can be formulated in Equation (9). This weight w_j is generated from the fuzzy AHP weighting described in the previous section.

$$\tilde{v}_{ij} = \tilde{r}_{ij} \times w_j \quad (9)$$

Step 5. Compute the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS)

Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) can be calculated based on Equations (10) and (11).

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

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

Step 6. Compute the distance from each alternative to the FPIS and the FNIS

The computation of the distance from each alternative can be formulated in Equation (12). Let be the distance from each alternative A_i to the FPIS and the FNIS, respectively.

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

Step 7. Compute the closeness coefficient CC_i for each alternative

For each alternative (A_i), we can calculate the Closeness Coefficient (CC_i) based on Equation (13).

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*} \quad (13)$$

Step 8. Rank the alternatives

The alternative with the highest closeness coefficient represents the best alternative.

2.2. Case Study

This research presents an open-source ERP system selection case study at an SME Transportation Service Provider in Indonesia. This research involves eight **experts in identifying criteria and sub-criteria, pairwise comparison assessment of criteria and sub-criteria, and performance assessment of each alternative open-source ERP system.**

In identifying criteria and sub-criteria, an in-depth literature study was conducted to obtain a list of criteria often used in ERP system selection problems. The literature used is research that discusses ERP system selection in general. The criteria and sub-criteria used are

decided through focus group discussions with experts in selecting an open-source ERP system. The focus group discussion Criteria and sub-criteria results are classified into five aspects, and 19 criteria are determined, presented in Table 3.

Table 3 Criteria and sub-criteria for selecting open-source ERP systems

Main Criteria	ID	Sub Criteria
Cost	C1	Consultant and implementation cost
	C2	Support and maintenance cost
	C3	Hosting cost
Reputation	C4	Brand image
	C5	Update availability history
	C6	Sustainability
Package	C7	Number of free modules
	C8	Availability of 3rd party modules
	C9	Accommodating logistics service business processes
	C10	Integration with satellite-based navigation system
	C11	Integration level between modules
Operation and Technical	C12	Implementation time
	C13	User-friendliness
	C14	Online help and tutorials
	C15	Ease of data migration
	C16	Ease of maintenance
Flexibility	C17	Ease to customization
	C18	Upgradeability
	C19	Potential for future strategy

Through focus group discussions, the experts also conducted pairwise comparison assessments of criteria and sub-criteria. Meanwhile, the experts also managed to identify 11 alternative open-source ERP systems that were considered for selection. The performance assessment of each alternative open-source ERP system was also carried out through focus group discussions.

3. Results and Discussion

3.1. Criteria and sub-criteria weight

This section presents the weighting criteria and sub-criteria results based on fuzzy AHP. The results of the weighting of criteria and sub-criteria for selecting open-source ERP systems are presented in Table 4. Based on the results, the package criteria carry a weight value of 0.342. This criterion holds the highest weight among the selection criteria for open-source ERP systems. The next set of criteria, ranked in descending order of weight, includes cost (0.248), reputation (0.180), operation & technical (0.146), and flexibility (0.085).

Based on the findings, the criteria of the ERP package play a crucial role as they significantly impact the successful implementation and adoption of the system within a business. It has been emphasized that the packaging of open-source ERP systems can affect the system's cost and complexity. This research is in line with the research findings presented by Zhang et al. (2005) and Ngai et al. (2008) which found that in the selection of ERP systems, the

criteria for the ERP model package provided have an essential meaning in the adoption of ERP systems. It can ensure that the selected system fits business needs and can be integrated with existing information technology infrastructure. For example, some ERP systems offer a simplified installation process with limited customization options. In contrast, others provide a wide range of modules and customization possibilities that require substantial resources for implementation. Furthermore, it is essential for a package of an open-source ERP system to include adequate support and maintenance guidelines to ensure smooth system operation and alignment with the organization's needs, particularly for small and medium-sized enterprises (SMEs) (Amado & Belfo, 2021). As a result, SMEs should choose an open-source ERP system that offers a comprehensive suite of tools tailored to their specific business requirements. However, it should be noted that open-source ERP systems often have limited complementary modules included in the installation package. In particular, SMEs in the transportation services industry may face challenges as these systems may not offer modules that cater specifically to their needs. For example, implementing a fleet management module is crucial for effectively managing the transportation fleet in the transportation services industry. Therefore, the package of an open-source ERP system holds significant importance in the selection process as it can impact the costs, complexity, and effectiveness of implementing and integrating the system within an enterprise (Benlian & Hess, 2011).

Meanwhile, the cost criterion occupies the second position, which indicates that cost is an essential criterion after the package criterion. In open-source ERP systems, the installation package of the open-source ERP system is indeed provided free of charge. However, it does not mean the company does not need any costs. Some costs must be invested in the implementation process, such as consulting fees, maintenance, and hosting rental (Olson et al., 2018). Not only that, but companies also need to invest in supporting facilities and conduct training on the use of open-source ERP systems. Companies also need to incur costs if they use additional modules that are not free but are needed to accommodate the company's business processes.

Based on the weighting of criteria, this study's results indicate differences in the level of importance of aspects in selecting paid and open-source ERP systems. In previous research investigated by Kilic et al. (2015), the findings show that the selection of ERP systems for SMEs shows the cost aspect as the aspect with the highest weight on the paid ERP system. However, this study found that the package criteria became fundamental in open-source ERP systems because the features provided by open-source ERP systems were limited (Joseph Christianto, 2022). In contrast to paid ERP systems, the cost aspect becomes very significant because the modules are tailored to the business needs of the vendor. Therefore, SMEs adopting open-source ERP systems must ensure that the system has a package accommodating the company's business processes.

Interestingly, reputation was revealed as the third most crucial aspect that needs to be prioritized. Choosing an Open-source ERP system should not be haphazard. It is essential to pay attention to the provider's track record. It can minimize losses if there is a change in policy from a vendor that provides a system for free.

Subsequently, the fuzzy AHP was utilized to determine the relative importance of sub-criteria. The results indicate that the sub-criteria with the highest weights are Accommodating logistics service business processes (C9), support and maintenance cost (C2), and Consultant and implementation cost (C1), with weights of 0.160, 0.153, and 0.074, respectively. Accommodating logistics service business processes (C9) have the highest weight. This result is very reasonable because the case study of this research is on SME logistics service providers that require logistics features. The limited number of modules offered by open-source ERP systems makes analyzing the free modules provided from the start essential. The modules provided must accommodate the company's business processes, such as a module for the

vehicle assignment process in a logistics service business. The adopted open-source ERP system must have modules accommodating the business process. Meanwhile, the sub-criteria Implementation time (C12) and Online help and tutorials (C14) are ranked 18-19 with a weight of 0.011.

The fuzzy AHP findings indicate that the package criteria, with a weight of 0.342, is the most crucial factor to consider when choosing an open-source ERP system. It is highlighted that how the open-source ERP system is packaged has the potential to affect both the cost and complexity of its implementation. Additionally, the remaining criteria are prioritized as follows: Cost holds a weight of 0.248, reputation holds a weight of 0.180, Operation and Technical hold a weight of 0.180, and flexibility holds a weight of 0.085. On the other hand, the outcomes of the fuzzy AHP analysis also denote that the sub-criteria accommodating logistics service business processes (weighted at 0.160), Support and maintenance cost (weighted at 0.153), and consultant and implementation cost (weighted at 0.074) are the three sub-criteria that carry the most substantial weight and needed to be prioritized in selecting an open-source ERP system.

Table 4 Weighting criteria and sub-criteria for ERP system selection

Criteria	Weight	Sub-Criteria		Local Weight	Global Weight
Cost	0.248	C1	Consultant and implementation cost	0.297	0.074
		C2	Support and maintenance cost	0.617	0.153
		C3	Hosting cost	0.086	0.021
Reputation	0.180	C4	Brand image	0.426	0.077
		C5	Update availability history	0.148	0.027
		C6	Sustainability	0.426	0.077
Package	0.342	C7	Number of free modules	0.176	0.060
		C8	Availability of 3rd party modules	0.102	0.035
		C9	Accommodating logistics service business processes	0.467	0.160
		C10	Integration with satellite-based navigation system	0.061	0.021
		C11	Integration level between modules	0.195	0.067
Operation & Technical	0.146	C12	Implementation time	0.075	0.011
		C13	User-friendliness	0.373	0.054
		C14	Online help and tutorials	0.075	0.011
		C15	Ease of data migration	0.141	0.021
		C16	Ease of maintenance	0.337	0.049
Flexibility	0.085	C17	Ease to customization	0.225	0.019
		C18	Upgradeability	0.457	0.039
		C19	Potential for future strategy	0.319	0.027

3.2. Alternatives ERP score

The normalization of the closeness coefficient value presented in Table 5 is utilized to derive the score for each alternative. The results indicate that the scores attributed to each alternative do not exhibit a significant difference and are characterized by a comparable level of competitiveness. Nevertheless, it is noteworthy that Alternative 10 demonstrates the highest score, as evidenced by the normalized percentage of 13.03%. This study indicated that the criterion package holds the highest weight value. Furthermore, accommodating logistics service business processes are considered a sub-criterion with the most significant

global weight. According to the analysis, the Open-source ERP system alternative 10 possesses modules capable of accommodating the business processes of SMEs in the transportation services sector. For example, apart from other basic modules, a fleet management module allows transportation companies to attain specific tasks relating to a company's fleet of vehicles. In addition, many third-party modules can be used for free.

Table 5 Rank of alternatives based on TOPSIS

	d*	d-	Cj	Normalized	Ranking
Alt1	0.511	0.367	0.417	7.73%	10
Alt2	0.390	0.495	0.558	10.34%	2
Alt3	0.426	0.461	0.519	9.61%	3
Alt4	0.485	0.400	0.452	8.37%	8
Alt5	0.481	0.411	0.460	8.52%	7
Alt6	0.469	0.411	0.466	8.64%	6
Alt7	0.495	0.383	0.436	8.07%	9
Alt8	0.448	0.441	0.495	9.18%	4
Alt9	0.520	0.372	0.417	7.72%	11
Alt10	0.259	0.616	0.703	13.03%	1
Alt11	0.464	0.420	0.475	8.80%	5

3.2. Managerial implication

An ERP system is designed to increase business productivity by coordinating parts of an organization's operations through an integrated database and software applications. Many SMEs need help implementing an ERP system even though the benefits are evident because of the prohibitive investment costs. However, many ERP system vendors lately provide open-source systems to implement in the company's business operations. Experts and practitioners estimate that about two-thirds of ERP system implementations fail due to incompatibility of business procedures and expensive implementation costs. Therefore, selecting an ERP system in the ERP adoption/implementation process is necessary, especially for open-source systems. The selection of a scientifically sound open-source ERP system is essential in the ERP adoption/implementation process due to the large variety of open-source ERP system offerings. Each open-source ERP system has strengths and weaknesses. Therefore, to increase the chances of success, all available open-source ERP system selection criteria and sub-criteria options must be carefully considered. MCDM decision-making tools are widely used to assist the ERP system selection process because there are many criteria and sub-criteria to be considered. This procedure was chosen because it can accommodate the trade-offs of the criteria and sub-criteria used in the ERP system selection.

This study aims to select an open-source ERP system faced by an SME transportation service provider in Indonesia. The criteria for selecting an open-source ERP system are determined based on the needs and desires of the company's top management. After the criteria and sub-criteria are determined, a fuzzy AHP methodology is proposed to weight the criteria and sub-criteria. Furthermore, the assessment of each alternative open-source ERP system offered. Fuzzy TOPSIS is used by utilizing the weights of the criteria and sub-criteria of the fuzzy AHP methodology to determine the preference for open-source ERP systems.

The selection of open-source ERP systems is evaluated based on several criteria Cost, Reputation, Package, Operation & Technical, and Flexibility. These five criteria are translated into 19 sub-criteria. The results show that the Package criteria have a weight value more significant than the other criteria, followed by the cost criteria. Based on the weighting of sub-criteria with fuzzy AHP, the three sub-criteria with the most weight are Accommodating logistics service business processes (C9), Support and maintenance costs (C2), and Consultant

and implementation costs (C1). This finding shows how SMEs consider package and cost criteria in selecting an open-source ERP system. The most critical to consider is the sub-criteria of features that are by the company's problems, such as the Accommodating logistics service business processes (C9) sub-criteria.

Meanwhile, cost needs to be considered, such as the Support and maintenance costs (C2) and Consultant and implementation costs (C1) sub-criteria. Although open source, SMEs also require support and maintenance costs (C2) and Consultant and implementation costs (C1). Therefore, the cost is also essential when selecting an ERP system.

Based on the proposed method that integrates fuzzy AHP and fuzzy TOPSIS, the results show that the proposed procedure is technically sound and acceptable to the organization. When the ambiguity and complexity of the decision situation are addressed by combining the benefits of two decision support methods, decision-makers can feel confident in their choice. The fuzzy AHP method can help managers and decision-makers weight the criteria and sub-criteria for selecting an open-source ERP system. This procedure can easily weight the criteria and sub-criteria. Meanwhile, fuzzy TOPSIS is proven to efficiently rank the preferences of open-source ERP system alternatives based on incomplete information.

4. Conclusion

The study aims to select an open-source ERP system for SME transportation service providers. Five criteria and 19 sub-criteria are proposed to solve the problem of selecting an open-source ERP system. This study proposes an MCDM methodology integrating fuzzy AHP and TOPSIS in ERP system selection. Fuzzy AHP is applied to determine the weight of each criterion and sub-criteria. The fuzzy TOPSIS method determines the score and ranking of each alternative ERP system. This study makes a valuable contribution to the existing literature on open-source ERP systems by identifying key factors crucial in selecting these systems and identifying the most suitable open-source ERP system alternative for SMEs. The findings of this study have practical implications and can guide businesses to improve their efficiency and financial outcomes.

The study reveals that the selection of an open-source ERP system should prioritize package criteria as essential factors. The packaging of the open-source ERP system significantly impacts implementation costs and complexity, potentially affecting the effectiveness of the installation process and system integration within an enterprise. Additionally, cost is ranked as the second most crucial criterion, given the financial conditions of SMEs. It is essential to consider expenses incurred during the implementation process, including consulting fees, maintenance, hosting rental, training, and supporting facilities, as these can be seen as investments toward enhancing the economic performance of the business.

Furthermore, the study highlights specific important sub-criteria, including accommodating logistics service business processes, support and maintenance costs, and consultant and implementation costs. These findings are highly relevant, considering the focus of the study on logistics attributes that are essential for SMEs in the logistics service provider industry. It is crucial to carefully analyze the initially provided free modules due to the limited number of modules available in open-source ERP systems. The selected open-source ERP system should include modules that align with the operational workflows of the business, such as a module for vehicle allocation in a logistics enterprise. In addition, the ERP system in Alternative 10 is the open-source ERP system with the highest preference, especially for transportation service provider SMEs. This ERP system in alternative 10 has advantages in the packages offered, especially having modules that can be configured according to the business processes of Transportation Service Provider SMEs.

However, there are still limitations in this study. The completeness of the proposed framework may be limited because the attributes proposed in this study were obtained from the

literature and assessed by eight experts. It is recommended for future research to expand and deepen the proposed attributes to improve the discussion and ERP system selection framework. In addition, due to the specific knowledge, experience, and understanding of ERP systems and the transportation service provider industry, the limited number of experts involved as respondents of this study may cause bias in interpreting the results. Therefore, to address this issue, increasing the number of expert respondents is essential for future studies. Furthermore, future research should include other industries besides SMEs and the transportation service provider industry to understand ERP system selection better. Meanwhile, this study also ignored the relationship between criteria. Therefore, future research must consider the relationship between criteria in selecting open-source ERP systems.

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ACCEPTANCE OF MANUSCRIPT

Dear **Muhammad Faisal Ibrahim 1, Taufik Kurrahman 2 and Dana Marsetiya Utama 3***

I am pleased to inform you that based on the referees reports, your paper entitled

Open-Source ERP Systems Selection: An Integrated Method based on Fuzzy AHP -TOPSIS

has been accepted for publication in Journal of Logistics, Informatics and Service Science
The paper will be published in the No.4 issue of 2023.
With best wishes,
Yours sincerely
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Open-Source ERP Systems Selection: An Integrated Method based on Fuzzy AHP -TOPSIS

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Abstract. The Enterprise Resource Planning (ERP) system is a software solution that facilitates the integration of a company's business processes to enhance its efficiency. The utilization of licensed ERP systems, which entail significant costs, excludes Small and Medium Enterprises (SMEs) from accessing such systems. Consequently, SMEs require open-source ERP systems. This study aims to identify the essential criteria and sub-criteria that must be prioritized in the selection of open-source ERP systems. This study also aims to determine the ideal open-source ERP system alternatives for SMEs by incorporating the Fuzzy Analytic Hierarchy Process (AHP)- Fuzzy Technique for Order Preference by Similarities to Ideal Solution (TOPSIS) methodology. Five criteria and 19 sub-criteria are used to select open-source ERP systems. A case study is presented on a Transportation Service provider SME in Indonesia with 11 alternative open-source ERP systems selected for this problem. The findings indicate that the Package criteria hold the most significant importance in selecting open-source ERP systems, owing to their potential influence on the associated costs and complexities during implementation. Moreover, the crucial sub-criteria for selecting an open-source ERP system are the accommodating logistics service business processes, support and maintenance cost, and consultant and implementation cost. Meanwhile, according to the analysis conducted on the 11 open-source ERP systems, it has been determined that the 10th alternative open-source ERP system is the top-ranked option. This study contributes significantly to the existing literature on open-source ERP systems by identifying the most suitable open-source ERP system alternative for SMEs and highlighting the critical selection criteria for such systems. Additionally, the findings provide practical recommendations and instructions for enterprises aiming to enhance their financial and operational performance.

Keywords: Selection, Enterprise resource planning, ERP, Fuzzy AHP, Fuzzy TOPSIS

1. Introduction

One of the most important developments in information technology (IT) in the 1990s was enterprise resource planning (ERP) systems (Deb et al., 2022). ERP has become one of the most widely used business systems that shifts a company's focus from functionality to procedure-driven infrastructure (Al‐Mashari, 2002; Sethi & Karnawat, 2018; Utama & Yulianto, 2014). Inventory control, one of the first significant activities of modern production systems, was established in the 1960s, followed by "materials requirement planning" in the 1970s and "manufacturing resources planning II" in the 1980s (Velcu, 2007). ERP-based IT systems had a positive impact in the late 1990s (Umble et al., 2003). Thus, enterprise processes increasingly rely on computer information systems and related applications (Fernando et al., 2021; Park & Seo, 2020). Due to global market competition and ever-changing customer demands, enterprise operations are becoming more complex, and ERP is becoming a cutting-edge response to the complexity of modern business (Karsak & Özogul, 2009). ERP is software that organizes and integrates related enterprise resources (Shukla et al., 2016). In other words, the main reason for implementing ERP is to organize data across the enterprise (Botta-Genoulaz et al., 2005; May et al., 2013). Automation of business processes and improved supply chain management through e-commerce are benefits that can be derived from a well-implemented ERP (Liao et al., 2007).

In addition, ERP systems encourage improvements to business processes in an organization by reducing redundancy (Alaskari et al., 2021). ERP can also improve productivity and quality of work (Maditinos et al., 2012). Due to these advantages, ERP is becoming increasingly popular among businesses to become and remain competitive (Deep et al., 2008). ERP has three phases that involve selection, execution, and usage. ERP selection involves problem identification, requirements specification, evaluation of alternatives, and system selection. ERP selection is the most crucial step in ERP installation (Forslund & Jonsson, 2010). Selecting an enterprise ERP has been done in various ways. Priority-based models, optimization, and multi-criteria decision-making (MCDM) are popularly used in ERP selection (Tan et al., 2012). Recently, multi-criteria decision-making (MCDM) models have become one of the popular methods for selecting the best ERP system (Kilic et al., 2014). Since ERP is essential for companies today, choosing the right system that fits their goals and capabilities is crucial and complex (Kilic et al., 2015). Therefore, choosing the right ERP system is vital to minimize the risk of failure and ensure successful implementation (Alaskari et al., 2019; Kilic et al., 2014; Svensson & Thoss, 2021).

The multi-criteria decision-making model has been utilized in ERP selection. Using the MCDM Model, Gürbüz et al. (2012) assessed ERP based on integrated Measuring Attractiveness with a Categorical-Based Evaluation Technique, Analytic Network Process (ANP), and Choquet integral. Park and Jeong (2013) integrated QoS and MCDM Models to select ERP applications with Social Networks. This study provides a guide for selecting the best SaaS ERP system based on criteria. Using the hybrid fuzzy MCDM Model with DEMATEL, ANP, and Analytical Hierarchy Process (AHP) models, Hinduja and Pandey (2019) selected a cloud-based ERP system for businesses. The fuzzy MCDM Model effectively addresses the ERP selection issue. Kazancoglu and Burmaoglu (2013) selected ERP software for a steel forming and hot-dip galvanizing company using TODIM. Some other procedures have also been proposed, such as DEMATEL and fuzzy AHP (Jafarnejad et al., 2012), AHP (Rouyendegh & Erkan, 2011), Intuitionistic Fuzzy Information(Deb et al., 2022), fuzzy SWARA-COPRAS (Garg et al., 2022), Fuzzy AHP dan TOPSIS (Dalyan et al., 2022), and AHP-TOPSIS (Amirkabiri & Rostamiyan, 2018) (Hansen et al., 2023) (Uddin et al., 2021). Ayağ and Yücekaya (2019) evaluated the ERP system using the MCDM Model and grey relational analysis based on fuzzy ANP. The authors utilized the fuzzy extension of the ANP method to reflect the uncertainty and ambiguity of decision-makers in order to find more trustworthy solutions. Recently, considering fuzzy information, Thanh (2022) proposed the Fuzzy Analytic Hierarchy Process model (FAHP) and the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS).

Various ERP selection procedures have been suggested in prior studies. Nevertheless, the utilized

criteria are predominantly centered on selecting licensed and fee-based ERP systems, primarily catering to large organizations with substantial investment costs. This approach neglects the needs of small and medium enterprises (SMEs) that lack the financial resources to invest in licensed ERP systems. Thus, this study posited a need for discourse on ERP systems, particularly open-source ERP systems suitable to enhance SMEs. Currently, SMEs can utilize various open-source ERP systems (Adriana & Amalia-Elena, 2022). Open-source ERP systems refer to ERP systems that have publicly accessible source code. It implies that developers and programmers can scrutinize and modify it at their discretion. Subsequently, individuals can distribute updated iterations or alternative versions that integrate their modifications. Open-source ERP generally has a free license but limited modules and customization (Joseph Christianto, 2022). Several open-source ERP systems exist, but each system possesses its own set of merits and demerits. Utilizing an open-source ERP system can serve as a valuable tool in meeting a company's information and operational requirements, thereby contributing to enhanced competitiveness. The cost of implementation is recognized as a fundamental aspect that influences ERP adoption decisions in enterprises, especially SMEs. Therefore, open-source ERP systems that have many features and ease of use are potentially chosen by SMEs. Although prior studies have addressed the selection of ERP systems, the selection of open-source ERP systems remains limited. Additionally, the discussion and implementation of ERP systems for SMEs are frequently overlooked. Therefore, this study strives to identify the primary selection criteria for open-source ERP systems for SMEs.

In selecting open-source ERP systems, the criteria and subcriteria for selecting open-source ERP systems differ from licensed and paid ERP systems (Adriana & Amalia-Elena, 2022; Bhatt et al., 2021). Thus, new criteria and sub-criteria must be identified under the nature of open-source ERP systems. Since it involves many criteria and subcriteria, selecting an open-source ERP system is a complex and critical decision-making problem. Therefore, this study aims to select an open-source ERP system by proposing an MCDM methodology that integrates Fuzzy AHP-TOPSIS. Fuzzy AHP is proposed to determine the weights of criteria and sub-criteria in a structured manner based on pairwise comparisons. At the same time, Fuzzy TOPSIS is proposed to determine the preference ranking of open-source ERP system selection. Integrating these two MCDM methods aims to overcome the complexity of open-source ERP selection that involves unclear or vague information. Both methods have been used individually or in combination with other methods in previous ERP selection studies. However, the combination of Fuzzy AHP and Fuzzy TOPSIS was not found in the open-source ERP system selection problem. To address this issue, this study aims to achieve the following objectives:

1) To identify the essential criteria and sub-criteria required to be prioritized for the selection of open-source ERP systems based on qualitative data;
2) To determine an ideal alternative among open-source ERP systems;
3) To provide practical guidance to SMEs for enhancing their operations.

Subsequently, the contribution of this study are as follows: (1) It identifies the criteria and sub-criteria in selecting open-source ERP systems; (2) The hierarchical framework for selecting open-source ERP systems, which is based on the integrated Fuzzy AHP and Fuzzy TOPSIS, contributes to and enriches the existing literature. Additionally, it helps decision-makers determine the best possible open-source ERP system alternatives.; (3) The industrial recommendations in this study can be the guidelines for enterprises to attain enhanced operations and economic performance.

The remaining sections of this study will be organized as follows. Methods are described in Section 2. In Section 3, the results and discussion are presented in detail. Finally, the conclusion is provided in Section 4.

2. Methods

2.1. Proposed Integrated Method

This section presents the proposed integrated method of selecting an open-source ERP system. The

proposed method of selecting an open-source ERP system is shown in Figure 1. In selecting an open-source ERP system, there are four main stages. These stages include identifying criteria and sub-criteria for open-source ERP selection, weighting them using fuzzy AHP, identifying alternatives and assessing their performance using a fuzzy rating scale, and ranking them using fuzzy TOPSIS.
Integrating Fuzzy AHP and Fuzzy TOPSIS MCDM procedures is based on vague decision data information. With fuzzy procedures, the effect of incomplete information can be reduced in decision-making. The fuzzy AHP procedure is proposed for the Weight assessment of criteria and sub-criteria for open-source ERP selection using fuzzy AHP. The weight of criteria and sub-criteria from fuzzy AHP is used Fuzzy TOPSIS method to assess the preference of alternatives. Fuzzy TOPSIS is a frequently used preference assessment and ranking method. Previous studies have also seen its application in various sectors. Details of each stage of the Proposed Integrated Method in open-source ERP selection are presented in the following subsections.

2.2.1 Proposed Integrated Method

Identification Criteria and Sub-criteria open-source ERP selection are based on a literature review in this first stage. It is done to find a set of criteria and sub-criteria to select an open-source ERP system. To get a broader of the criteria and sub-criteria used, the collection of a list of criteria and sub-criteria is not limited to open-source ERP systems. Criteria and sub-criteria were also collected from licensed and paid ERP systems. Furthermore, a group of experts was involved in a focus group discussion to determine the appropriate criteria and sub-criteria for selecting an open-source ERP system. Through the expert discussion and literature review results, new criteria and sub-criteria were used in selecting an open-source ERP system. Furthermore, the selected criteria and sub-criteria are weighted with the Fuzzy AHP procedure, described in detail in the next section.

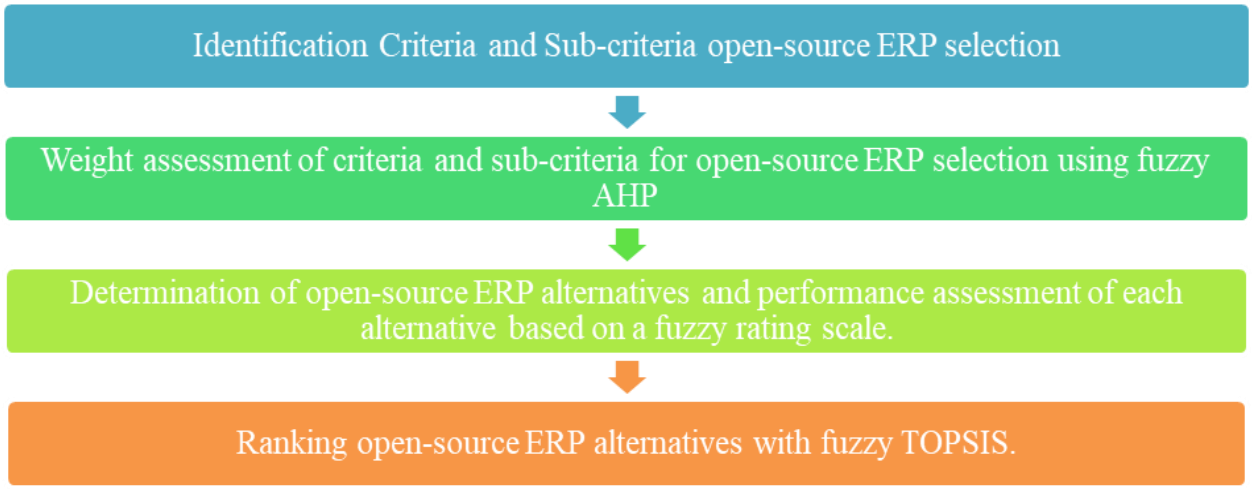

Fig.1: Proposed method of selecting an open-source ERP system

2.2.2 Weight assessment of criteria and sub-criteria using fuzzy AHP

This section presents the weighting based on the selected criteria and sub-criteria. The weighting of criteria and sub-criteria is carried out using the fuzzy AHP method. Fuzzy AHP is a procedure to overcome the shortcomings of the classic AHP procedure (Baroto et al., 2022; Ibrahim et al., 2021; Utama, 2021; Utama et al., 2021). According to Liu et al. (2020), the fundamental difference between AHP and fuzzy AHP is replacing crisp values with fuzzy sets. In previous research, fuzzy AHP has been used to solve various problems, such as software selection performance analysis (Afolayan et al., 2020; Che et al., 2020) and supplier selection (Amallynda et al., 2022; Djunaidi et al., 2019; Ho et al., 2021; Kar, 2015; Kilincci & Onal, 2011; Wijaya & Widodo, 2022). The proposed fuzzy AHP procedure is adopted from the fuzzy AHP procedure proposed by Kilic et al. (2014). The weighting stages based on criteria and sub-criteria with fuzzy AHP are described as follows:

Step 1: Define fuzzy pairwise comparison matrix

Define fuzzy pairwise comparison matrix with $F = [\tilde{c}_{ij}]_{n\times n}$ as a matrix for several n criteria compared to goals. $\tilde{c}_{ij}$ is a fuzzy set representing the relative importance of criterion i over j. Vice versa $1/\tilde{c}_{ij}$ equal to the relative importance of Criterion j over i or $\tilde{c}_{ji}$. Pairwise comparisons of criteria and sub-criteria are based on focus group discussions with experts. The pairwise comparison assessment is based on a triangular fuzzy number scale, as presented in Table 1. For example, if the assessment results of the relative importance of criteria 1 over criteria 2 are described by a triangular fuzzy number (4,5,6). So, criteria 2 over criteria 1 will be worth (1/6, 1/5, 1/4).

Step 2: Calculate the fuzzy weights of the criteria

At this stage, a fuzzy set will be obtained that describes the weight of importance of each criterion. One method to get the fuzzy weight of each criterion is the geometric mean method proposed by Buckley (1985). Equation (1) computes the geometric mean of the fuzzy comparison value of criterion i for each criterion. Furthermore, the fuzzy weight of the i-th criterion, represented by a triangular fuzzy number, is found in Equations (2) and (3).

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

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

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

Table 1: Variable Linguistic and Triangular Fuzzynumber AHP Importance

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
ExI	Extremely Importance	9,9,9	One element is absolutely more important than the other
IV	Intermediate Values	1,2,3; 3,4,5; 5,6,7; 7,8,9	When a compromise between two elements is required

Step 3: Defuzzify the fuzzy weights

At this stage, the weights in fuzzy sets will be converted into crisp weights for further comparison. It is necessary because fuzzy sets will be difficult to compare directly. According to Liu et al. (2020), and The Center of Area (COA) method, or the centroid method, is one of the most common defuzzification methods. Nonfuzzy value M_i from fuzzy number $\widetilde{w}_i$ can be calculated using Equation (4).

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

M_i is a nonfuzzy number, normalized weight N_i obtained by normalization. After getting each N_i, global weight of all criteria M_i obtained by multiplying the locally normalized criterion weights by the normalized weights of the related dimensions.

2.2.3 Determination alternatives and performance assessment based on a fuzzy scale

The next stage is the determination of alternatives and performance assessment based on a fuzzy scale. Managers and decision-makers determine alternative open-source ERP systems that can be implemented in the company. The open-source ERP system alternatives must be selected based on the organization's requirements. Experts also evaluate each criterion and sub-criterion of alternative open-source ERP systems through focus group discussions. Table 2 displays the linguistic variables and Triangular fuzzy number performance evaluation of the open-source ERP stem.

Table 2: Variabel Linguistic and Triangular fuzzy number performance assessment

		Triangular Fuzzy Number		
Variable Linguistic	Code	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

2.2.4 2.1.4. Ranking open-source ERP alternatives using fuzzy TOPSIS

The last stage in the selection of open-source ERP systems is the ranking of alternatives using fuzzy TOPSIS. TOPSIS requires that chosen alternatives have the shortest Euclidean distance from the positive ideal solution, which minimizes cost and maximizes benefit criteria. (Natalia et al., 2020). This study uses the fuzzy TOPSIS to determine the alternatives' ranking in open-source ERP system selection. This research adopts the fuzzy TOPSIS procedure proposed by Nădăban et al. (2016). The detailed procedures of fuzzy TOPSIS are as follows:

Step 1. Specify a rating for alternatives

Assume there is a decision group with K members, the fuzzy rating of the k^{th} decision-maker about alternative A_i concerning the criterion C_j is denoted in Equation (5).

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

Step 2. Compute the aggregated fuzzy ratings for alternatives

The aggregated fuzzy rating $\tilde{x}_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right)$ of i^{th} alternative w.r.t. j^{th}. The criterion is obtained in Equation (6).

$$a_{ij} = \min\{a_{ij}^k\}, b_{ij} = \frac{1}{k}\sum b_{ij}^k, c_{ij} = \max\{c_{ij}^k\} \quad (6)$$

Step 3. Compute the normalized fuzzy decision matrix

The normalized fuzzy decision matrix is $\tilde{R} = [\tilde{r}_{ij}]$ can be seen in Equations (7) and (8).

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

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

Step 4. Compute the weighted normalized fuzzy decision matrix

The weighted normalized fuzzy decision matrix is $\tilde{V} = (\tilde{v}_{ij})$ can be formulated in Equation (9). This weight w_j is generated from the fuzzy AHP weighting described in the previous section.

$$\tilde{v}_{ij} = \tilde{r}_{ij} \times w_j \quad (9)$$

Step 5. Compute the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS)

Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) can be calculated based on Equations (10) and (11).

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

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

Step 6. Compute the distance from each alternative to the FPIS and the FNIS

The computation of the distance from each alternative can be formulated in Equation (12). Let be the distance from each alternative A_i to the FPIS and the FNIS, respectively.

$$d_i^* = \sum d(\tilde{v}_{ij}, \tilde{v}_j^*), d_i^- = \sum d(\tilde{v}_{ij}, \tilde{v}_j^-) \quad (12)$$

Step 7. Compute the closeness coefficient $\mathbf{CC_i}$ for each alternative

For each alternative (A_i), we can calculate the Closeness Coefficient (CC_i) based on Equation (13).

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*} \quad (13)$$

Step 8. Rank the alternatives

The alternative with the highest closeness coefficient represents the best alternative.

2.2. Case Study

This research presents an open-source ERP system selection case study at an SME Transportation Service Provider in Indonesia. This research involves eight experts in identifying criteria and sub-criteria, pairwise comparison assessment of criteria and sub-criteria, and performance assessment of each alternative open-source ERP system.

In identifying criteria and sub-criteria, an in-depth literature study was conducted to obtain a list of criteria often used in ERP system selection problems. The literature used is research that discusses ERP system selection in general. The criteria and sub-criteria used are decided through focus group discussions with experts in selecting an open-source ERP system. The focus group discussion Criteria and sub-criteria results are classified into five aspects, and 19 criteria are determined, presented in Table 3.

Table 3: Criteria and sub-criteria for selecting open-source ERP systems

Main Criteria	ID	Sub Criteria
Cost	C1	Consultant and implementation cost
	C2	Support and maintenance cost
	C3	Hosting cost
Reputation	C4	Brand image
	C5	Update availability history
	C6	Sustainability
Package	C7	Number of free modules
	C8	Availability of 3rd party modules
	C9	Accommodating logistics service business processes
	C10	Integration with satellite-based navigation system
	C11	Integration level between modules
Operation and Technical	C12	Implementation time
	C13	User-friendliness
	C14	Online help and tutorials
	C15	Ease of data migration
	C16	Ease of maintenance
Flexibility	C17	Ease to customization
	C18	Upgradeability
	C19	Potential for future strategy

3. Results and Discussion

3.1. Criteria and sub-criteria weight

This section presents the weighting criteria and sub-criteria results based on fuzzy AHP. The results of the weighting of criteria and sub-criteria for selecting open-source ERP systems are presented in Table 4. Based on the results, the package criteria carry a weight value of 0.342. This criterion holds the highest weight among the selection criteria for open-source ERP systems. The next set of criteria, ranked in descending order of weight, includes cost (0.248), reputation (0.180), operation & technical (0.146), and flexibility (0.085).

Based on the findings, the criteria of the ERP package play a crucial role as they significantly impact the successful implementation and adoption of the system within a business. It has been emphasized that the packaging of open-source ERP systems can affect the system's cost and complexity. This research is in line with the research findings presented by Zhang et al. (2005) and Ngai et al. (2008) which found that in the selection of ERP systems, the criteria for the ERP model package provided have an essential meaning in the adoption of ERP systems. It can ensure that the selected system fits business needs and can be integrated with existing information technology infrastructure. For example, some ERP systems offer a simplified installation process with limited customization options. In contrast, others provide a wide range of modules and customization possibilities that require substantial resources for implementation. Furthermore, it is essential for a package of an open-source ERP system to include adequate support and maintenance guidelines to ensure smooth system operation and alignment with the organization's needs, particularly for small and medium-sized enterprises (SMEs) (Amado & Belfo, 2021). As a result, SMEs should choose an open-source ERP system that offers a comprehensive suite of tools tailored to their specific business requirements. However, it should be noted that open-source ERP systems often have limited complementary modules included in the installation package. In

particular, SMEs in the transportation services industry may face challenges as these systems may not offer modules that cater specifically to their needs. For example, implementing a fleet management module is crucial for effectively managing the transportation fleet in the transportation services industry. Therefore, the package of an open-source ERP system holds significant importance in the selection process as it can impact the costs, complexity, and effectiveness of implementing and integrating the system within an enterprise (Benlian & Hess, 2011).

Meanwhile, the cost criterion occupies the second position, which indicates that cost is an essential criterion after the package criterion. In open-source ERP systems, the installation package of the open-source ERP system is indeed provided free of charge. However, it does not mean the company does not need any costs. Some costs must be invested in the implementation process, such as consulting fees, maintenance, and hosting rental (Olson et al., 2018). Not only that, but companies also need to invest in supporting facilities and conduct training on the use of open-source ERP systems. Companies also need to incur costs if they use additional modules that are not free but are needed to accommodate the company's business processes.

Based on the weighting of criteria, this study's results indicate differences in the level of importance of aspects in selecting paid and open-source ERP systems. In previous research investigated by Kilic et al. (2015), the findings show that the selection of ERP systems for SMEs shows the cost aspect as the aspect with the highest weight on the paid ERP system. However, this study found that the package criteria became fundamental in open-source ERP systems because the features provided by open-source ERP systems were limited (Joseph Christianto, 2022). In contrast to paid ERP systems, the cost aspect becomes very significant because the modules are tailored to the business needs of the vendor. Therefore, SMEs adopting open-source ERP systems must ensure that the system has a package accommodating the company's business processes.

Interestingly, reputation was revealed as the third most crucial aspect that needs to be prioritized. Choosing an Open-source ERP system should not be haphazard. It is essential to pay attention to the provider's track record. It can minimize losses if there is a change in policy from a vendor that provides a system for free.

Subsequently, the fuzzy AHP was utilized to determine the relative importance of sub-criteria. The results indicate that the sub-criteria with the highest weights are Accommodating logistics service business processes (C9), support and maintenance cost (C2), and Consultant and implementation cost (C1), with weights of 0.160, 0.153, and 0.074, respectively. Accommodating logistics service business processes (C9) have the highest weight. This result is very reasonable because the case study of this research is on SME logistics service providers that require logistics features. The limited number of modules offered by open-source ERP systems makes analyzing the free modules provided from the start essential. The modules provided must accommodate the company's business processes, such as a module for the vehicle assignment process in a logistics service business. The adopted open-source ERP system must have modules accommodating the business process. Meanwhile, the sub-criteria Implementation time (C12) and Online help and tutorials (C14) are ranked 18-19 with a weight of 0.011.

The fuzzy AHP findings indicate that the package criteria, with a weight of 0.342, is the most crucial factor to consider when choosing an open-source ERP system. It is highlighted that how the open-source ERP system is packaged has the potential to affect both the cost and complexity of its implementation. Additionally, the remaining criteria are prioritized as follows: Cost holds a weight of 0.248, reputation holds a weight of 0.180, Operation and Technical hold a weight of 0.180, and flexibility holds a weight of 0.085. On the other hand, the outcomes of the fuzzy AHP analysis also denote that the sub-criteria accommodating logistics service business processes (weighted at 0.160), Support and maintenance cost (weighted at 0.153), and consultant and implementation cost (weighted at 0.074) are the three sub-criteria that carry the most substantial weight and needed to be prioritized in selecting an open-source ERP system.

Table 4: Weighting criteria and sub-criteria for ERP system selection

Criteria	Weight	Sub-Criteria		Local Weight	Global Weight
Cost	0.248	C1	Consultant and implementation cost	0.297	0.074
		C2	Support and maintenance cost	0.617	0.153
		C3	Hosting cost	0.086	0.021
Reputation	0.180	C4	Brand image	0.426	0.077
		C5	Update availability history	0.148	0.027
		C6	Sustainability	0.426	0.077
Package	0.342	C7	Number of free modules	0.176	0.060
		C8	Availability of 3rd party modules	0.102	0.035
		C9	Accommodating logistics service business processes	0.467	0.160
		C10	Integration with satellite-based navigation system	0.061	0.021
		C11	Integration level between modules	0.195	0.067
Operation & Technical	0.146	C12	Implementation time	0.075	0.011
		C13	User-friendliness	0.373	0.054
		C14	Online help and tutorials	0.075	0.011
		C15	Ease of data migration	0.141	0.021
		C16	Ease of maintenance	0.337	0.049
Flexibility	0.085	C17	Ease to customization	0.225	0.019
		C18	Upgradeability	0.457	0.039
		C19	Potential for future strategy	0.319	0.027

3.2. Alternatives ERP score

The normalization of the closeness coefficient value presented in Table 5 is utilized to derive the score for each alternative. The results indicate that the scores attributed to each alternative do not exhibit a significant difference and are characterized by a comparable level of competitiveness. Nevertheless, it is noteworthy that Alternative 10 demonstrates the highest score, as evidenced by the normalized percentage of 13.03%. This study indicated that the criterion package holds the highest weight value. Furthermore, accommodating logistics service business processes are considered a sub-criterion with the most significant global weight. According to the analysis, the Open-source ERP system alternative 10 possesses modules capable of accommodating the business processes of SMEs in the transportation services sector. For example, apart from other basic modules, a fleet management module allows transportation companies to attain specific tasks relating to a company's fleet of vehicles. In addition, many third-party modules can be used for free.

Table 5: Rank of alternatives based on TOPSIS

	d*	d-	Cj	Normalized	Ranking
Alt1	0.511	0.367	0.417	7.73%	10
Alt2	0.390	0.495	0.558	10.34%	2
Alt3	0.426	0.461	0.519	9.61%	3
Alt4	0.485	0.400	0.452	8.37%	8
Alt5	0.481	0.411	0.460	8.52%	7
Alt6	0.469	0.411	0.466	8.64%	6

Alt7	0.495	0.383	0.436	8.07%	9
Alt8	0.448	0.441	0.495	9.18%	4
Alt9	0.520	0.372	0.417	7.72%	11
Alt10	0.259	0.616	0.703	13.03%	1
Alt11	0.464	0.420	0.475	8.80%	5

3.3. Managerial implication

An ERP system is designed to increase business productivity by coordinating parts of an organization's operations through an integrated database and software applications. Many SMEs need help implementing an ERP system even though the benefits are evident because of the prohibitive investment costs. However, many ERP system vendors lately provide open-source systems to implement in the company's business operations. Experts and practitioners estimate that about two-thirds of ERP system implementations fail due to incompatibility of business procedures and expensive implementation costs. Therefore, selecting an ERP system in the ERP adoption/implementation process is necessary, especially for open-source systems.

The selection of a scientifically sound open-source ERP system is essential in the ERP adoption/implementation process due to the large variety of open-source ERP system offerings. Each open-source ERP system has strengths and weaknesses. Therefore, to increase the chances of success, all available open-source ERP system selection criteria and sub-criteria options must be carefully considered. MCDM decision-making tools are widely used to assist the ERP system selection process because there are many criteria and sub-criteria to be considered. This procedure was chosen because it can accommodate the trade-offs of the criteria and sub-criteria used in the ERP system selection.

This study aims to select an open-source ERP system faced by an SME transportation service provider in Indonesia. The criteria for selecting an open-source ERP system are determined based on the needs and desires of the company's top management. After the criteria and sub-criteria are determined, a fuzzy AHP methodology is proposed to weight the criteria and sub-criteria. Furthermore, the assessment of each alternative open-source ERP system offered. Fuzzy TOPSIS is used by utilizing the weights of the criteria and sub-criteria of the fuzzy AHP methodology to determine the preference for open-source ERP systems.

The selection of open-source ERP systems is evaluated based on several criteria Cost, Reputation, Package, Operation & Technical, and Flexibility. These five criteria are translated into 19 sub-criteria. The results show that the Package criteria have a weight value more significant than the other criteria, followed by the cost criteria. Based on the weighting of sub-criteria with fuzzy AHP, the three sub-criteria with the most weight are Accommodating logistics service business processes (C9), Support and maintenance costs (C2), and Consultant and implementation costs (C1). This finding shows how SMEs consider package and cost criteria in selecting an open-source ERP system. The most critical to consider is the sub-criteria of features that are by the company's problems, such as the Accommodating logistics service business processes (C9) sub-criteria.

Meanwhile, cost needs to be considered, such as the Support and maintenance costs (C2) and Consultant and implementation costs (C1) sub-criteria. Although open source, SMEs also require support and maintenance costs (C2) and Consultant and implementation costs (C1). Therefore, the cost is also essential when selecting an ERP system.

Based on the proposed method that integrates fuzzy AHP and fuzzy TOPSIS, the results show that the proposed procedure is technically sound and acceptable to the organization. When the ambiguity and complexity of the decision situation are addressed by combining the benefits of two decision support methods, decision-makers can feel confident in their choice. The fuzzy AHP method can help managers and decision-makers weight the criteria and sub-criteria for selecting an open-source ERP system. This procedure can easily weight the criteria and sub-criteria. Meanwhile, fuzzy TOPSIS is

proven to efficiently rank the preferences of open-source ERP system alternatives based on incomplete information.

4. Conclusion

The study aims to select an open-source ERP system for SME transportation service providers. Five criteria and 19 sub-criteria are proposed to solve the problem of selecting an open-source ERP system. This study proposes an MCDM methodology integrating fuzzy AHP and TOPSIS in ERP system selection. Fuzzy AHP is applied to determine the weight of each criterion and sub-criteria. The fuzzy TOPSIS method determines the score and ranking of each alternative ERP system. This study makes a valuable contribution to the existing literature on open-source ERP systems by identifying key factors crucial in selecting these systems and identifying the most suitable open-source ERP system alternative for SMEs. The findings of this study have practical implications and can guide businesses to improve their efficiency and financial outcomes.

The study reveals that the selection of an open-source ERP system should prioritize package criteria as essential factors. The packaging of the open-source ERP system significantly impacts implementation costs and complexity, potentially affecting the effectiveness of the installation process and system integration within an enterprise. Additionally, cost is ranked as the second most crucial criterion, given the financial conditions of SMEs. It is essential to consider expenses incurred during the implementation process, including consulting fees, maintenance, hosting rental, training, and supporting facilities, as these can be seen as investments toward enhancing the economic performance of the business.

Furthermore, the study highlights specific important sub-criteria, including accommodating logistics service business processes, support and maintenance costs, and consultant and implementation costs. These findings are highly relevant, considering the focus of the study on logistics attributes that are essential for SMEs in the logistics service provider industry. It is crucial to carefully analyze the initially provided free modules due to the limited number of modules available in open-source ERP systems. The selected open-source ERP system should include modules that align with the operational workflows of the business, such as a module for vehicle allocation in a logistics enterprise. In addition, the ERP system in Alternative 10 is the open-source ERP system with the highest preference, especially for transportation service provider SMEs. This ERP system in alternative 10 has advantages in the packages offered, especially having modules that can be configured according to the business processes of Transportation Service Provider SMEs.

However, there are still limitations in this study. The completeness of the proposed framework may be limited because the attributes proposed in this study were obtained from the literature and assessed by eight experts. It is recommended for future research to expand and deepen the proposed attributes to improve the discussion and ERP system selection framework. In addition, due to the specific knowledge, experience, and understanding of ERP systems and the transportation service provider industry, the limited number of experts involved as respondents of this study may cause bias in interpreting the results. Therefore, to address this issue, increasing the number of expert respondents is essential for future studies. Furthermore, future research should include other industries besides SMEs and the transportation service provider industry to understand ERP system selection better. Meanwhile, this study also ignored the relationship between criteria. Therefore, future research must consider the relationship between criteria in selecting open-source ERP systems.

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