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Developing a Hybrid Method of Analytical Hierarchy Process and Additive Ratio Assessment for Ranking Suppliers: A Case Study of an Indonesian Concrete Manufacturing Company

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Abstract
Indonesia is developing its infrastructure to remain competitive in the global market, focusing on projects such as the construction of toll roads and bridges, which require large volumes of precast concrete products. Accordingly, it is important to focus on the quality of suppliers so that the products meet the requirements of companies and consumers. This case study aimed to develop a proposed model for ranking suppliers, employing the Additive Ratio Assessment and Analytical Hierarchy Process. Furthermore, it examined the practical application of the proposed model in an Indonesian concrete manufacturing company. The Delphi method was employed to enhance decision-making in criteria selection, considering that it determines the reliability of the supplier ranking. The study demonstrated that the proposed method yielded a practical solution and was not sensitive to parameter changes. Sensitivity analysis can help decision-makers evaluate the resilience of the process by determining the effect of change in the primary criteria on supplier ranking. Therefore, establishing a straightforward methodology enables managers in the concrete industry to identify the most suitable supplier. Additionally, this approach assists managers in categorizing intricate decision-making challenges into straightforward methodologies. The study provides managers in the Indonesian concrete industry with a thorough understanding of the variables that must be assessed when selecting suppliers.

Keywords
Additive Ratio Assessment (ARAS), Analytical Hierarchical Process (AHP), Delphi, Criteria Selection, Supplier ranking.

Introduction

Indonesia is intensively developing its infrastructure to remain competitive in the global market and boost its economy. Infrastructure projects such as the construction of toll roads, bridges, overpasses, and underpasses require abundant precast concrete products. Accordingly, precast concrete companies must produce high-quality concrete in large quantities at short notice to meet the growing demand for precast concrete. Suppliers are an integral part of the concrete industry and are essential in providing goods to support business activities. They are considered one of the key factors for a company's success. It is imperative to focus on the quality of suppliers so that the products meet the requirements of companies and consumers (Yadav & Sharma, 2016). Therefore, supplier selection has been recognized as a critical issue for firms as they strive to maintain a strategic competitive advantage (Gupta et al., 2019).

PT Wijaya Karya Beton (Wika Beton) is a leading manufacturer of precast concrete products in Indonesia and is actively involved in various major infrastructure projects. Its contribution to national toll road construction projects is considered significant. It implements a make-to-order production system, which is managed by medium- to large-sized companies. The production process is time-consuming but sustainable (Ristono et al., 2021). The company manufactures piles, electric poles, sleepers for rail, bridge concrete products, retaining walls, water-building concrete, building concrete, and maritime-building concrete, among others. The

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company produced 204,993 units of concrete in 2021–2022. The company reported that production increased by 32% from 2021 to 2022. The demand for concrete products is increasing in the building construction sector. Concrete products contain several constituent components, including concrete iron, which determines its quality. Raw materials in the form of concrete iron are procured from several suppliers. Companies have often expressed concerns that suppliers fail to meet their expectations (Ristono et al., 2021), leading to delays in product delivery and quality concerns.

In the wake of increasing competition, companies are required to develop an efficient supply chain and maintain good supplier relationships (Bag et al., 2023). To maximize performance and minimize challenges, PT Wika Beton conducted an assessment to determine priority supplier selection. Generally, supplier assessments are conducted every semester to evaluate supplier performance for each period. The procurement department of the Ministry of Finance and Human Resources evaluates the assessment.

Supplier selection is one of the challenges associated with multi-criteria decision-making (MCDM). Consequently, numerous MCDM methodologies, including Additive Ratio Assessments (ARAS), have been implemented in supplier selection research. The computational procedure for ARAS is distinct compared to several other MCDM methods, including TOPSIS, Vlse kriterijumska optimizacijai compromise revenge (VIKOR), WASPAS, MARCOS, and COPRAS (Karabasevic et al., 2016). Nevertheless, ARAS has certain drawbacks in that it requires weighting criteria.

Weighting criteria in supplier selection frequently involve an Analytical Hierarchy Process (AHP) (Ristono et al., 2020b). The integration of two multi-attribute decision-making methods to select a supplier using AHP to calculate the weight of the criteria has been examined extensively (Ristono et al., 2020b). The final ranking is determined through a pairwise relative evaluation of the requirements, a benefit associated with AHP (Dožić et al., 2023). Additionally, the AHP approach is logical and understandable, and the calculation process is relatively simple (Dožić et al., 2023). The advantages include verification of data inconsistencies, reduced subjectivity owing to the inclusion of human components, and universality Ristono et al., 2020a). Nevertheless, the mathematical method is comparatively easy, and the AHP approach's reasoning is comprehensible and reasonable (Dožić et al., 2023). Consequently, the criterion is primarily weighted using AHP.

Therefore, applying AHP to this issue can help corroborate the decision-making process and select appropriate solutions systematically. During its development, ARAS and AHP for supplier evaluation were integrated into its design. Mavi (2015) employed AHP as a weighting criterion and ARAS to identify environment-friendly suppliers. Tamošaitiene et al. (Tamošaitiene et al., 2017) combined AHP and ARAS to assess suppliers in construction companies. (Liao et al., 2016) evaluated watch suppliers using AHP and ARAS, while (Büyüközkan and Göçer (2018) similarly researched supplier evaluation at airports. Fu (2019) utilized AHP and ARAS to identify the most suitable catering suppliers that satisfied airline standards. (Özdağoğlu et al., 2019) combined them to identify suppliers for water treatment facilities, while Ath (2024) integrated both to select sustainable fertilizer suppliers in an indeterminate environment.

Previous AHP–ARAS-integrated research assumed that the criteria had been provided (Ristono et al., 2018b). These studies focused only on methods for selecting alternative suppliers, and most research on supplier selection has yet to further examine the selection criteria (Ristono et al., 2018a). Selection of criteria is an essential step in the supplier selection process (Ali et al., 2023). Many methods can be used to select criteria, such as Delphi, decision trial and evaluation laboratory (DEMATEL), analysis of variance (ANOVA), factor analysis, interpretive structural modeling (ISM), structural equation modeling (SEM), and AHP (Ristono et al., 2018a).

Wahyuningsih et al. (2022) used factor analysis to select the criteria used as a basis for selecting suppliers using AHP–ARAS integration. Factor analysis requires rigorous statistical calculations (Costello & Osborne, 2005; Tavakol & Dennick, 2011). It is a sophisticated statistical technique that requires researchers to make numerous judgments that influence the answers (Gaskin & Happell, 2014). Another limitation is that the factor analysis approach is ineffective when non-linear relationships exist among factors; in reality, the relationships between factors and variables within a specific domain are unlikely to be perfectly linear (Watkins, 2018). Another limitation is the large sample size used for factor analysis (Scheeringa, 2024). Increased sample sizes yield more stable factor analytical outcomes regarding the loadings of variables on factors derived from a correlation matrix (Luu & ElBassiouny, 2020). Ideally, the sample size should be five to ten times the total scale component (Costello & Osborne, 2005). This was considered sufficient because it surpasses the recommended minimum of ten observations per variable (Tanwar & Agarwal, 2024). Factor analysis must account for a projected 20% incomplete rate when determining the sample size (Huda et al., 2024).

This study used the Delphi method to determine these criteria. The advantage of Delphi is that no specific sample size criteria has been adopted in the literature because it relies on group dynamics rather than statistical power to reach a consensus among experts (Cafiso et al., 2013). Another advantage is that it combines quantitative and qualitative data (Brady, 2015). Furthermore, expert responses can be collected using an open questionnaire (Koskey et al., 2023). Expert opinions are analyzed thematically, compiled by researchers, and presented to the same panel of experts to review the synthesized results and indicate their agreement or disagreement levels (Koskey et al., 2023). Several rounds were conducted until a consensus was reached that collectively represented expert opinions (Hue & Oanh, 2023). The experts can modify their responses in each round. Modifications may occur after exposure to the perspectives of other experts or clarification of opinions (Drumm et al., 2022). Someone outside the panel, often a researcher, facilitates the process and the responses remain unnoticed by different experts.

This study preliminarily considers the factors essential for a company by performing a factor analysis using the Delphi method. The factors obtained are weighted using the AHP method as a reference for the weight of each factor in the ARAS method. One of the factors examined is sensitive data; therefore, a sensitivity test is necessary to provide a clear view of the company and determine supplier priorities.

This study makes three novel contributions to supplier selection: incorporating Delphi, which has been implemented in the Indonesian concrete industry, and integrating AHP and ARAS into the supplier selection process. Second, in contrast to previous research, pairwise comparisons of AHP no longer require expert questionnaires, but rather the results from the Delphi second round. Finally, it is imperative to establish a straightforward methodology to enable managers in the Indonesian concrete industry to identify the most suitable suppliers. Additionally, this approach can help assist managers in dividing intricate decision-making challenges into straightforward methodologies.

Research Method

The robustness of the proposed method is evaluated. Initially, various factors are analyzed and qualitative data from experts in the company are used. After identifying the factors using the Delphi method, AHP is used to weigh the criteria. The ratio consistency of the data is checked; it must be less than the acceptable region of < 0.1, for the data to be accepted. In this study, supplier ratings for each factor are determined using ARAS.

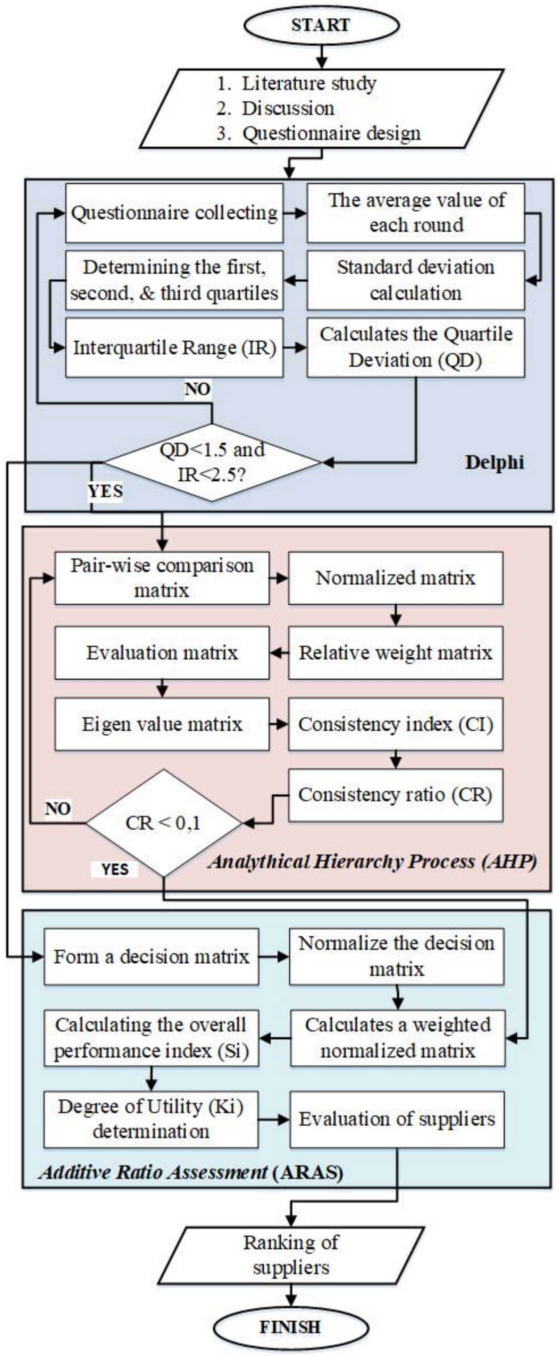

Fig. 1. Proposed method

Experts panel

Conceptual requirements are the primary determinants of an expert panel rather than representativeness (Moser & Korstjens, 2018). Based on their specialization, the number of specialists could range from 5 to 20 (Rowe & Wright, 2011). According to Yusoff et al. (Yusoff et al., 2021), the choice of experts requires at least seven. Mustapha et al. (Mustapha et al., 2017) also acknowledge that seven samples are sufficient in the Delphi procedure when the experts are very similar. Previous studies have shown that at least ten experts are needed to reach a large consensus when using decision-making to analyze data (Yaakob et al., 2020). The specialists had to have at least five years of experience, confirming their experience in a given field (Mokhtar & Yasin, 2018).

This paper included ten experts from the procurement, building, and commissioning divisions of PT Wika Beton; they had more than 15 years of experience in a similar field. The experts selected were from the population used in Delphi considering their expertise in supplier selection at PT Wika Beton. A sampling plan is considered suitable when the selected participants and settings are adequate to provide the necessary information to thoroughly comprehend the phenomenon being studied (Moser & Korstjens, 2018). Ten experts were enough for obtaining information and deciding how to evaluate and confirm the model in this study.

First stage

In the first stage, criteria considered necessary for the company are obtained. In the first Delphi round, ten experts reached a consensus regarding the criteria used to select suppliers at PT Wika Beton. In the second round, each expert assessed individual criteria using a Likert scale. These values are crucial to ensure that the most critical conditions are satisfied. The focus is on how the criteria influence the subject matter, rather than the inherent importance of the criteria themselves. The results of this second round were also analyzed to determine the criteria used to select suppliers at PT Wika Beton.

Second stage

The average rating value of each selected criterion in the second round of Delphi is the basis for input in the pairwise comparison of AHP. Generally, AHP is divided into three stages (Secundo et al., 2017). The first stage includes defining the problem and forming a hierarchy of these problems (Dožić & Kalić, 2015). This is one of the advantages of AHP because, at this stage, the problem can be revealed and deconstructed in depth while developing a hierarchical structure (Deretarla et al., 2023). The second stage determines the priorities of the elements by comparing pairs to the relative weighting of the criteria (Deretarla et al., 2023). The equation used at this stage is Eq. (1) (Saaty, 1994, 2008; Saaty & Ozdemir, 2003). The third stage is synthesis, which measures the consistency ratio (CR) index using Eq. (2) and (3) (Saaty, 1994, 2008; Saaty & Ozdemir, 2003). This study aims to determine whether the relative weighting results of these criteria are valid (Saaty & Ozdemir, 2003). Pairwise comparisons are considered valid if the CR is less than 0.1. (Liu, 2022; Ristono, 2019).

$$W_i = \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{bmatrix} = \begin{bmatrix} \left[\dfrac{a_{11}}{\sum_{i=1}^{n} a_{i1}} + \dfrac{a_{12}}{\sum_{i=1}^{n} a_{i2}} + \ldots + \dfrac{a_{1n}}{\sum_{i=1}^{n} a_{in}} \right] \left(\dfrac{1}{n} \right) \\ \left[\dfrac{a_{21}}{\sum_{i=1}^{n} a_{i1}} + \dfrac{a_{22}}{\sum_{i=1}^{n} a_{i2}} + \ldots + \dfrac{a_{2n}}{\sum_{i=1}^{n} a_{in}} \right] \left(\dfrac{1}{n} \right) \\ \vdots \\ \left[\dfrac{a_{n1}}{\sum_{i=1}^{n} a_{i1}} + \dfrac{a_{n2}}{\sum_{i=1}^{n} a_{i2}} + \ldots + \dfrac{a_{nn}}{\sum_{i=1}^{n} a_{in}} \right] \left(\dfrac{1}{n} \right) \end{bmatrix} \tag{1}$$

$$\lambda_i = \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_n \end{bmatrix} = \begin{bmatrix} \left[\dfrac{a_{11}}{W_1} + \dfrac{a_{12}}{W_2} + \ldots + \dfrac{a_{1n}}{W_n} \right] \left(\dfrac{1}{W_1} \right) \\ \left[\dfrac{a_{21}}{W_1} + \dfrac{a_{22}}{W_2} + \ldots + \dfrac{a_{2n}}{W_n} \right] \left(\dfrac{1}{W_2} \right) \\ \vdots \\ \left[\dfrac{a_{n1}}{W_1} + \dfrac{a_{n2}}{W_2} + \ldots + \dfrac{a_{nn}}{W_n} \right] \left(\dfrac{1}{W_n} \right) \end{bmatrix} \tag{2}$$

$$\mathrm{CR} = \left[\frac{\lambda_{\max} - n}{n - 1} \right] \left(\frac{1}{RI} \right) \tag{3}$$

Third stage

In this study, the ARAS method was combined with AHP for supplier evaluation. ARAS was first introduced by Zavadskas and Turskis (2010) to select suppliers in the solid waste disposal industry. The advantage of the ARAS method is that the utility value function determines the relative efficiency of feasible alternatives, which is directly proportional to the value and weight of the criteria considered (Zavadskas et al., 2010).

The initial step in ARAS is to form a decision matrix using Eq. (4) (Zavadskas et al., 2010). The next step is to normalize the decision matrix using Eq. (5) for the criteria of benefits, and Eq. (6) for the criteria of non-benefits, and then multiply by the weight for each criterion (output from AHP) using Eq. (7) (Zavadskas et al., 2012). The sum of these values for each criterion yielded the optimality function (S_i) value (see Eq. (8)). Supplier evaluation is based on the degree of utility, which is the value of the optimality function divided by each supplier's ideal optimality function (Zavadskas et al., 2010; Zavadskas et al., 2012). The optimal function, degree of utility, and ranking of each supplier are listed in Table 4.

$$X_{ij} = \begin{bmatrix} x_{01} \dots x_{0n} \\ \vdots \quad \ddots \quad \vdots \\ x_{m1} \dots x_{mn} \end{bmatrix}; i = 1 \dots m; j = 1 \dots n \tag{4}$$

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \tag{5}$$

$$x^*_{ij} = \frac{1}{x_{ij}}; \bar{x}_{ij} = \frac{x^*_{ij}}{\sum_{i=0}^{m} x_{ij}} \tag{6}$$

$$\hat{x}_{ij} = \bar{x}_{ij} w_j; \quad i = 1 \dots m; \quad j = 1 \dots n \tag{7}$$

$$S_i = \sum_{j=1}^{n} \hat{x}_{ij}; \quad i = 1 \dots m \tag{8}$$

Results and Discussion

Criteria selection

As mentioned earlier, ten experts participated in the initial stage of the study, including the raw material procurement manager, production manager, warehouse manager, and members of their respective teams. Considering that the respondents had previously worked in similar companies for over 15 years, their answers were considered valid. In the first round of Delphi, seven criteria were obtained from focus group discussions with respondents, which became the basis for supplier selection: quality, price, delivery, accessibility, reputation, relationships, and flexibility.

The results from the second-round Delphi stages are illustrated in Tables 1 and 2: evaluation of the criteria based on convergence. If the standard deviation is < 1.5 and the interquartile range is < 2.5, the instrument converges. Based on Table 2, it can be concluded that all criteria were considered in the supplier selection.

Table 1
The results of the first round

Criteria	Expert									
	1	2	3	4	5	6	7	8	9	10
Quality	5	5	4	5	5	4	5	5	5	5
Delivery	5	5	5	4	4	5	4	4	5	5
Price	5	4	5	4	5	4	5	4	3	3
Accessibility	5	4	5	4	5	3	5	4	5	4
Reputation	3	4	5	4	3	4	3	3	3	5
Relationship	4	5	4	3	4	5	4	5	4	4
Flexibility	2	3	2	5	4	3	4	4	5	5

Table 2
The results of the second round

Criteria	Me	SD	Q_1	Q_2	Q_3	IR	QD
Quality	4.78	0.34	4.13	4.25	4.57	0.44	0.22
Delivery	4.57	0.30					
Price	4.13	0.51					
Accessibility	4.35	0.40					
Reputation	3.62	1.01					
Relationship	4.16	0.78					
Flexi bility	3.52	1.44					

Notes: Me = Mean, SD = Standard Deviation, Q_1 = First Quartile, Q_2 = Second Quartile, Q_3 = Third Quartile, IR = Interquartile Range, QD = Quartile Deviation.

Criteria weighting

The next step involved pairwise comparisons of the mean scores of the seven criteria to obtain the pairwise comparison matrix. The results are summarized in Table 3. Based on a pairwise comparison calculated using AHP, the weight of the criteria is obtained, as shown in the column on the extreme right of Table 3. The relative weight of these criteria was validated by calculating CR, which was less than 0.1; therefore, it is considered valid.

Table 3 demonstrates that quality and delivery factors are critical for evaluating the material supplier, weighing 16.4% and 15.7%, respectively, followed by accessibility, relationship, price, reputation, and flexibility. Proven experience in the company is the most critical criterion, with a total weight of almost 35%, followed by accessibility and relationship at 29.2%. The company manufactures concrete for infrastructure products. The management prioritizes quality and accuracy of delivery of raw materials over other factors. Every infrastructure development project focuses on accurate scheduling to complete a high-quality project under contractual agreement.

Table 3
Pairwise comparison

criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	W_j
C_1	1.00	1.05	1.16	1.10	1.32	1.15	1.36	0.164
C_2	0.96	1.00	1.11	1.05	1.26	1.10	1.30	0.157
C_3	0.86	0.90	1.00	0.95	1.14	0.99	1.17	0.142
C_4	0.91	0.95	1.05	1.00	1.20	1.05	1.17	0.149
C_5	0.76	0.79	0.88	0.83	1.00	0.87	1.24	0.124
C_6	0.87	0.91	1.01	0.96	1.15	1.00	1.18	0.143
C_7	0.74	0.77	0.85	0.81	0.97	0.85	1.00	0.121

Notes: C_1 = Quality, C_2 = Delivery, C_3 = Price, C_4 = Accessibility, C_5 = Reputation, C_6 = Relationship, C_7 = Flexibility.

Supplier selection

Regarding supplier evaluation, ARAS requires assessments for individual criteria. The details of the data are presented in Table 4. The data are classified into two types: benefit (quality, accessibility, reputation, relationship, and flexibility) and non-benefit criteria (quality, delivery, and delivery).

Table 4
Performance of supplier

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
PT.ISBS	0.09	4.4	80	70	86	80	95
PT.MS	0.07	4.2	70	70	90	70	80
PT.CBS	0.08	5.2	80	80	78	80	90
PT.IST	0.08	4	60	75	82	70	65
PT.JB	0.06	5.6	70	70	92	60	55
PT.WNG	0.06	5.8	80	70	86	90	70
PT.SDH	0.09	5	85	70	80	70	60
PT.RB	0.06	4.8	75	65	80	60	55

Equation (1) is used to build a decision matrix for supplier data for each criterion, as shown in columns, while suppliers are in rows. Equation (2) normalizes the benefit-type data in the decision matrix. Benefit criteria carry a value; the bigger the value, the better. Equation (3) normalizes non-benefit data in the decision matrix. Meanwhile, the smaller the non-benefit value, the better. Equation (4) is used to multiply the data in the normalized decision matrix by the criteria weights, which are obtained from the AHP weighting results. Equation (5) measures individual suppliers' degree of utility; the higher the degree of utility, the better the supplier.

Based on Table 5, the evaluation results of the proposed method indicate that the sequence is PT. MS >PT. IST >PT. ISBS >PT. WNG >PT. CBS >PT. JB >PT. RB >PT. SDH. This is consistent with the current situation. ARAS was initially employed to evaluate the feasibility of the company's selection of raw material suppliers. Eight suppliers are compared using seven weighted decision criteria. A ranking of supplier priorities is established (Table 4) under the decision-maker's decision: Priority 1 is PT. MS, Priority 2 is PT IST, Priority 3 is PT ISBS, Priority 4 is PT WNG, Priority 5 is PT CBS, Priority 6 is PT JB, Priority 7 is PT RB, and Priority 8 is PT SDH. The most suitable supplier is PT MS, as determined by the feasibility of selecting raw material suppliers in the company through ARAS.

Table 5
Degree of utility

Supplier	S_i	K_i	*Rank*
PT.ISBS	0.11163	0.85300	3
PT.MS	0.11448	0.87477	1
PT.CBS	0.10970	0.83830	5
PT.IST	0.11297	0.86322	2
PT.JB	0.10636	0.81272	6
PT.WNG	0.11029	0.84277	4
PT.SDH	0.09910	0.75727	8
PT.RB	0.10461	0.79941	7

PT MS and PT IST should be selected as the best options according to the degree of utility, as shown in Table 4. Both suppliers have the highest weight owing to their proven experience and knowledge of the company's requirements, with utility indexes of 0.875 and 0.863, respectively. Their delivery service of raw materials is the lowest, at 4.2 and 4 days, respectively (See Table 4). Moreover, PT Wika Beton has been involved in various strategic toll road projects in Indonesia, such as the Trans-Java Toll Road, Trans-Sumatra Toll

Road, and other projects that are part of developing inter-regional connectivity in Indonesia. When selecting a material supplier, the company focuses on material quality and specialized delivery factors to ensure customer satisfaction, service, and accurate scheduling to complete a high-quality infrastructure project under a contractual agreement. Therefore, maintaining an accurate project implementation schedule is vital for PT Wika Beton to accelerate national infrastructure development under the government's vision to improve transportation networks.

The proposed model is validated using sensitivity analysis, which focuses on the change in each weighting of the criteria. Sensitivity analysis enables decision makers to evaluate the resilience of a process by determining the effect of changes to the primary criteria on supplier ranking. The ranking of a supplier is considered sensitive to a criterion if a minor adjustment in its weighting results in a change. The superior ranking for PT. MS and PT. IST can be attributed to the high weightage of the primary criterion – "quality" and "delivery" – in comparison to other suppliers, as indicated by the performance sensitivity graph.

Sensitivity analysis concerning quality: nine circumstances are chosen and the ranking is completed while considering additional weights. Scenario 1 represents the currently researched scenario with current weights. Scenario 2: the quality criteria weight decreases by –20% from the initial weight, whereas other weights adjust. Scenario 3: the quality criteria weight decreases by −15% from the initial weight, while other weights adjust. Scenario 4: the quality criteria weight decreases by −10% from the initial weight, as other weights adjust. Scenario 5: the quality criteria weight decreases by –5% from the initial weight, while other weights adjust. Scenario 6: the quality criteria weight increases by 5% from the initial weight, while other weights adjust. Scenario 7: the quality criteria weight increases by 10% from the initial weight, whereas other weights adjust. Scenario 8: the quality criteria weight increases by 15% from the initial weight, whereas other weights adjust. Scenario 9: the quality criterion weight increases by 20% from the initial weight, whereas other weights adjust. Scenario 10: the quality criteria weight increases by 25% from the initial weight, while other weights adjust. The results are shown in Fig. 2. The ranking of suppliers did not change when quality was 20.52%, increased by 25% from 16.42%; delivery was 15.02%; price was 13.49%; accessibility was 14.24%; reputation was 11.75%; relationship was 13.59%; and flexibility was 11.39%. In conclusion, sensitivity analysis of the quality criteria reaffirmed the reliability and robustness of our results. Regardless of the quality value, the ranked supplier remains unchanged, providing a reliable and stable basis for supplier evaluation. It also ensures a dependable and consistent foundation for supplier evaluation, irrespective of the quality value.

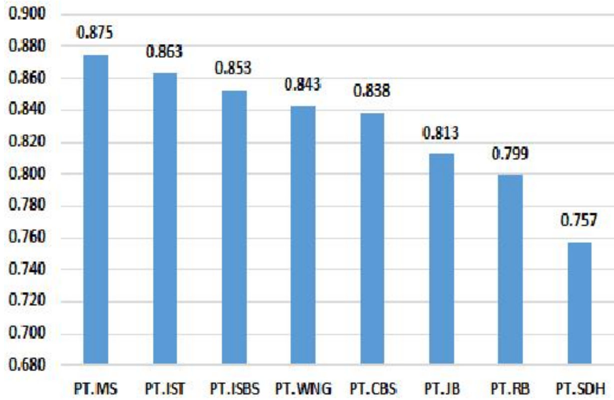

Fig. 2. The results of the proposed model

Sensitivity analysis was conducted based on the following criteria: delivery, price, accessibility, reputation, relationship, and flexibility. The scenario developed for the quality criterion was consistent with the sensitivity analysis applied to other criteria. Figures 3–9 illustrate the findings. Sensitivity analysis reaffirmed the reliability and robustness of our results for all criteria. The ranked supplier remains constant regardless of the values of all criteria, thereby establishing a dependable and consistent foundation for supplier evaluation.

	PT.MS	PT.IST	PT.ISBS	PT.WNG	PT.CBS	PT.JB	PT.RB	PT.SDH
0%	0.8748	0.8632	0.8530	0.8428	0.8383	0.8127	0.7994	0.7573
-20%	0.8755	0.8675	0.8605	0.8396	0.8436	0.8053	0.7913	0.7608
-15%	0.8753	0.8664	0.8586	0.8404	0.8423	0.8071	0.7933	0.7599
-10%	0.8751	0.8653	0.8568	0.8412	0.8410	0.8090	0.7954	0.7590
-5%	0.8749	0.8643	0.8549	0.8420	0.8396	0.8109	0.7974	0.7581
5%	0.8746	0.8622	0.8511	0.8436	0.8370	0.8146	0.8014	0.7564
10%	0.8746	0.8622	0.8511	0.8436	0.8370	0.8146	0.8014	0.7564
15%	0.8746	0.8622	0.8511	0.8436	0.8370	0.8146	0.8014	0.7564
20%	0.8746	0.8622	0.8511	0.8436	0.8370	0.8146	0.8014	0.7564
25%	0.8746	0.8622	0.8511	0.8436	0.8370	0.8146	0.8014	0.7564

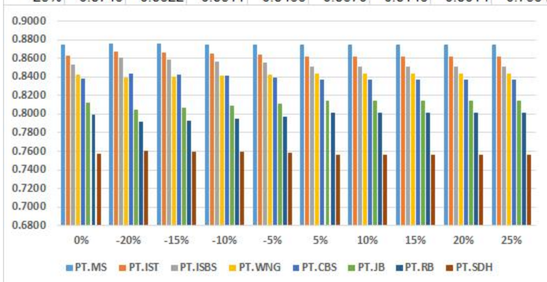

Fig. 3. The changes in the weighting of quality criteria

Managerial implication

This case study has significant managerial implications. The Delphi methodology provides managers in the Indonesian concrete industry with a thorough

	PT.MS	PT.IST	PT.ISBS	PT.WNG	PT.CBS	PT.JB	PT.RB	PT.SDH
0%	0.8748	0.8632	0.8530	0.8428	0.8383	0.8127	0.7994	0.7573
-20%	0.8719	0.8581	0.8512	0.8483	0.8410	0.8161	0.7978	0.7557
-15%	0.8727	0.8594	0.8517	0.8469	0.8403	0.8153	0.7982	0.7561
-10%	0.8734	0.8607	0.8521	0.8455	0.8397	0.8144	0.7986	0.7565
-5%	0.8741	0.8619	0.8526	0.8442	0.8390	0.8136	0.7990	0.7569
5%	0.8755	0.8645	0.8534	0.8414	0.8376	0.8119	0.7998	0.7577
10%	0.8762	0.8658	0.8539	0.8400	0.8369	0.8110	0.8002	0.7581
15%	0.8769	0.8671	0.8543	0.8386	0.8363	0.8102	0.8006	0.7585
20%	0.8776	0.8684	0.8548	0.8372	0.8356	0.8093	0.8010	0.7588
25%	0.8783	0.8696	0.8552	0.8358	0.8349	0.8085	0.8014	0.7592

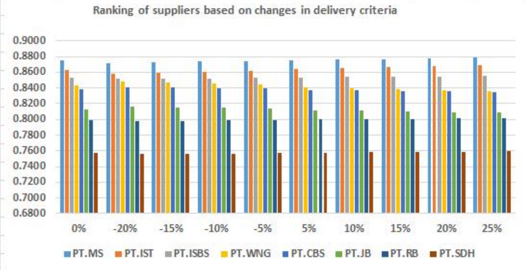

Fig. 4. The changes in the weighting of delivery criteria

	PT.MS	PT.IST	PT.ISBS	PT.WNG	PT.CBS	PT.JB	PT.RB	PT.SDH
0%	0.8748	0.8632	0.8530	0.8428	0.8383	0.8127	0.7994	0.7573
-20%	0.8754	0.8585	0.8568	0.8459	0.8415	0.8110	0.7991	0.7590
-15%	0.8752	0.8597	0.8558	0.8451	0.8407	0.8115	0.7992	0.7586
-10%	0.8751	0.8608	0.8549	0.8443	0.8399	0.8119	0.7992	0.7581
-5%	0.8749	0.8620	0.8539	0.8435	0.8391	0.8123	0.7993	0.7577
5%	0.8746	0.8644	0.8521	0.8420	0.8375	0.8131	0.7995	0.7568
10%	0.8745	0.8656	0.8511	0.8412	0.8367	0.8136	0.7996	0.7564
15%	0.8743	0.8668	0.8502	0.8404	0.8359	0.8140	0.7996	0.7560
20%	0.8742	0.8680	0.8493	0.8397	0.8351	0.8144	0.7997	0.7555
25%	0.8740	0.8692	0.8483	0.8389	0.8343	0.8148	0.7998	0.7551

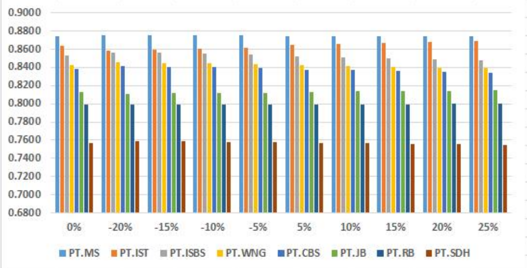

Fig. 5. The changes in the weighting of price criteria

	PT.MS	PT.IST	PT.ISBS	PT.WNG	PT.CBS	PT.JB	PT.RB	PT.SDH
0%	0.8748	0.8632	0.8530	0.8428	0.8383	0.8127	0.7994	0.7573
-20%	0.8748	0.8607	0.8526	0.8417	0.8332	0.8105	0.7987	0.7534
-15%	0.8748	0.8613	0.8527	0.8420	0.8345	0.8111	0.7989	0.7544
-10%	0.8748	0.8619	0.8528	0.8422	0.8357	0.8116	0.7990	0.7553
-5%	0.8748	0.8626	0.8529	0.8425	0.8370	0.8122	0.7992	0.7563
5%	0.8748	0.8639	0.8531	0.8430	0.8396	0.8133	0.7996	0.7582
10%	0.8748	0.8645	0.8532	0.8433	0.8408	0.8138	0.7998	0.7592
15%	0.8748	0.8651	0.8533	0.8436	0.8421	0.8144	0.8000	0.7602
20%	0.8748	0.8658	0.8534	0.8439	0.8434	0.8150	0.8002	0.7611
25%	0.8748	0.8664	0.8536	0.8441	0.8447	0.8155	0.8003	0.7621

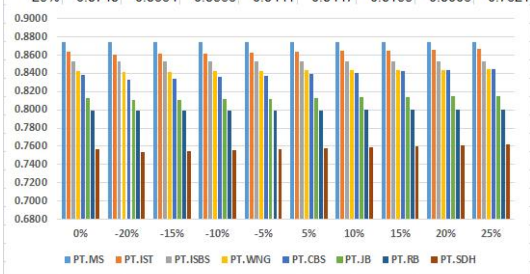

Fig. 6. The changes in the weighting of accessibility criteria

	PT.MS	PT.IST	PT.ISBS	PT.WNG	PT.CBS	PT.JB	PT.RB	PT.SDH
0%	0.8748	0.8632	0.8530	0.8428	0.8383	0.8127	0.7994	0.7573
-20%	0.8720	0.8624	0.8511	0.8403	0.8382	0.8076	0.7973	0.7543
-15%	0.8727	0.8626	0.8515	0.8409	0.8382	0.8089	0.7978	0.7550
-10%	0.8734	0.8628	0.8520	0.8415	0.8382	0.8102	0.7983	0.7558
-5%	0.8741	0.8630	0.8525	0.8421	0.8383	0.8114	0.7989	0.7565
5%	0.8755	0.8634	0.8535	0.8434	0.8383	0.8140	0.7999	0.7580
10%	0.8761	0.8636	0.8540	0.8440	0.8383	0.8153	0.8005	0.7588
15%	0.8768	0.8639	0.8545	0.8446	0.8384	0.8166	0.8010	0.7595
20%	0.8775	0.8641	0.8550	0.8452	0.8384	0.8179	0.8015	0.7603
25%	0.8782	0.8643	0.8554	0.8459	0.8384	0.8192	0.8021	0.7610

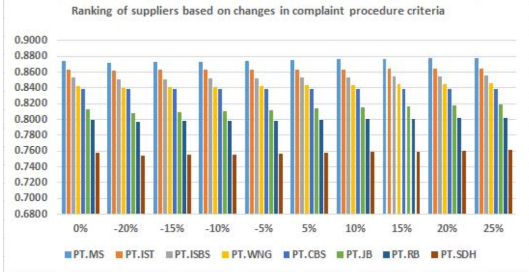

Fig. 7. The changes in the weighting of reputation criteria

	PT.MS	PT.IST	PT.ISBS	PT.WNG	PT.CBS	PT.JB	PT.RB	PT.SDH
0%	0.8748	0.8632	0.8530	0.8428	0.8383	0.8127	0.7994	0.7573
-20%	0.8781	0.8660	0.8520	0.8374	0.8368	0.8175	0.8036	0.7565
-15%	0.8773	0.8653	0.8523	0.8387	0.8371	0.8163	0.8026	0.7567
-10%	0.8764	0.8646	0.8525	0.8401	0.8375	0.8151	0.8015	0.7569
-5%	0.8756	0.8639	0.8528	0.8414	0.8379	0.8139	0.8005	0.7571
5%	0.8739	0.8625	0.8532	0.8441	0.8387	0.8115	0.7983	0.7574
10%	0.8731	0.8618	0.8535	0.8455	0.8391	0.8103	0.7973	0.7576
15%	0.8723	0.8611	0.8537	0.8468	0.8395	0.8091	0.7962	0.7578
20%	0.8715	0.8604	0.8540	0.8482	0.8398	0.8079	0.7952	0.7580
25%	0.8706	0.8597	0.8542	0.8495	0.8402	0.8067	0.7941	0.7582

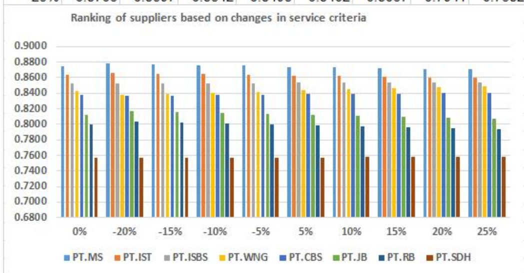

Fig. 8. The changes in the weighting of relationship criteria

	PT.MS	PT.IST	PT.ISBS	PT.WNG	PT.CBS	PT.JB	PT.RB	PT.SDH
0%	0.875	0.863	0.853	0.843	0.838	0.813	0.799	0.757
-20%	0.876	0.869	0.849	0.846	0.835	0.820	0.806	0.761
-15%	0.876	0.867	0.850	0.845	0.836	0.818	0.804	0.760
-10%	0.875	0.866	0.851	0.844	0.837	0.816	0.803	0.759
-5%	0.875	0.865	0.852	0.844	0.837	0.814	0.801	0.758
5%	0.875	0.862	0.854	0.842	0.839	0.811	0.798	0.756
10%	0.874	0.861	0.855	0.841	0.840	0.809	0.796	0.755
15%	0.874	0.859	0.856	0.840	0.841	0.807	0.795	0.754
20%	0.874	0.858	0.857	0.840	0.841	0.806	0.793	0.753
25%	0.874	0.856	0.858	0.839	0.842	0.804	0.791	0.752

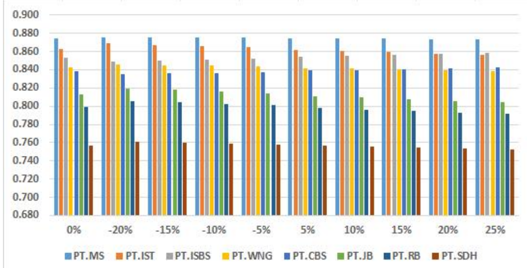

Fig. 9. The changes in the weighting of flexibility criteria

understanding of the variables that must be assessed when selecting suppliers. The selected methodology prioritizes this criterion. Managers can use the hierarchical structure of the proposed supplier-selection methodology to rank suppliers based on various factors and criteria. The sensitivity analysis also evaluates the influence of adjusting the weights of requirements on the ranking of suppliers, which aids managers in making well-informed decisions.

The managerial decision to select PT MS and PT IST as optimal suppliers is both appropriate and robust. Traditionally, cost is considered a significant factor, necessitating minimal deliberation for rejection, whereas other factors are assigned a specific degree of significance. However, in Indonesia, concrete products are essential for infrastructure development and managers are responsible for ensuring that their production is operational. Therefore, the survival of the Indonesian concrete industry depends on supplier selection. Choosing a suitable supplier positively influences a concrete manufacturing company's downstream activities by helping reduce production time and increasing customer satisfaction.

Furthermore, managers should prioritize factors other than cost, as they have been relegated to the background because of the product's significance for the organization's survival and high demand. The production process must operate smoothly by prioritizing the delivery criteria. Consequently, the supplier with the fastest delivery time should be prioritized and considered the best option, irrespective of their performance in other areas.

Additionally, this approach assists managers in organizing complex issues into manageable hierarchies. The company in the case study observed a 10% decrease in the later stages of the project after several months of implementation, which is a clear indication of the efficacy of the proposed methodology. The administration of the case companies is entirely dedicated to implementing the supplier ranking identified in this paper and the distribution of orders under that ranking. This commitment is a testament to their confidence in the efficacy of their methodology, reassuring other industry managers. The underfeed must be informed of their position.

The concrete company's managerial staff evaluates various factors when selecting a supplier. Subsequently, the factors are assigned weights. Minor weight fluctuations do not compromise supplier preferences when determining the most appropriate choice. Managers must guarantee that minor weight fluctuations do not compromise supplier preferences, because environmental factors may induce fluctuations in weight. To achieve this, a sensitivity analysis of the criteria is performed to determine the supplier selection, which is contingent on changes in the weights of the underlying factors. Subsequently, the supplier's decision is evaluated for resilience.

Conclusions

The selection of the most suitable raw material supplier for the Indonesian concrete industry was based on the following criteria: material quality, competitive pricing, rapid delivery, accessibility, reputation, relationships, and flexibility. The most critical criteria included raw material quality and fast delivery, with weights of 16.4% and 15.7%, respectively, followed by competitive pricing, accessibility, reputation, relationship, and flexibility in that order. With a utility value of 0.87477, PT MS was the optimal choice. The quality of raw materials and fast delivery are of significant importance to PT Wika Beton, which selects its raw materials at a competitive price despite its cost-cutting plans in the supply chain, to guarantee customer satisfaction and the highest quality of service.

Choosing suppliers to implement effective strategies in the Indonesian concrete industry necessitates careful consideration of business management practices. The process of selecting suppliers in this sector should consider multiple criteria that incorporate both quantitative and qualitative factors. A model utilizing AHP was designed to address this issue by incorporating ARAS. Comparable evaluations should be undertaken for matters other than the selection of raw material suppliers for the concrete manufacturing sector. The applicability of the study outcomes to various contexts should be determined to assist decision makers and practitioners in selecting raw material providers in the future. This study establishes a benchmark for formulating effective strategies for the concrete production sector.

The study has several methodological research constraints, including the dataset, methodologies, and criteria employed. Future research may incorporate additional decision makers from the concrete manufacturing business to enhance outcomes, as other stakeholders may exhibit varying preferences. Methodologically, diverse indicators may serve as criteria for future research, and new research may be undertaken by employing various MCDM methodologies and their integrated variants. From a practical standpoint, using a hybrid method that amalgamates expert judgment with sustainability-focused vague multi-criteria decision-making presents a viable solution to an uncertain supplier selection dilemma.

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