An Integrated ANP and MARCOS for Green Supplier Selection: A Case Study on Construction Industry

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ABSTRACT

Raw material suppliers are essential in production, especially in the construction industry. It is because suppliers determine the availability of raw materials in a project. The research aims to propose a new integrated procedure for Green Supplier Selection in the Construction Industry. The proposed integration method is Analytical Network Process (ANP) and Measurement Alternatives and Ranking according to Compromise Solution (MARCOS) method. Both methods are Multi-Criteria Decision Making (MCDM) procedures. The ANP method is used to determine the weight of each criterion, and the MARCOS method is used to determine the weight of the best supplier. Seventeen criteria are used in supplier selection involving economic and environmental dimensions. The results showed that based on the ANP method, the most important criterion was the consistent quality of goods. Meanwhile, three suppliers were analyzed for selection based on the MARCOS procedure. The results show that the best supplier is supplier X with a utility function value of 0.749. These results show that the proposed procedure (integration of ANP and MARCOS) effectively solves Green Supplier Selection.

1. Introduction

Green supply chain management (GSCM) is a part of supply chain management that focuses on economic and environmental issues [1]. The GSCM concept seeks to reduce waste and environmental impacts caused by supply chain activities [2]. One part of GSCM is supplier selection which considers an environmental perspective, popularly called green supplier selection [3, 4]. In this era of globalization, green suppliers are expected to reduce the impact of global warming, which is a world threat. Therefore, green suppliers are suitable for minimizing environmental problems [5-8]. Meanwhile, in the construction industry, suppliers play an essential role in the availability of raw materials based on product quality, product price, timeliness of production, cost efficiency, and product defects [9-12]. These supplier selection criteria only focus on the economic dimension [13].

Various studies have been proposed on supplier selection problems in the construction industry. Yazdani, et al. [14] developed an integrated procedure of decision-

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making trial and evaluation laboratory (DEMATEL) and evaluation based on distance from average solution (EDAS). Their research focused on economic and environmental dimensions. Eshtehardian, et al. [9] implemented Analytic Network Process (ANP) and Analytic Hierarchy Process (AHP) methods that focus on the economic dimension. Wang, et al. [15] proposed the AHP - Gray Relational Analysis (GRA) procedure on the same dimension. Some other procedures to focus on the economic dimension are AHP [16] and Grey Combined Compromise Solution (CoCoSo-G) [17]. With a focus on the economic and environmental dimensions, Basar [18] used the ANP method. Based on the description of previous research, most studies focus on the economic dimension. The environmental dimension has received less attention. In addition, previous research ignored the relationship between criteria. Meanwhile, the weight of criteria is also influenced by the relationship between other criteria.

Measuring alternatives and ranking according to the compromise solution (MARCOS) method has recently been widely applied to various problems. Stević, et al. [19] and Puška, et al. [20] utilized this procedure for supplier selection in healthcare and ranking evaluation software. This Multi-Criteria Decision Making (MCDM) procedure utilizes multiple criteria to assess several choices. The advantage of the MARCOS Method is that it considers ideal and anti-ideal solutions that make decisions more accurate despite many criteria and alternatives. Therefore, researchers try to utilize this procedure in supplier selection in the construction industry. From several previous studies, no research utilizes the integration of ANP and MARCOS in supplier selection in the construction industry. Therefore, this study aims to integrate the ANP and MARCOS methods in supplier selection in the construction industry. The integration of ANP and MARCOS methods is implemented due to the advantages of each method. ANP method is applied to weight the criteria based on the relationship between criteria [8, 12], and MARCOS is implemented to assess alternative suppliers. The work presented here provides one of the first investigations on selecting suppliers by integrating ANP and MARCOS.

2. Literature Review

This section summarizes research on the MARCOS method and supplier selection in the construction industry. Table 1 shows the literature review of MARCOS procedure applications. It shows that the MARCOS method has evaluated supplier selection, human resources, software, and e-service quality. Unfortunately, this procedure has never been applied to supplier selection in the construction industry.

Furthermore, the literature review of supplier selection in the construction industry is shown in Table 2. The results show that many studies proposed various procedures for solving supplier selection in the construction industry. Most researchers utilize single-procedure MCDM, such as AHP [21] and TOPSIS [22]. Interval-valued intuitionistic fuzzy geometric weighted Heronian means (IVIFGWHM) is also proposed by Yin, et al. [23] and Fuzzy Best-Worst Method (BWM) proposed by Hoseini, et al. [24]. These studies ignored the weight of criteria based on the relationship between criteria. Few studies have investigated criterion weights based on the relationship between criteria. The ANP method is a popular procedure used for Weighting based on the relationship between criteria. This procedure has been applied by Eshtehardian, et al. [9] and Basar [18]. However, no research has been integrating the ANP method with the MARCOS method in supplier selection in the construction industry. Because it is still a new procedure, the MARCOS Method is rarely used in supplier selection problems. No research implements it in the construction industry. The ANP method determines the weight of criteria in supplier selection based on the relationship between criteria. Meanwhile, the MARCOS Method is used to determine the best supplier.

Table 1 Literature review of MARCOS procedure application

Authors	Method	Applications
Puška, et al. [20]	MARCOS	Evaluation software
Stević, et al. [19]	MARCOS	Supplier selection Healthcare industry
Stević and Brković [25]	FUCOM - MARCOS	Evaluation of Human Resources in a Transport Company
Chakraborty, et al. [26]	D-MARCOS	Supplier selection in an iron and steel industry
Bakır and Atalık [27]	Fuzzy AHP – fuzzy MARCOS	Evaluation of e-service quality in the airline industry
Puška, et al. [28]	Fuzzy MARCOS	Sustainable Suppliers in Food Industry

Table 2 Literature Review supplier selection in Construction Industry

Authors	Method	Interrelations Criteria	Dimension
Yazdani, et al. [14]	DEMATEL-EDAS	V	Economy, environment
Lu and Geyao [21]	AHP	-	Economy, environment
Safa, et al. [22]	Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)	-	Economy
Patil and Kumthekar [16]	AHP	-	Economy
Eshtehardian, et al. [9]	ANP- AHP	V	Economy
Cengiz, et al. [29]	ANP	V	Economy
Chen, et al. [30]	Mixed integer linear programming	-	Economy
Yin, et al. [23]	IVIFGWHM	-	Economy, environment
Yazdani, et al. [17]	Grey Combined Compromise Solution (CoCoSo-G)	-	Economy
Wang, et al. [15]	AHP - Grey Relational Analysis (GRA)	-	Economy
Hoseini, et al. [24]	Fuzzy Best-Worst Method (BWM)	-	Social, environment
Basar [18]	ANP	V	Environment
This research	ANP - MARCOS	V	Economy, environment

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3. Methods

3.1 Proposed framework

This section presents the proposed framework for solving green supplier selection. Fig. 1 shows the proposed framework for green supplier selection. It demonstrates that four stages of supplier selection are proposed. The first stage begins with the identification of criteria, and the second stage determines the relationship between criteria. The third stage is weighting with ANP based on pairwise comparison assessment of criteria relationships. In stage four, the proposed framework concludes by ranking suppliers using the MARCOS method.

