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

Jurnal Optimasi Sistem Industri

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

Case Study

Spare Parts Supplier Selection Design: A Case Study of A Railway Company

Robby Ady Asmara, Lien Herliani Kusumah

Faculty of Engineering, Universitas Mercu Buana, Menteng, Jakarta, 10340, Indonesia

ARTICLE INFORMATION

Received : August 20, 2021
Revised : November 11, 2021
Available online : November 29, 2021

KEYWORDS

Supplier selection, spare parts, rolling stock, railway company, MCDM

CORRESPONDENCE

Phone : +62815 17 136371
E-mail : rasmara88@gmail.com

A B S T R A C T

Spare parts support is essential for rolling stock maintenance management. The current supplier selection model determines the selected supplier based on evaluating one aspect of the criteria (product aspect). The selection of suppliers with poor performance occurred between 2018-2020 related to the delivery of goods that exceeded the deadline and goods that did not meet specifications. The first objective of this research is to analyze and determine the relevant priority criteria for selecting suppliers of rolling stock spare parts for railway companies. The second objective is to determine the rolling stock spare parts supplier by using the evaluation criteria determined in the previous process. The method used in this research is the integration of the Fuzzy Delphi Method (FDM), Analytical Hierarchy Process (AHP), and Technique for Others Preference by Similarity to Ideal Solutions (TOPSIS). FDM is used to select important criteria for the selection of suppliers of rolling stock parts. AHP is used to assist in choosing various criteria through evaluation in determining the criteria's weight. TOPSIS is used to assess supplier ratings. A total of 13 criteria from 19 alternative criteria have been selected for railway companies, especially in selecting rolling stock spare parts suppliers. Furthermore, the selection becomes the basis for bidding. Finally, Supplier A is the supplier with the highest relative closeness value (0.591), followed by Supplier B (0.545), and the lowest is Supplier C (0.282).

INTRODUCTION

Maintenance of assets and equipment is essential for industries with significant investment assets (e.g., railroad companies) [1]. The purpose of maintenance is to manage the maintenance, control, and repair of machinery or equipment to meet system requirements and availability and high levels of service and cost-efficiency [1]-[4]. Inventory managed by a company but not as a process output is known as inventory of maintenance, repair, and overhaul (MRO) [5]. Procurement of MRO material is helpful to support the process of maintenance, repair, and operation so that the safety and feasibility of the system can be controlled. Therefore, MRO procurement is as essential as direct material procurement (provides direct value/benefit impact) because it has an essential role in the organization [6].

Spare parts inventory, labor capacity, and maintenance are synergistic indicators informing the total maintenance cost [7]. Therefore, how to get an efficient supply of spare parts becomes very important. Estimating the demand for spare parts depends on the number of equipment, parts failure behavior, and the recognized maintenance policy of the organization, where this data is used as the primary inventory management data [8]-[10]. Zhu et al. [10] conducted a study that builds dynamic inventory control based on a data-sharing platform which can further be helpful for the development of inventory optimization.

Supplier selection in many works of literature presents a Multi-Criteria Decision-Making (MCDM) model to evaluate some suppliers with a set of criteria to meet organizational needs [11]. Evaluation with multi-criteria considerations can be used to assess suppliers qualitatively and quantitatively [12]-[16]. On the other hand, evaluating suppliers based on only one aspect will allow selecting superior in one aspect that is weak in other aspects.

Organizations need to consider the best model to choose the correct evaluation in supplier selection problems [17]-[18]. Twenty-three evaluation criteria proposed by [19] became a reference in the research of [20]-[21]. However, the evaluation criteria for quality, price, delivery, and service are the criteria most frequently used by the industry at large [16], [18]. Furthermore, this study needs to understand that the criteria adopted by organizations can vary according to local culture and business conditions [12].

In recent years, the industry has begun to trigger environmental, social, and economical as critical industry factors in the future. Important suppliers play a role in creating green supply chains.

DOI: 10.25077/josi.v20.n2.p125-135.2021

Several previous researchers used the literature review method to discuss selecting green suppliers by using several green criteria. Marzouk and Sabbah [22] obtain criteria using a continuous approach from the literature and semi-structured interviews with experienced experts. The selection criteria obtained are social management commitment, social code of conduct, donation for sustainable projects, occupational health and safety management system, safety practices, the annual number of accidents, rights of stakeholders, stakeholder relations, technical training of employees, child labor, gender diversity, contract labor, national origin, wages, ethnicity, color, working hours [22].

Javad et al. [23] selected green suppliers in the steel industry; they proposed initial criteria from the literature review and then used an expert approach through questionnaires, interviews, and discussions. The main criteria obtained are collaboration, environmental investment and economic benefits, availability of green resources and competencies, environmental management initiatives, research and design initiatives, environmentally-friendly purchasing capabilities, regulatory obligations, market pressures, and demands, followed by 38 sub-criteria. Kilic and Yalcin [24] propose different criteria in selecting green suppliers. They combined the classical and the green criteria from the results of the literature review. Classic criteria include flexibility, quality, price, and delivery. In contrast, the green criteria include recycling, transportation, green image, and green R&D.

Kumar et al. [13] Examine the loss rate of each selected criteria (quality, delivery, price, service) before weighing and ranking suppliers. With the integration of Taguchi Loss Function, AHP, and TOPSIS, they claim that this method can minimize the potential for supplier rating reversals that generally occur in the MCDM method. Luzon and El-Sayegh [20] offered 23 criteria to experts and then produced ten criteria relevant to the industry, namely: quality, price, delivery, warranty and claims, service, technical capability, production facilities and capabilities, performance history, position financial, geographic location.

Sultana et al. [25] eliminated the proposed criteria to obtain the most probable criteria with the help of the decision-maker's perception. The selected criteria are supplier criteria, product performance criteria, service performance criteria with fourteen sub-criteria. Mavi [26] selected green suppliers to determine the criteria for further studies: quality, waiting for time, flexibility, green design, resource consumption (material, energy, water), and environmental performance assessment. Furthermore, the research has determined that the consumption of resources (materials, energy, water) is important from an expert's point of view.

Polat and Eray [21] see that the selection process should be based on mathematical analysis rather than the instincts and experience of project managers. