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Research article

Fuzzy-AHP MOORA approach for vendor selection applications

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ABSTRACT

Vendor selection is a critical activity in order to support the achievement of company success and competitiveness. Significantly, the company has some specific standards in the selection. Therefore, an evaluation is needed to see which vendors match the company's criteria. The purpose of this study is to evaluate and select the proposed vendor in a web-based decision support system (DSS) by using the fuzzy-AHP MOORA approach. The fuzzy-AHP method is used to determine the importance level of the criteria, while the MOORA method is used for alternative ranking. The results showed that vendor 4 has the highest score than other alternatives with a value of 0.2536. Sensitivity analysis showed that the proposed DSS fuzzy-AHP MOORA concept was already solid and suitable for this problem, with a low rate of change.

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1. Introduction

The process of vendor selection is one of the critical company activities managed by the procurement department. Vendor selection has a significant effect on strategic and operational performance in an organization [1]. Choosing the right vendor can improve quality and flexibility to meet customer satisfaction [2]. The primary purpose of choosing a vendor is to reduce the purchase risk, maximize the overall value of the buyer, and develop the intimate and long-term relationship between the buyer and the seller. Therefore, purchasing managers should develop and use effective processes to find a qualified vendor to grant business qualifications. Thus, it is necessary to evaluate the selection to determine the right vendor that matches the company's criteria.

Evaluation in the selection of vendor certainly requires relevant criteria as benchmarks in its assessment. In developing and selecting criteria, the criteria must reflect the company's supply chain strategy and the characteristics of the items to be supplied. This process means that assessing criteria like quality and services is a big part of a procurement manager's job, along with negotiating to find the best available pricing and savings for their company. Well-designed criteria can improve the performance and reduce the risk of the procurement system in supply chain management.

Several decision-making methods have been widely used in the field of vendor or supplier selection. Multi-Criteria Decision Making (MCDM) is a method that has been popular in decision-making problems. MCDM is a mathematical technique for assisting in the decision-making process by evaluating and ranking multiple alternatives and conflicting criteria in complex situations [3]. MCDM has many methods, including SAW, ELECTRE, VIKOR, MAUT, PROMETHEE, SMART, WP, and TOPSIS. In the last few decades, the MCDM method has been integrated with some other methods. The

primary objective of integration is to strengthen and empower the MCDM method to deal with various decision problems more effectively [4]. Many research with the MCDM technique uses a combination with other MCDM techniques [5]. This fact is based on some MCDM focuses on specific areas. For example, the AHP, BCM, and BWM methods focus more on weighting criteria [6]. Therefore, this method can be integrated with other methods with an excellent alternative ranking [7], such as MOORA, TOPSIS, VIKOR, and PROMOTHEE. For instance, an integrated AHP-TOPSIS prioritizes vendor rating criteria [8], BWM-VIKOR approach for supplier selection [9]. They combine two methods to complement each other's shortcomings in order to strengthen the evaluation. In its current application, AHP is likely to be found for criteria weighting. They use AHP because it provides a framework to make effective decisions in complex decision-making situations (e.g., vendor selection). However, in some weighting criteria using existing methods (such as the 1-9 scale pairwise comparisons), the criteria weighting cannot be measured only by a crisp value due to a lack of information, uncertainty, and ambiguity in human qualitative judgments [10]. Therefore, the decision-makers hesitancy must be expressed in fuzzy sets [11], where fuzzy is likely more in line with the actual situations and can obtain more convincing ranking results [12]. Hence, an extended fuzzy sets approach with an evaluation comparison matrix, such as the fuzzy-AHP method, is implemented. In this way, this study chose fuzzy-AHP for weighting criteria, and the MOORA method as an alternative ranking refers to comparison result [13], shows MOORA has better advantages compared to other methods in alternative selection.

The fuzzy-AHP method is a fuzzy extension of conventional AHP, where this method implements fuzzy sets in the AHP pairwise comparison matrix. The fuzzy-AHP method is known as one of the popular approaches that have been used extensively in several studies [14, 15, 16, 17]. Fuzzy-AHP is very suitable to be chosen for use because this method can provide fuzzy weight values for predefined criteria, which can minimize subjective assessments of the weighted criteria set by the decision-maker [18]. On the other hand, the MOORA method is one of the newest multi-criteria decision-making (MCDM) methods. This method is built on the knowledge of the previous MCDM method flaws [1]. This method is considered simple and computationally easy in decision-making by eliminating inappropriate alternatives while selecting the most suitable alternatives to strengthen the selection process [19]. These fuzzy-AHP and MOORA methods have also been used or combined with other methods in the vendor or supplier field [20, 21, 22, 23].

The selection of vendors in this study begins with determining the criteria obtained from literature studies adjusted and selected by the company's decision-maker. The criteria specified are: 1) Quality, 2) Price/Cost, 3) Services, 4) Warranties and Claim Policies, 5) Delivery, 6) Product Development. After these criteria are determined, the decision-maker assigns weight for each criterion with AHP pairwise comparison. These criteria will be used and calculated with the fuzzy-AHP method, and the result will be used as weights for the MOORA method. Finally, the decision-maker determines the weights of each vendor using the MOORA method. The results obtained can be used as a reference for the company in determining the vendor selection.

2. Related Work

Several studies have been conducted to understand the vendor selection context. Choosing vendor or supplier criteria is one of the crucial contexts to discussed in the process of evaluation. Hence, Taherdoost and Brard [24] provided a review of the supplier criteria. The criteria they proposed were generalized and not targeting specific types of industry. They classified each criterion based on the relevant related sources, which consists of 25 criteria. In this study, these criteria are offered and selected by the company's decision-maker for preliminary technical and evaluation. Thus, these criteria are used for the evaluation process in a decision support system.

Many MCDM tools were implemented for determining the weight of the criteria. AHP is one of the most popular MCDM methods. For example, Dweiri et al. [25], proposed a DSS with AHP method to select an automotive industry supplier in Pakistan. They used AHP in selecting suppliers because it gave decision-makers confidence in the consistency and robustness throughout the process. However, the shortcomings of this pairwise comparison scale are considered a little less capable of dealing with the uncertainty of subjective judgments from experts. Therefore, to cover the shortcomings of AHP pairwise comparisons, fuzzy numbers were introduced in AHP called fuzzy-AHP to solve uncertainty

with more accurate real-time. The fuzzy-AHP method has been used quite a lot before in various sectors, such as research conducted by Ghorui et al. [14], applied fuzzy-AHP for identification dominant risk factor of COVID-19. Akbar et al. [15], utilized the fuzzy-AHP method for prioritization cloud-based outsource software development. Ogundoyin et al. [16], applied fuzzy-AHP on fog computing services to prioritize its trust standards. In another study, Gou-chenxi [17], developed fuzzy-AHP for the evaluation of electromechanical system components.

On the other hand, fuzzy-AHP has also been broadly utilized for weighting criteria and combined with other vendor or supplier selection methods. For example, Li et al. [20], studied integrated fuzzy-AHP TOPSIS. They proposed a combination of approaches based on fuzzy-AHP TOPSIS approaches to evaluate the selection of network suppliers. In another study, Awasthi et al. [21], proposed fuzzy-AHP VIKOR for the selection of sustainable global suppliers. Based on the research that has been obtained, fuzzy-AHP can be combined with other MCDM methods that have good alternative assessments. Many MCDM methods have good alternative assessments, but MOORA is recently the most advanced MCDM method, which uses a statistical approach to select the best-proposed alternatives [23]. Performance comparison of the MOORA method with other MCDM methods has been carried out [13], indicating that MOORA has better advantages over other methods in the alternative selection. In its application, Patnaik et al. [23] using AHP-MOORA in composite material selection, applied this method to help select the alternative polymer composites for engineering applications. Another study, Setyono et al. [22], developed MOORA and COPRAS with the BWM method for supplier selection. They used BWM as weighting criteria, while MOORA and COPRAS for alternative ranking. Although different combined MCDM methods have been reported in different previous articles, fuzzy-AHP MOORA has been less likely to be found. Therefore, an effort was made to get the best alternative of vendor selection using the fuzzy-AHP MOORA approach.

3. Methodology

3.1. System design

The extremely competitive environment of today's business makes it nearly impossible for businesses to produce low price high-quality products without utilizing proper vendors [26]. The vendor selection is a highly sensitive activity since the various vendors have different advantages and disadvantages [27]. On the other hand, the process of vendor selection can be used for both certain and uncertain data [28].

In this study, the proposed application is built for the selection of network switch vendors. The vendor alternative is provided according to the processes currently running in the company, and the criteria used are obtained from the perspective of the company's decision-makers. The criteria and alternatives of network switch vendor shown in Fig. 1.

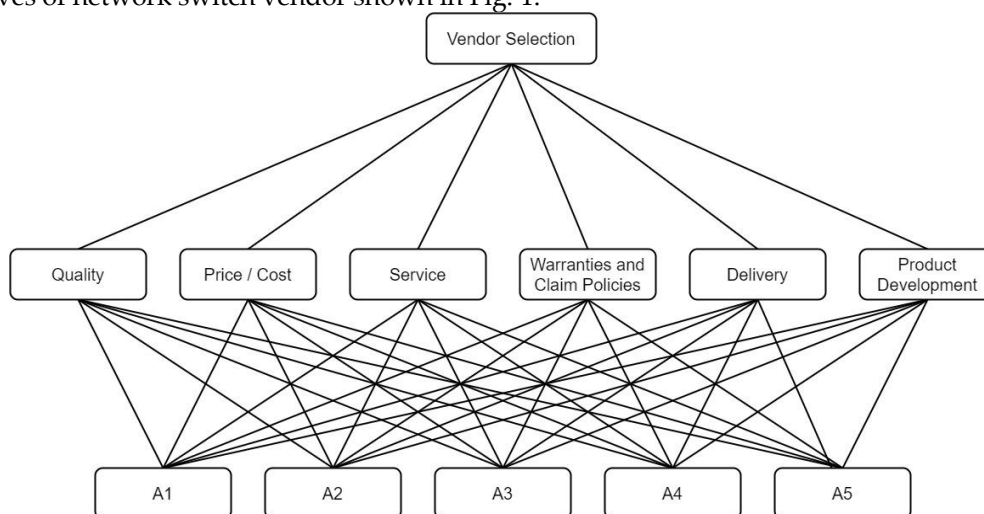


Fig. 1. AHP hierarchy

3.2. Information systems framework

Through three stages: input, process, and output, the information systems framework in this study is implemented. In the first stage, the criteria and alternative data are used as input data. Then at the process stage, the criteria and alternative data will be evaluated through several steps. The evaluation

step begins with the AHP approach, each of these criteria is weighted, and the consistency is calculated. If the results are appropriate, then proceed to the next stage, namely fuzzy-AHP. The fuzzy-AHP step is used to convert the linguistic criteria into a TFNs scale. It is calculated through several steps and then obtained the criterion weight. Finally, the final step in the process stage is to determine alternative priorities using the MOORA approach through four steps. Once the results are obtained, the results will be displayed in the decision support system output as suggestions for selecting the right vendor. The complete information systems framework is shown in Fig. 2.

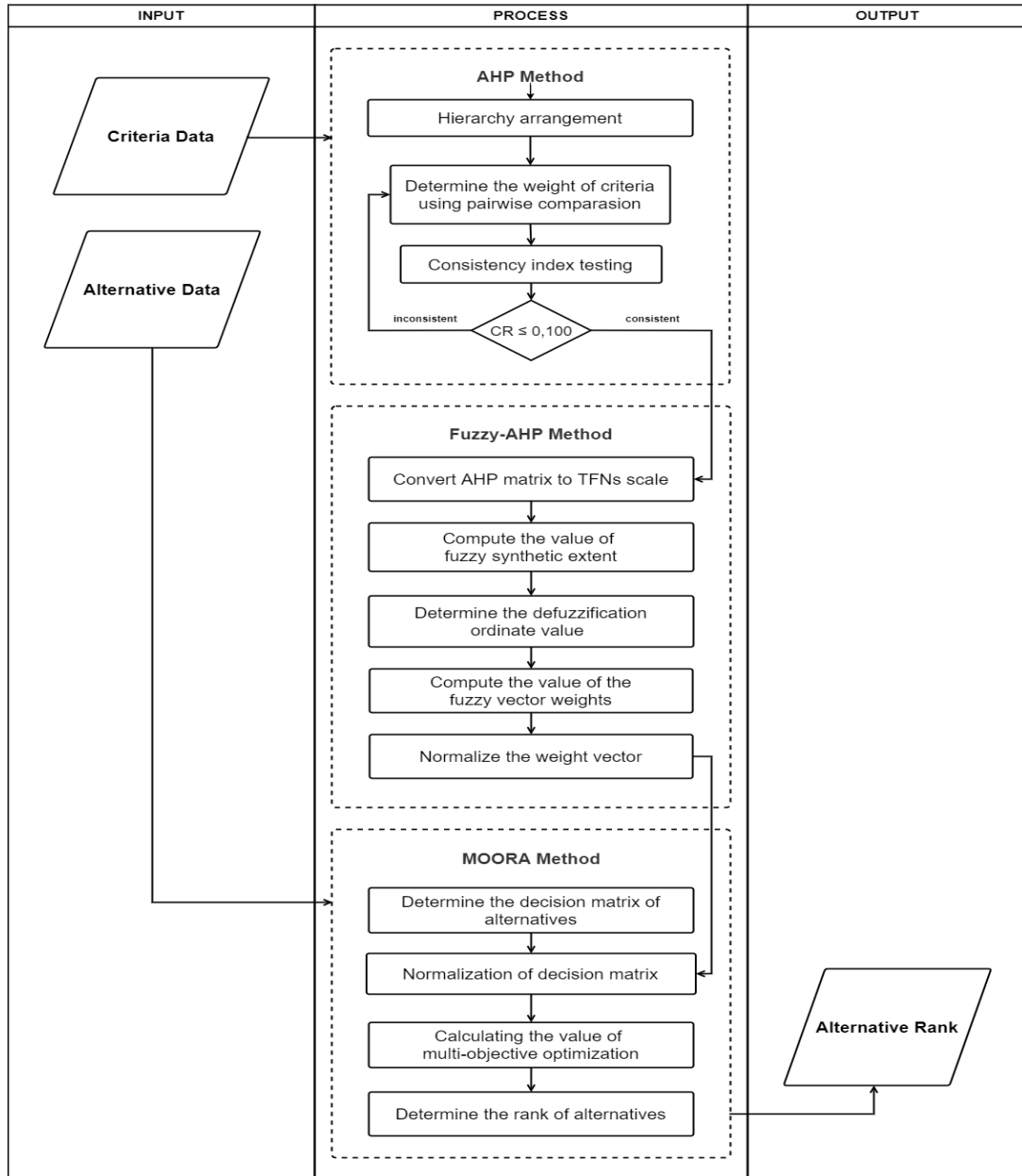


Fig. 2. Information systems framework

3.3. Fuzzy set theory

Some of the fuzzy set theories we adopted in this study are summarized as follows [7, 16, 29, 30].

Definition 1: Fuzzy set theory

Let X be a set, where the elements of X are represented by x , that is $X = \{x\}$. The fuzzy set is described in Eq. 1, as follows,

$$A = \{x, \mu_A(x), x \in X\} \tag{1}$$

where A is the fuzzy set, $\mu_A: X \rightarrow [0,1]$ is the function of fuzzy set membership A , $\mu_A(x) \in [0,1]$ is an element of the set A for the membership degree x .

Definition 2: Triangular fuzzy numbers (TFNs),

TFNs is expressed by \tilde{M} as a fuzzy set with a the variable (l, m, u) , as seen in Fig. 3.

The function of membership $\mu_{\tilde{M}}(x)$ is described in Eq. 2, as follows,

$$\mu(x|\tilde{M}) = \begin{cases} 0, & x < l, \\ \frac{x-l}{m-l}, & l \leq x \leq m, \\ \frac{u-x}{u-m}, & m \leq x \leq u, \\ 0, & x > u, \end{cases} \quad (2)$$

where $\mu(x|\tilde{M})$ is the TFN's membership function, l, m, u are the lower, middle, and upper crisp numerical values, respectively. TFN's membership function shown in Fig. 3.

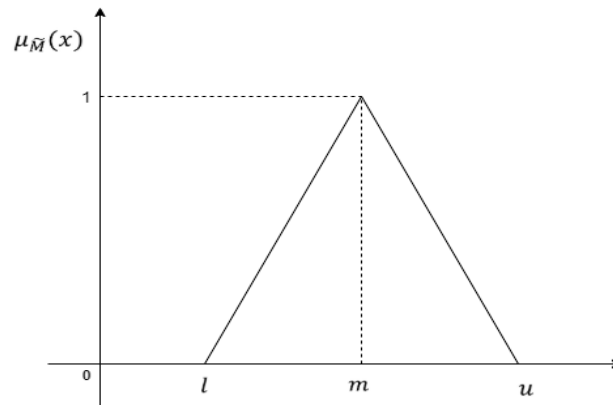


Fig. 3. Triangular fuzzy numbers

3.4. Fuzzy-AHP method

The fuzzy-AHP method starts with calculation from conventional AHP. The AHP method was introduced by Saaty [31], as a solution to MCDM problems. This method is effective in dealing with both quantitative and qualitative data problems. Although AHP aims to gather the opinions of experts, it cannot deal with the ambiguity in human reasoning. Therefore, an integration of fuzzy sets in AHP was introduced by Chang. A fuzzy-AHP method is the implementation of fuzzy sets in the AHP pairwise comparison matrix, represented by three variables called the Triangular Fuzzy Number (TFN). Each triangular fuzzy symbolized by (l, m, u) each has a value, according to the membership function, which includes three consecutive weights. TFNs are used for measurements related to human subjective judgments using linguistic language. By this mean, the TFN function model can analyze the uncertainty and ambiguity [32]. The TFN is reflected by $\tilde{M} = (l, m, u)$, where l stands for low (lowest value), m stands for middle (most expected value), and u stands for up (highest value). TFNs scale of fuzzy-AHP pairwise comparison is shown in Table 1.

Table 1. AHP pairwise comparison and TFNs scale

Linguistic terms	Crips	TFNs	TFNs reciprocal
		(l, m, u)	(u^{-1}, m^{-1}, l^{-1})
Equally importance	1	(1, 1, 1)	(1, 1, 1)
Intermediate	2	(1, 2, 3)	(1/3, 1/2, 1)
Moderate importance	3	(2, 3, 4)	(1/4, 1/3, 1/2)
Intermediate	4	(3, 4, 5)	(1/5, 1/4, 1/3)
Strong importance	5	(4, 5, 6)	(1/6, 1/5, 1/4)
Intermediate	6	(5, 6, 7)	(1/7, 1/6, 1/5)
Very strong importance	7	(6, 7, 8)	(1/8, 1/7, 1/6)
Intermediate	8	(7, 8, 9)	(1/9, 1/8, 1/7)
Extreme importance	9	(8, 9, 9)	(1/9, 1/9, 1/8)

In this study, the fuzzy-AHP method starts with the conventional AHP method, as follows [31]:

Step I: Hierarchy arrangement

The preparation step starts from getting the criteria and alternatives. These criteria and alternatives are organized into a hierarchical structure, as shown in Fig. 1.

Step II: Assessment of criteria

Make a pairwise comparison matrix describing the relative contribution of each criteria element using the AHP pairwise comparison scale shown in Table 1 with following Eq. 3,

$$\tilde{x} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (3)$$

where \tilde{x} is the comparison matrix, m are number of alternatives; n are the number of criteria.

Step III: Consistency Testing

After the paired matrix has been made, the consistency is checked next. The first step of consistency testing is to normalize the paired matrix by dividing each column elements by the sum of all column elements, formulated as following Eq. 4,

$$\tilde{x}_{ij} = \frac{x_{ij}}{\sum_{j=1}^n x_{ij}} \quad \forall i, j, \quad x_{ij} \in X \quad (4)$$

where n is the criteria number. Each criterion weight is represented by the eigenvector, which is given by the following Eq. 5,

$$w_i = \frac{\sum_{j=1}^n x_{ij}}{n} \quad (5)$$

where w_i is the eigenvector in row i , $\sum_{j=1}^n x_{ij}$ is the normalized pairwise matrix of the sum of all value in i row and n is the criteria number.

The crisp matrix's eigenvalue λ is calculated by multiply each AHP crisp matrix elements by the appropriate eigenvector. After that, the largest eigenvalue (λ_{max}) is obtained by adding up each eigenvalue λ and divided by n . Hence, λ_{max} is expressed in Eq. 6, as follows,

$$\lambda_{max} = \frac{\sum \lambda}{n} \quad (6)$$

where $\sum \lambda$ is the sum of the eigenvalue λ and n is the number of λ .

The consistency test of the assessment is carried out to find out how good the consistency is. The consistency test of the sized matrix is calculated by the following Eq. 7,

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

where CI represents the consistency index, λ_{max} represents the largest eigenvalue of the matrix with order n , and n represents the number of criteria.

Step IV: Inconsistency Boundary Measurement

The inconsistency limit is computed using CR (Consistency Ratio), the consistency ratio is formulated in Eq. 8, as follows,

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

where the RI value is obtained by the random index that shown in Table 2.

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

RI is determined by the value of N , in which N is the criteria number. RI represents the set of numbers index proposed by Saaty [33]. If the consistency ratio (CR) is more than 0.1, then the pairwise comparison ratio must be repeated. The consistency ratio is valid if the value is less or equal to 0.1. Then the AHP pairwise comparison can be used.

The subsequent steps of the fuzzy-AHP method used are as follows [8]:

Step V: Converting AHP scale to TFNs scales

After the results of the analysis using AHP are obtained, the next step is to convert the AHP scale into TFNs scale. TFNs scale shown in Table 1.

Step VI: Calculate the fuzzy synthetic extent value

The fuzzy synthetic extent value is computed by the Eq. 9,

$$S_i = \sum_{j=1}^m M_{g_i}^j \otimes \left[\sum_{i=1}^n \sum_{j=1}^m M_{g_i}^j \right]^{-1} \quad (9)$$

where S_i is the fuzzy synthetic extent value and $\sum_{j=1}^m M_{g_i}^j$ is obtained by executing a fuzzy addition operation of m extent analysis values for a specific matrix's, as shown in Eq. 10,

$$\sum_{j=1}^m M_{g_i}^j = \left(\sum_{j=1}^m l_j, \sum_{j=1}^m m_j, \sum_{j=1}^m u_j \right) \quad (10)$$

where $(\sum_{j=1}^m l_j, \sum_{j=1}^m m_j, \sum_{j=1}^m u_j)$ is the sum of each l, m, u criterion row.

Meanwhile to get the value of $[\sum_{i=1}^n \sum_{j=1}^m M_{g_i}^j]^{-1}$ a fuzzy addition operation is performed for the entire triangular fuzzy number $M_{g_i}^j$ ($j = 1, 2, \dots, m$) as shown in Eq. 11,

$$\sum_{i=1}^n \sum_{j=1}^m M_{g_i}^j = (\sum_{i=1}^n \sum_{j=1}^m l_{ij}, \sum_{i=1}^n \sum_{j=1}^m m_{ij}, \sum_{i=1}^n \sum_{j=1}^m u_{ij}) \quad (11)$$

where $\sum_{i=1}^n \sum_{j=1}^m l_{ij}$ is the sum of column element l , $\sum_{i=1}^n \sum_{j=1}^m m_{ij}$ is the sum of column element m , and $\sum_{i=1}^n \sum_{j=1}^m u_{ij}$ is the sum of column element u .

So we get the Eq. 12 as follows.

$$[\sum_{i=1}^n \sum_{j=1}^m M_{g_i}^j]^{-1} = \left(\frac{1}{\sum_{i=1}^n \sum_{j=1}^m u_{ij}}, \frac{1}{\sum_{i=1}^n \sum_{j=1}^m m_{ij}}, \frac{1}{\sum_{i=1}^n \sum_{j=1}^m l_{ij}} \right) \quad (12)$$

Step VII: Compute the possibility degree between fuzzy numbers

For two fuzzy triangular numbers $S_1 = (l_1, m_1, u_1)$ and $S_2 = (l_2, m_2, u_2)$ with the probability level of $S_1 \geq S_2$, obtained by the following Eq. 13.

$$V(S_1 \geq S_2) = \begin{cases} 1, & \text{if } m_1 \geq m_2 \\ 0, & \text{if } l_2 \geq m_1 \\ \frac{l_1 - u_1}{(m_1 - u_1) - (m_2 - u_2)}, & \text{otherwise} \end{cases} \quad (13)$$

Step VIII: Calculate the degree of possibility for a fuzzy number

Calculate the probability degree where each fuzzy number is greater than k fuzzy numbers: S_i ($i = 1, \dots, k$), calculated by the following Eq. 14, Eq. 15, and Eq. 16.

$$V(S \geq S_1, S_2, \dots, S_k) \quad (14)$$

$$V[(S \geq S_1) \text{ and } V(S \geq S_2) \text{ and } \dots \text{ and } V(S \geq S_k)] \quad (15)$$

$$\min V(S \geq S_i), \quad i = 1, 2, \dots, k. \quad (16)$$

After V is obtained, then determine the value of the defuzzification ordinate (d'), by the Eq. 17.

$$d'(A_i) = \min V(S_i \geq S_k), \text{ for } k = 1, 2, \dots, n; k \neq i. \quad (17)$$

The vector's weight is then given by the Eq. 18,

$$W' = (d'(A_1), d'(A_2), \dots, d'(A_n))^T \quad (18)$$

where W' is vector weights, A_i ($i = 1, 2, \dots, n$) are n elements

Step IX: Normalize the weight vector

Each weight vector which is still in the fuzzy numbers form further normalized by the Eq. 19,

$$d(A_i) = \frac{d'(A_i)}{\sum_{i=1}^n d'(A_i)}, \quad i = 1, 2, \dots, n \quad (19)$$

Each vector element's weight is divided by the vector's total weight, resulting a total number of normalized weights is 1. Thus with normalization, we get the normalized weight vectors (W). The results of the weighted criterion with fuzzy-AHP will be used in the MOORA method for alternative ranking calculations.

3.5. MOORA method

The steps of the MOORA method to be used is defined as follows [34]:

Step I: Forming a paired comparison matrix

The MOORA method starts with making a paired comparison matrix with Eq. 20, as follows,

$$x_{ij} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \quad (20)$$

where x_{ij} is the comparison matrix response of alternative j to criterion i , n are the criterion and m are the alternatives.

Step II: Normalization of the decision matrix

MOORA refers to a ratio system, where the ratio value is the alternative value on a criterion compared with the denominator representing all alternatives of the criterion. The sum of each alternative squares is the denominator of the value of each alternative to per criterion. The normalization shown in Eq 21,

$$x^*_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^m x_{ij}^2}} \quad (21)$$

where x_{ij} is the response of the i alternative to the j criterion, $i = 1, 2, 3, 4, \dots, m$ is the alternative sequence number, $j = 1, 2, 3, 4, \dots, n$ is the attribute sequence criterion number, and x^*_{ij} represents a dimensionless number included in the interval $[0, 1]$ expressing the normalized value of the i alternative to the j criterion.

Step III: Calculating the value of multi-objective optimization

In calculating the optimization value, normalization results are sought to obtain the maximum and minimum values for each criterion. The maximum value for the criteria is the benefit value, while the minimum value for the criteria is the cost value. The optimization calculation is the sum of the criteria value with the benefit value then subtracting the criteria value from the cost value, as shown in Eq. 22,

$$y_i = \sum_{j=1}^g x_{ij} - \sum_{i=g+1}^n x_{ij} \tag{22}$$

where $j = 1, 2, \dots, g$ is the number of criterion that are maximized, $i = g + 1, g + 2, \dots, n$ is the number of criterion that are minimized, y_i is the normalized rating value from alternative i to all criterion and x_{ij} alternative value i on criterion j . Within this formula, a dimensionless measure in the interval $[0; 1]$ is referred to as linearity.

Step IV: Determine the alternative rank from the results of the MOORA calculation

Finally, depending on the benefit attributes in the decision matrix, the value of y_i can be positive or negative. The alternative with the highest y_i value the best alternative in the ranking results; thus, this alternative is the best choice according to the calculation. Meanwhile, the alternative that has the lowest value (y_i) is the worst preference among other alternatives.

4. Results and Discussion

This segment describes the results of the vendor selection using the fuzzy-AHP and MOORA based on the decision support system. As explained in the previous section, the selection of vendors needs to be carried out in several stages.

4.1. Determination of the criteria weights using AHP method

The first stage of fuzzy-AHP begins with determining each criterion's importance using an AHP pairwise comparison matrix, which company experts determine from the purchasing department. The result of pairwise comparison with the AHP scale is showed in Table 3.

Table 3. AHP pairwise comparison

Code	QL	PR	SV	WC	DL	PD
QL	1	2	2	3	3	4
PR	1/2	1	1	2	3	3
SV	1/2	1	1	2	2	2
WC	1/3	1/2	1/2	1	1/2	2
DL	1/3	1/3	1/2	2	1	1/2
PD	1/4	1/3	1/2	1/2	2	1

After that, by dividing each column element by the sum of all the column elements, the AHP pairwise comparison matrix is normalized using Eq. 4. The result showed in Table 4.

Table 4. AHP normalized pairwise comparison

Code	QL	PR	SV	WC	DL	PD
QL	0.342935528	0.387146729	0.363636364	0.285714286	0.260869565	0.32
PR	0.171467764	0.193573364	0.181818182	0.19047619	0.260869565	0.24
SV	0.171467764	0.193573364	0.181818182	0.19047619	0.173913043	0.16
WC	0.114197531	0.096786682	0.090909091	0.095238095	0.043478261	0.16
DL	0.114197531	0.06445993	0.090909091	0.19047619	0.086956522	0.04
PD	0.085733882	0.06445993	0.090909091	0.047619048	0.173913043	0.08

Then we obtained the eigenvector (w_i) and eigenvalue (λ). The result shown in Table 5.

Table 5. The eigenvector and eigenvalue

Code	Eigenvector (w_i)	Eigenvalue (λ)
QL	0.326717079	6.280957465
PR	0.206367511	6.363830321
SV	0.178541424	6.301145257
WC	0.100101610	6.305071431
DL	0.097833211	6.235550172
PD	0.090439166	6.367006488

Next we obtained the eigenvalue (λ_{max}) using Eq. 6. Hence,

$$\lambda_{max} = \frac{(6.280957465 + 6.363830321 + 6.301145257 + 6.305071431 + 6.235550172 + 6.367006488)}{6}$$

$$= 6.308926856$$

Since there are six criterion under consideration, $n = 6$, and according to Table 2, the corresponding value of 6 on the RI is 1.25. Thus, the CI based on Eq. 7 is calculated as:

$$CI = \frac{(6.308926856-6)}{(6-1)} = 0.0617853712$$

Then the consistency ratio (CR) is calculated based on Eq. 8 :

$$CR = \frac{0.0617853712}{1.25} = 0.049428297$$

Since the CR value obtained is 0.049428297 and the value is < 0.10 , the AHP pairwise comparison matrix in Table 3 is consistent and acceptable.

4.2. Prioritizing the local weights with fuzzy-AHP method

The fuzzy-AHP method starts with converting AHP pairwise comparison matrix in Table 3 into the TFNs scale showed in Table 1. In a TFN pairwise comparison matrix, the row has the TFN value if the criterion row is more important than the criterion column. Otherwise, the reciprocal value will be given if the criterion row is less critical than the criterion column, as shown in Table 1. The result of pairwise comparison with the TFN scale is shown in Table 6.

Table 6. TFNs scale of AHP pairwise comparison

Code	QL	PR	SV	WC	DL	PD
QL	(1,1,1)	(1,2,3)	(1,2,3)	(2,3,4)	(2,3,4)	(3,4,5)
PR	(1/3,1/2,1)	(1,1,1)	(1,1,1)	(1,2,3)	(2,3,4)	(2,3,4)
SV	(1/3,1/2,1)	(1,1,1)	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)
WC	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)	(1,2,3)
DL	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,2,3)	(1,1,1)	(1/3,1/2,1)
PD	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/3,1/2,1)	(1,2,3)	(1,1,1)

The synthetic process is carried out by adding up each fuzzy number in the row and column. After that, fuzzy synthetic extent can be obtained by Eq. 9. The result is shown in Table 7.

Table 7. The sum of each row and fuzzy synthetic extent (S_i)

Code	Sum of row			Fuzzy synthetic extent (S_i)			
	$\sum l$	$\sum m$	$\sum u$	l	m	u	
QL	10	15	20	QL	0.1485	0.312	0.6211
PR	7.3333	10.5	13	PR	0.1089	0.2184	0.4348
SV	5.3333	8.5	12	SV	0.0792	0.1768	0.3727
WC	3.25	4.8333	7.5	WC	0.0483	0.1005	0.2329
DL	3.167	4.667	7	DL	0.047	0.0971	0.2174
PD	3.17	4.583	6.8333	PD	0.0463	0.0953	0.2122
Sum	32.2	48.0833	67.3333				

The next stage is to determine the possibility degree between fuzzy numbers (V) and possibility degree for a fuzzy number (d_i) using Eq. 13 to Eq. 17. The result is shown in Table 8.

Table 8. The possibility degree for a fuzzy numbers (d')

Quality (QL)		Price / Cost (PR)		Services (SV)	
V	d'	V	d'	V	d'
$C1 \geq C2$	1	$C2 \geq C1$	0.7536	$C3 \geq C1$	0.6238
$C1 \geq C3$	1	$C2 \geq C3$	1	$C3 \geq C2$	0.8638
$C1 \geq C4$	1	$C2 \geq C4$	1	$C3 \geq C4$	1
$C1 \geq C5$	1	$C2 \geq C5$	1	$C3 \geq C5$	1
$C1 \geq C6$	1	$C2 \geq C6$	1	$C3 \geq C6$	1
Warranties & Claim Policies (WC)		Delivery (DL)		Product Development (PD)	
V	d'	V	d'	V	d'
$C4 \geq C1$	0.2853	$C5 \geq C1$	0.2427	$C6 \geq C1$	0.2272
$C4 \geq C2$	0.5127	$C5 \geq C2$	0.4721	$C6 \geq C2$	0.4564
$C4 \geq C3$	0.6684	$C5 \geq C3$	0.6341	$C6 \geq C3$	0.6202
$C4 \geq C5$	1	$C5 \geq C4$	0.9799	$C6 \geq C4$	0.9693
$C4 \geq C6$	1	$C5 \geq C6$	1	$C6 \geq C5$	0.9896

After the degree of possibility for a fuzzy numbers (d') are obtained, then the minimum value of each d' is taken using Eq. 17 as follows:

$$\begin{aligned}
 d'(QL) &= \min V (S_1 \geq S_2, S_3, S_4, S_5, S_6) \\
 &= \min V (S_1 \geq 1, 1, 1, 1, 1) = 1 \\
 d'(PR) &= \min V (S_2 \geq S_1, S_3, S_4, S_5, S_6) \\
 &= \min V (S_2 \geq 0.7536, 1, 1, 1, 1) = 0.7536 \\
 d'(SV) &= \min V (S_3 \geq S_1, S_2, S_4, S_5, S_6) \\
 &= \min V (S_3 \geq 0.6238, 0.8638, 1, 1, 1) = 0.6238 \\
 d'(WC) &= \min V (S_4 \geq S_1, S_2, S_3, S_5, S_6) \\
 &= \min V (S_4 \geq 0.2853, 0.5127, 0.6684, 1, 1) = 0.2853 \\
 d'(DL) &= \min V (S_5 \geq S_1, S_2, S_3, S_4, S_6) \\
 &= \min V (S_5 \geq 0.2427, 0.4721, 0.6341, 0.9799, 1) = 0.2427 \\
 d'(PD) &= \min V (S_6 \geq S_1, S_2, S_3, S_4, S_5) \\
 &= \min V (S_6 \geq 0.2272, 0.4564, 0.6202, 0.9693, 0.9896) = 0.2272
 \end{aligned}$$

Then we get the weight vector for the matrix in fuzzy numbers (W') using Eq. 18. Subsequently, the weight vector is normalized in a non-fuzzy numbers (W) using Eq. 19. The result of W' and W showed in Table 9.

Table 9. The normalized criteria weight

Code	Criteria	Weight	Weight
		W'	W
QL	Quality	1	0.3192
PR	Price / Cost	0.7536	0.2406
SV	Services	0.6238	0.1991
WC	Warranties and Claim Policies	0.2853	0.0911
DL	Delivery	0.2427	0.0775
PD	Product Development	0.2272	0.0725

4.3. Conduct the alternative vendor ranking with the MOORA method

The MOORA method begins with determining the decision matrix, which consists of different alternatives to various criteria. These steps were obtained using Eq. 20, the result shown in Table 10.

Table 10. Decision matrix

Code	QL	PR	SV	WC	DL	PD
A1	5	4	4	5	5	4
A2	4	3	5	4	4	3
A3	5	5	4	4	5	4
A4	5	4	5	4	4	5
A5	4	4	5	5	3	4

The next stage is to determine the normalized decision matrix using Eq. 21, The result is shown in Table 11.

Table 11. Normalized decision matrix

Code	QL	PR	SV	WC	DL	PD
A1	0.4834	0.4417	0.3867	0.5051	0.5241	0.4417
A2	0.3867	0.3313	0.4834	0.4041	0.4193	0.3313
A3	0.4834	0.5522	0.3867	0.4041	0.5241	0.4417
A4	0.4834	0.4417	0.4834	0.4041	0.4193	0.5522
A5	0.3867	0.4417	0.4834	0.5051	0.3145	0.4417

After that, form a weighted normalized decision matrix by multiplying each element of the normalized decision matrix by the vector weight contained in Table 9. The result showed in Table 12.

Table 12. Weighted normalized decision matrix

Code	QL	PR	SV	WC	DL	PD
A1	0.1543	0.1063	0.077	0.046	0.0406	0.032
A2	0.1234	0.0797	0.0963	0.0368	0.0325	0.024
A3	0.1543	0.1328	0.077	0.0368	0.0406	0.032
A4	0.1543	0.1328	0.077	0.0368	0.0406	0.032
A5	0.1234	0.1063	0.0963	0.046	0.0244	0.032

Finally, the last step is to determine the value of y_i , using Eq. 22. The result is shown in Table 13.

Table 13. Multi-objective optimization value (y_i)

Code	Max (QL+SV+WC+DL+PD)	Min (PR)	$y_i = \text{Max} - \text{Min}$
A1	0.3499	0.1063	0.2543
A2	0.3130	0.0797	0.2442
A3	0.3407	0.1328	0.2335
A4	0.3599	0.1328	0.2161
A5	0.3221	0.1063	0.2085

The alternative ranking results of vendor selection shown in the Table 14 and Fig. 4.

Table 14. Alternative ranking

Code	Alternative	y_i	Rank
A1	Vendor 1	0.2437	2
A2	Vendor 2	0.2333	3
A3	Vendor 3	0.2079	5
A4	Vendor 4	0.2536	1
A5	Vendor 5	0.2158	4

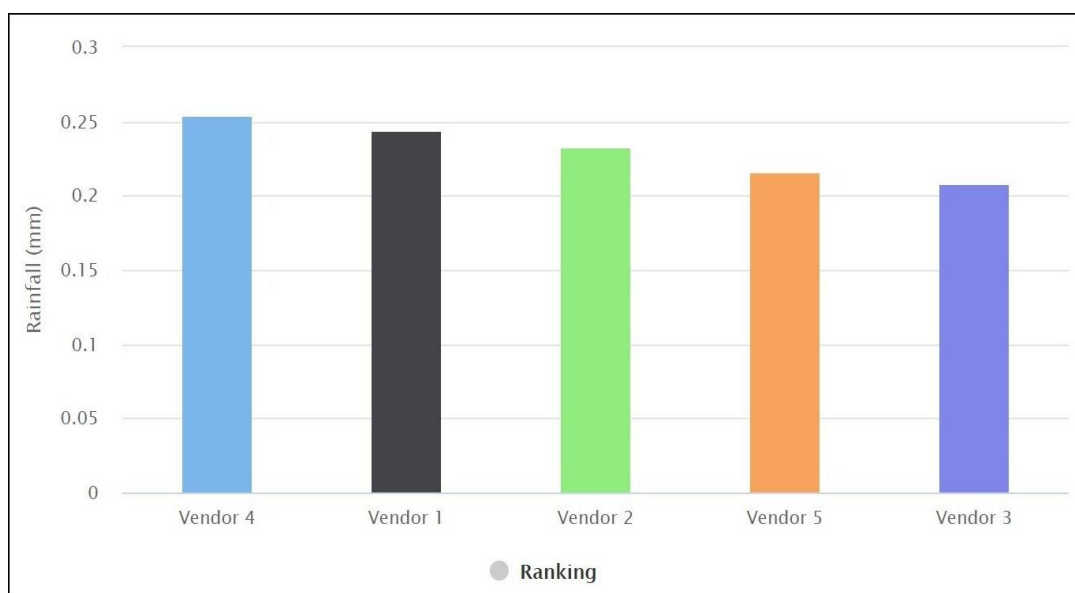


Fig. 4. Rank of alternatives

5. Sensitivity Analysis

The weight of the main criteria significantly influences the final priority of the alternative. Slight changes in relative weights may lead to significant changes in the final ranking. Since these criteria weights are generally based on highly subjective judgments, it is necessary to test the ranking stability under different criterion weights. Sensitivity analysis is carried out to maintain the precautionary principle in applying changes to a risk parameter. For this purpose, sensitivity analysis is performed using scenarios representing the future development of alternatives or varying perspectives on the relative weight of the criteria. Through decreasing or increasing the weight of each criterion, changes in alternative ranking can be observed. As a result, sensitivity analysis provides information on ranking stability. If the obtained ranking is especially vulnerable to a minor change in the weights criteria, it is recommended to evaluate the weights carefully.

In order to perform a sensitivity analysis, in this study, we tried to increase and reduce each criterion weight by 25%. In contrast, the weights of other criteria are kept the same, and the ranking results are recorded. Fig. 5 and Fig. 6 illustrate the impact of changes in criterion weight on the final alternative. Based on increasing criteria weight, the graph showed the QL criteria (quality), implying the results are more sensitive in vendors 3 and 5. On the other hand, vendors 1 and 2 are sensitive to PR criteria (price/cost), while vendor 4 remains stable in all criteria. The graph showed that vendors 3 and 5 are more sensitive in the PR criteria (price/cost) based on reducing criteria weight. Moreover, vendors 1 and 2 are sensitive in QL criteria (quality), while vendor 4 is relatively stable in all criteria. The weight changed by 25% where the alternative ranking results remain the same indicates that the fuzzy-AHP MOORA approach is stable and suitable for this problem.

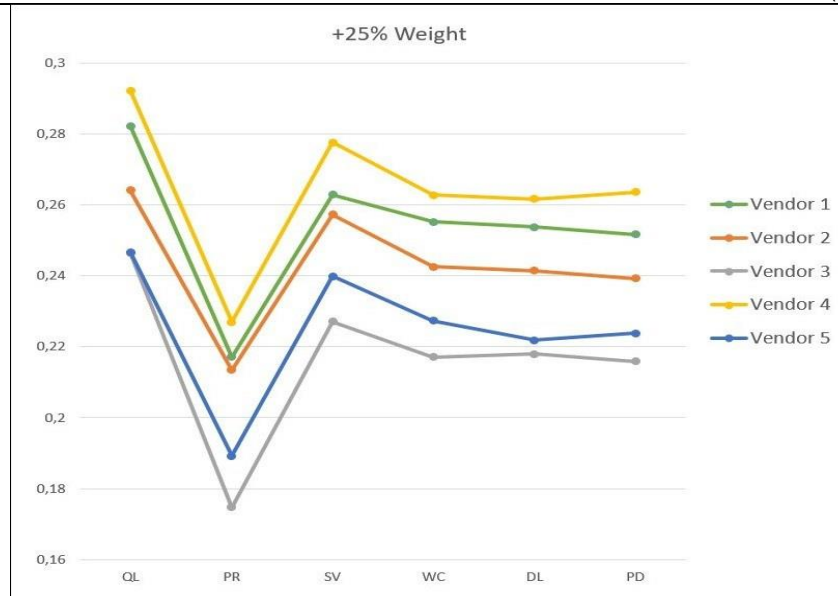


Fig. 5. Sensitivity analysis +25% weight

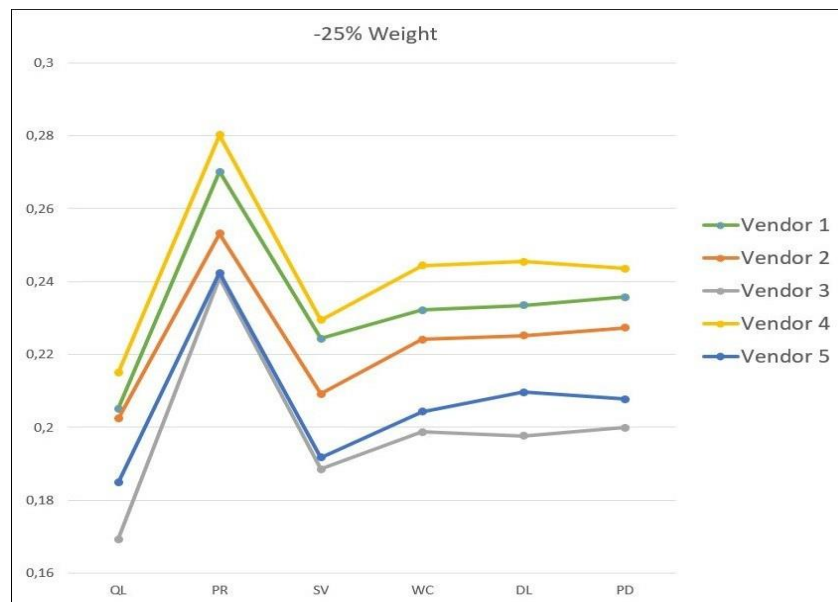


Fig. 6. Sensitivity analysis -25% weight

6. Conclusion

A web-based decision support system with the fuzzy-AHP MOORA method has been applied to evaluate the selection of network switch vendors. In this study, six criteria for choosing a vendor were found through literature review and then selected by the company decision-maker. The weight of each criterion has been obtained by the company decision-maker using AHP pairwise comparison. The results showed that the criterion “quality” with the weight of 0.3192 is the most critical criterion among the six criteria. The second is “price” with a weight of 0.2406. The “services”, “warranties and claim policies”, “delivery”, and “product development” criteria with weights of 0.1991, 0.0911, 0.0775, and 0.0725, respectively, were in the following ranks. Finally, the best vendor has been found after the alternatives assessment by the decision-maker using the MOORA method. The results depicted that based on the computation of the fuzzy-AHP MOORA method, the alternative sequence obtained is 4-1-2-5-3, indicates that alternative 4 (A4) has the highest score (0.2536), which makes it the best alternative to be chosen for this vendor selection problem. Sensitivity analysis showed that the proposed DSS fuzzy-AHP MOORA concept was already solid and suitable for this problem, with a low rate of change.

Suggestions for further research may try a hybridization with the new MCDM method such as BCM, BWM, and ARAS method in a fuzzy set. BCM and BWM can be used to weight the criteria like

the fuzzy-AHP method. ARAS is used as an alternative ranking method, where the ARAS method has similarity to the MOORA method, which is a ratio-based analysis.

Author Contributions

I'tishom Al Khoiry: Conceptualization, Methodology, Software, Writing-Reviewing and Editing.
Rahmat Gernowo: Methodology, Validation. Bayu Surarso: Methodology, Validation.

Declaration of Competing Interest

We declare that we have no conflict of interest.

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