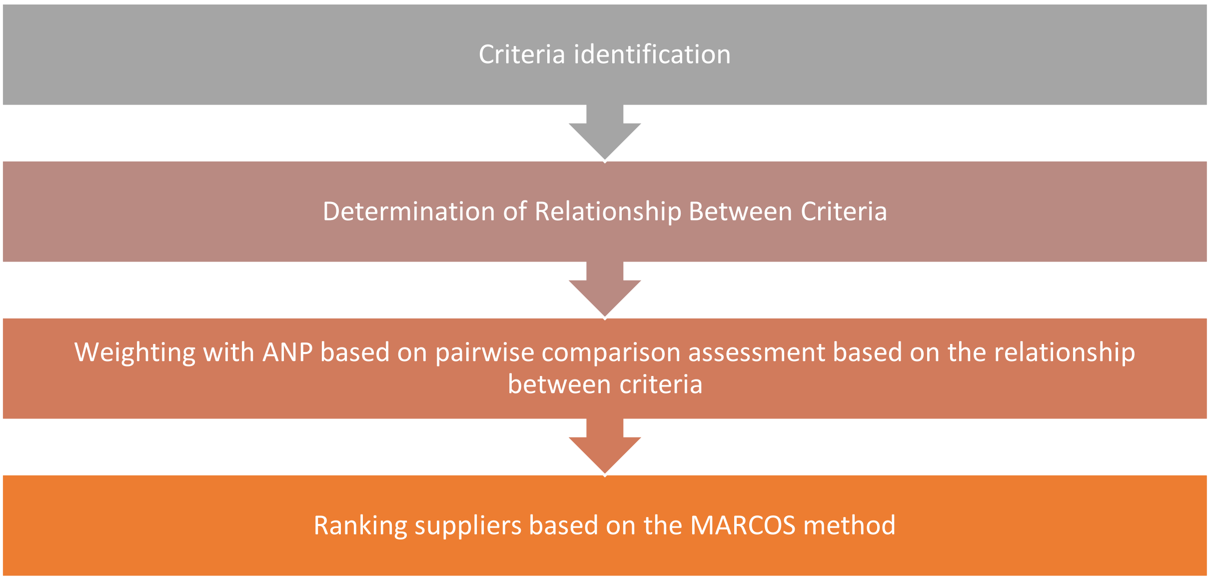

Fig. 1 Proposed Framework for green supplier selection

In the first stage, criteria identification is carried out based on previous research and the identification of important criteria in the company. The focus group discussion (FGD) method from decision-makers determines the criteria used in green supplier selection. In the second stage, the decision makers also conducted FGDs to determine the relationship between criteria. It is used as a pairwise comparison assessment between criteria in the ANP procedure.

The third stage is weighting with ANP based on pairwise comparison assessment based on the relationship between criteria [31]. The decision-makers conduct FGDs for pairwise comparison assessment based on the relationship between criteria. The pairwise comparison scale uses a 1-9 scale, as shown in Table 3. Furthermore, Equation (1) displays an unweighted matrix based on the results of the pairwise comparison assessment (A). Furthermore, the matrix is used in the next stage to calculate the weighted supermatrix. Equation (2) shows the new α-cut total relation matrix (Tα) that considers the value of α and matrix A. This matrix is generated by giving a value of 0 for matrix values < threshold value (α).

$$\mathrm{A} = \begin{matrix} \\ C1 \\ C2 \\ Cn \end{matrix} \begin{matrix} \begin{matrix} C1 & \quad C2 & \cdots & \quad Cn \end{matrix} \\ \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{12} & a_{22} & \cdots & a_{2n} \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \end{matrix} \tag{1}$$

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$$T\alpha = \begin{bmatrix} t_{11}^{\propto} & t_{1j}^{\propto} & t_{1n}^{\propto} \\ t_{i1}^{\propto} & t_{ij}^{\propto} & t_{in}^{\propto} \\ t_{n1}^{\propto} & t_{nj}^{\propto} & t_{nn}^{\propto} \end{bmatrix} \tag{2}$$

Meanwhile, Equations (3), (4), and (5) are used to determine the weighted supermatrix (Aw). Where the number of rows in the $T\alpha$ matrix is denoted as d_i. The last stage of the ANP procedure is the calculation of the Limiting supermatrix, denoted in Equation (6). The weight of each supplier criterion results from calculating the limit supermatrix. The weights generated in the ANP procedure are used to assess alternative suppliers with the MARCOS procedure.

$$d_i = \sum_{j=1}^{n} t_{ij}^{\propto} \tag{3}$$

$$Ts = \begin{bmatrix} t_{11}^{\propto}/d1 & t_{1j}^{\propto}/d1 & t_{1n}^{\propto}/d1 \\ t_{i1}^{\propto}/di & t_{ij}^{\propto}/di & t_{in}^{\propto}/di \\ t_{n1}^{\propto}/d3 & t_{nj}^{\propto}/d3 & t_{nn}^{\propto}/d3 \end{bmatrix}$$

$$Ts = \begin{bmatrix} t_{11}^{s} & t_{1j}^{s} & t_{1n}^{s} \\ t_{i1}^{s} & t_{ij}^{s} & t_{in}^{s} \\ t_{n1}^{s} & t_{nj}^{s} & t_{nn}^{s} \end{bmatrix} \tag{4}$$

$$Aw = \begin{bmatrix} t_{11}^{s}\ x\ a_{11} & t_{1j}^{s}\ x\ a_{12} & \cdots & t_{1n}^{s}\ x\ a_{1n} \\ t_{i1}^{s}\ x\ a_{12} & t_{ij}^{s}\ x\ a_{22} & \cdots & t_{in}^{s}\ x\ a_{2n} \\ t_{n1}^{s}\ x\ a_{n1} & t_{nj}^{s}\ x\ a_{n2} & \cdots & t_{nn}^{s}\ x\ a_{nn} \end{bmatrix} \tag{5}$$

$$\lim_{k\to\infty} W_w^k \tag{6}$$

Table 3 Pairwise comparison scale

Level of Importance	Description
1	Both elements are equally important
3	One element is slightly more important than the other element
5	One element is more important than the other
7	One element is more absolutely important than the other
9	One element is more absolute than the other
2,4,6,8	A value between two adjacent consideration values

The stages of the MARCOS method are adopted from the method proposed by Stević, et al. [19]. The procedure is used to determine the best supplier. The first step in the MARCOS procedure is to assess each alternative on each criterion by experts. Experts also determine the classification of assessment criteria based on the classification of benefits or costs. The assessment results of each alternative on each criterion are combined to form a matrix. The matrix is formed to define ideal (AI) and anti-ideal (AAI) solutions as in Equation (7).

$$X = \begin{matrix} \\ AAI \\ A_1 \\ A_2 \\ \cdots \\ A_m \\ AI \end{matrix} \begin{matrix} C1 & C2 & \cdots & Cn \\ \begin{bmatrix} X_{aa1} & X_{aa2} & \dots & X_{aan} \\ X_{11} & X_{12} & \dots & X_{1n} \\ X_{21} & X_{22} & \dots & X_{2n} \\ \dots & \dots & \dots & \dots \\ X_{m1} & X_{22} & \dots & X_{mn} \\ X_{ai1} & X_{ai2} & \dots & X_{ain} \end{bmatrix} \end{matrix} \quad (7)$$

Furthermore, the ideal solution (AI) and anti-ideal solution (AAI) are determined based on the assessment of each criterion and alternative. AI is the alternative with the best characteristics, and AAI is the worst characteristics. The values of AAI and AI are formulated in Equations (8) and (9). Where B represents the benefit criteria, and C describes the cost criteria. The next step is to normalize the matrix ($N = [n_{ij}]_{mxn}$) using Equations (10) and (11). where elements X_{ij} and X_{ai} represent elements in the X matrix.

$$AA1 = \min_i X_{ij} \quad if \text{ j} \in \text{B} \quad \max_i X_{ij} \quad if \text{ j} \in \text{C} \quad (8)$$

$$A1 = \max_i X_{ij} \quad if \text{ j} \in \text{B} \quad \min_i X_{ij} \quad if \text{ j} \in \text{C} \quad (9)$$

$$n_{ij} = \frac{X_{ai}}{X_{ij}} \quad if\ j \in C \quad (10)$$

$$n_{ij} = \frac{X_{ij}}{X_{ai}} \quad if\ j \in B \quad (11)$$

Meanwhile, based on the normalization matrix, the weight matrix $V = [v_{ij}]_{mxn}$ is determined using Equation (12). w_j shows the weight of the criteria resulting from the ANP procedure. The next step is to calculate the utility level of alternative K_i. The utility level of an alternative in the anti-ideal solution and ideal solution is calculated based on Equations (13) and (14). $Si\ (i = 1,2,\dots,m)$ is the number of elements of the weighted matrix V, which can be calculated based on Equation (15).

$$V_{ij} = n_{ij}\ x\ w_j \quad (12)$$

$$K_i^- = \frac{S_i}{S_{aai}} \quad (13)$$

$$K_i^+ = \frac{S_i}{S_{ai}} \quad (14)$$

$$S_i = \sum_{\text{i=1}}^{\text{n}} v_{ij} \quad (15)$$

The next step is determining the alternative utility function $f(K_i)$, which compromises the alternative ideal and anti-ideal solutions shown in Equation (16). where $f(K_i^-)$ shows the utility function on the anti-ideal solution and $f(K_i^+)$ represents the utility function of the ideal solution. Equation (17) shows the utility function of the solution for the anti-ideal, and Equation (18) shows the utility function of the ideal solution. The result of the utility function is used to rank each supplier. The supplier with the largest utility function value is the best.

$$f(K_i) = \frac{K_i^+ + K_i^-}{1+\frac{1-f(K_i^+)}{f(K_i^+)}+\frac{1-f(K_i^-)}{f(K_i^-)}} \quad (16)$$

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} \quad (17)$$

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} \quad (18)$$

3.2 Case Study and Data

This section presents data and case studies on the construction industry in Indonesia. The selected raw material suppliers are steel pipe suppliers for construction. Three decision-makers were involved in conducting FGDs to determine the green supplier selection criteria. The green supplier selection criteria from the FGD are shown in Table 4. In addition, the decision makers also conducted FGDs to determine the relationship between criteria. The interrelationship between green supplier criteria is shown in Fig. 2. From the interrelationship between criteria, experts conduct FGDs to assess pairwise criteria comparisons. A pairwise comparison assessment of each criterion is presented in Table 5 to Table 18. Meanwhile, the company must choose three suppliers of steel pipes for construction. Assessment data for each criterion and supplier are presented in Table 19.

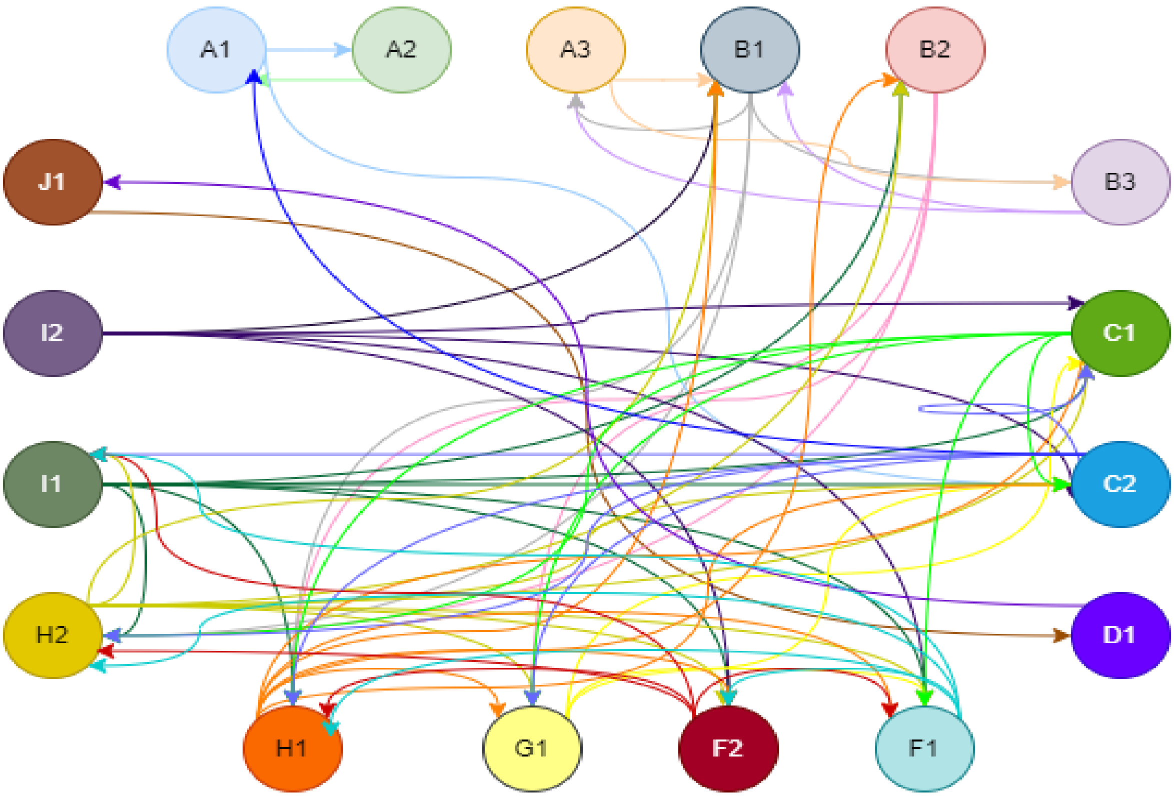

Fig. 2 Relationship between Green supplier criteria

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Table 4 Green supplier selection criteria

No	Aspect	Dimensions	Criteria	Code	Classification
1.	Cost [21]	Economy	Price [29]	A1	Cost
			Order fee [21]	A2	Cost
			Delivery cost [32]	A3	Cost
2.	Delivery [29]	Economy	On-time delivery [29]	B1	Benefit
			Appropriate quantity [24]	B2	Benefit
			distance [21]	B3	Cost
3.	Quality [32]	Economy	Product defect rate [24]	C1	Benefit
			Consistent quality [21]	C2	Benefit
4.	Environment [14]	Environment	Environmentally friendly certification [14]	D1	Benefit
5.	Responsiveness [9]	Economy	Ease of replacement of defective goods [29]	F1	Benefit
			Responsiveness to customer complaints [32]	F2	Benefit
6.	Warranties and claim policies [14]	Economy	Guarantee of goods [33]	G1	Benefit
7.	Performance history [9]	Economy	Ability to keep agreements [9]	H1	Benefit
			Ability to maintain services [9]	H2	Benefit
8.	Technical capability [21]	Economy	Labor competence [21]	I1	Benefit
			Adequate facilities [29]	I2	Benefit
9.	Management and organization [9]	Economy	Completeness of company documents [21]	J1	Benefit

Table 5 Pairwise Comparison of the Effect of Price of Goods (A1)

	A1	A2	C2
A1	1	1/3	3
A2		1	5
C2			1

Table 6 Pairwise Comparison of the Influence of Order Cost (A2)

	A1	A2
A1	1	1/3
A2		1

Table 7 Pairwise Comparison of the Influence of Delivery Cost Criteria (A3) and Delivery Distance (B3)

	A3	B1	B3
A3	1	1/3	1/3
B1		1	2
B3			1

Table 8 Pairwise comparisons of influence to On-Time Delivery (B1)

	A3	B1	B3	H1	H2
A3	1	1/3	1/3	1/2	1/2
B1		1	2	2	3
B3			1	3	3
H1				1	2
H2					1

Table 9 Pairwise Comparison of the Influence of the Appropriate Quantity (B2)

	B2	G1	H1	H2
B2	1	2	2	2
G1		1	1	2
H1			1	2
H2				1

Table 10 Pairwise Comparison of the Influence of Product Defect Rate (C1)

	C1	C2	F1	G1	H1	H2	I1
C1	1	1	1/3	½	1/3	1/3	1/3
C2		1	1/3	½	1/3	1/3	1/3
F1			1	2	1	1	1/3
G1				1	1	2	1
H1					1	2	1/4
H2						1	1
I1							1

Table 11 Pairwise Comparison of the Influence of Environmentally friendly certification (D1) and Completeness of Company Documents (J1)

	D1	J1
D1	1	2
J1		1

Table 12 Pairwise Comparison of the Effect of Consistent Quality (C2)

	A1	C1	C2	G1	H1	H2	I1
A1	1	2	3	1/3	1/3	1/3	1/3
C1		1	1	½	1/3	1/3	1/3
C2			1	1/2	1/3	1/3	1/3
G1				1	1	2	1
H1					1	2	1/4
H2						1	1
I1							1

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Table 13 Pairwise Comparison of the Influence of Ease of Replacement of Defective Goods (F1) and Speed of Response to Customers complaints (F2)

	F1	F2	H1	H2	I1
F1	1	2	1	1	1/3
F2		1	3	3	2
H1			1	2	1/4
H2				1	1
I1					1

Table 14 Pairwise Comparison of the Influence of Providing Guarantees for Goods (G1)

	C1	C2	F1	G1
C1	1	1	1/3	½
C2		1	1/3	½
F1			1	2
G1				1

Table 15 Pairwise Comparison of the Influence of the Ability to Maintain Agreement (H1)

	B1	B2	C1	C2	F1	F2	G1	H1	H2	I1
B1	1	2	5	5	3	3	3	2	3	2
B2		1	3	3	2	2	2	2	2	1
C1			1	1	1/3	1/3	0,5	1/3	1/3	1/3
C2				1	1/3	1/3	0,5	1/3	1/3	1/3
F1					1	2	2	1	1	1/3
F2						1	1	3	3	2
G1							1	1	2	1
H1								1	2	1/4
H2									1	1
I1										1

Table 16 Pairwise Comparison of the Influence of Ability to Maintain Service (H2)

	B1	B2	C1	C2	F1	F2	G1	H2	I1
B1	1	2	5	5	3	3	3	3	2
B2		1	3	3	2	2	2	2	1
C1			1	1	1/3	1/3	½	1/3	1/3
C2				1	1/3	1/3	½	1/3	1/3
F1					1	2	2	1	1/3
F2						1	1	3	2
G1							1	2	1
H2								1	1
I1									1

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Table 17 Pairwise Comparison of the Influence of Labor Competence (I1)

	B2	C1	C2	F1	F2	H1	H2	I1
B2	1	3	3	2	2	2	2	1
C1		1	1	1/3	1/3	1/3	1/3	1/3
C2			1	1/3	1/3	1/3	1/3	1/3
F1				1	2	1	1	1/3
F2					1	3	3	2
H1						1	2	1/4
H2							1	1
I1								1

Table 18 Pairwise Comparison of the Influence of Adequate Facilities (I2)

	B1	C1	C2	F2	H2	I2
B1	1	5	5	3	2	3
C1		1	1	1/3	1/3	1/3
C2			1	1/3	1/3	1/3
F2				1	3	¼
H2					1	¼
I2						1

Table 19 Assessment data for each criterion and supplier

Criteria	X	Y	Z
A1	Rp288.000	Rp310.000	Rp350.000
A2	Rp1.500.000	Rp1.500.000	Rp1.500.000
A3	Rp1.500.000	Rp1.400.000	Rp950.000
B1	7	5	3
B2	7	7	7
B3	110	103	69
C1	7	5	5
C2	9	7	5
D1	5	5	3
F1	7	7	5
F2	7	7	5
G1	7	7	5
H1	7	5	5
H2	7	5	5
I1	7	7	5
I2	7	5	5
J1	7	7	5

4. Results and Discussion

4.1 Criteria Weighting and supplier ranking

This section presents the results of research on criteria weights and supplier ranking. The criteria with the highest weight value are the consistent quality of goods

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(C2), followed by the criteria for the level of product defects (C1) and the Price of goods (A1). Meanwhile, environmentally friendly certification (D1) criteria occupy the last position or position seventeen.

Table 20 Criteria Weights based on ANP

Criteria	Wight
Consistent quality of goods (C2)	0.1793
Product defect rate (C1)	0.1366
Price of goods (A1)	0.1050
Ability to maintain service (H2)	0.0800
Ability to maintain agreement (H1)	0.0686
Delivery cost (A3)	0.0662
Ease of replacement of defective goods (F1)	0.0602
Provide a guarantee for goods (G1)	0.0566
Order cost (A2)	0.0474
Labor competence (I1)	0.0435
Speed of response to customers (F2)	0.0333
Appropriate quantity shipped (B2)	0.0262
Distance (B3)	0.0248
On-time Delivery (B1)	0.0237
Completeness of company documents (J1)	0.0183
Adequate facilities (I2)	0.0179
Environmentally friendly certification (D1)	0.0125

The top five criteria ranked by the ANP method are consistent quality (C2), product defect rate (C1), Price of goods (A1), ability to maintain service (H2), and ability to maintain agreement (H1)(see Table 20). Although this study aimed to rank green supplier selection, none of the top five criteria for supplier selection was related to environmental criteria. It indicates that industrial sectors in developing countries focus on quality, Price, and service. Criteria related to the environment receive little attention from experts in the field of management, especially in the construction industry.

Consistent quality (C2) ranks first among all green supplier selection criteria, with a score of 0.1793. Meanwhile, the product defect rate (C1) ranks second with a weight of 0.1366. Experts agree that the most important factors to consider when selecting suppliers in the construction sector are Consistent quality (C2) and Product defect rate (C1). First, in most construction projects, consistent quality (C2) and product defect rate (C1) are significant because they relate to the quality of construction projects. Poor construction project quality causes customers to be dissatisfied with the construction project. Secondly, the organization risks losing credibility and paying fines if the project does not meet the set quality.

The Price of goods (A1) occupies the third position with a weight of 0.1050. Companies also focus on profitability in choosing suppliers. Suppliers with a low price of goods (A1) are more profitable for the company, provided that the criteria of consistent quality (C2) and product defect rate (C1) are also good. Therefore, these three criteria are essential criteria for companies to be able to increase company profits.

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Environmentally friendly certification (D1) in the environmental dimension is the lowest criterion among other criteria. It is because the company less considers regulatory activities from government environmental agenciesCompanies often perceive Green certification (D1) as unimportant because it does not affect profitability. Therefore, this paradigm needs to be changed. When suppliers respect and comply with environmental regulations and standards, companies should be more likely to trust these suppliers and use their products.

The weighting results with ANP (Table 20) are used for ranking with the MARCOS method. Table 21 shows the ranking of suppliers based on the MARCOS procedure. The results show that the supplier with the largest utility function value is supplier X, with a value of 0.749. Supplier Y occupies the second position with a utility function value of 0.643, and Supplier Z occupies the third position with a value of 0.571.

Table 21 Supplier ranking based on MARCOS procedure

Supplier	S_i	K_i^-	K_i^+	$f(K_i^-)$	$f(K_i^+)$	$f(K_i)$	Rank
AAI	0.703						
X	0.967	1.376	0.967	0.413	0.587	0.749	1
Y	0.830	1.181	0.830	0.413	0.587	0.643	2
Z	0.736	1.048	0.736	0.413	0.587	0.571	3
AI	1.000						

4.2 Managerial Insights

Some critical theoretical and managerial implications are presented in this study. This study helps fill the gap in the literature by proposing a new procedure for green supplier selection in the construction industry. Using the MCDM technique by integrating ANP and MARCOS, the authors of this paper present a practical and adaptable decision support system intended to aid the green process of supplier selection. The proposed method is flexible in that it can be applied beyond the parameters of this paper, which is one of its main benefits. In other words, the criteria used and the context of their application are flexible enough to allow for additions and deletions. The proposed method assigns weights to the selected supplier selection criteria based on the interrelationship of the criteria. Ranking the selected suppliers can help managers and other decision-makers to make efficient strategies.

Supplier selection is just one area where the proposed ANP and MARCOS methods can be used. This procedure can also be adopted in companies' risk assessment and human resource management. As a result of its adaptability, generality, and practicability, the proposed method can be applied in various contexts. The study results show that the criteria can be weighted well and rank the suppliers.

5. Conclusion

This research aims to develop ANP and MARCOS integration procedures in supplier selection. There are 17 supplier selection criteria and three supplier alternatives. ANP procedure is proposed to weight the criteria based on the relationship between criteria. Meanwhile, MARCOS is used for ranking suppliers based on ANP weights. The results show that Consistent quality (C2) ranks first among all green supplier selection criteria, weighing 0.1793. Product defect rate (C1) comes second with a weight of 0.1366. Based on the MARCOS method, the supplier ranking results show that supplier X is the best supplier with the most significant utility function value. This research has limitations, including ignoring the social dimension in supplier selection. Further research must consider three dimensions at once, including economic, social, and environmental, in supplier selection.

Declarations

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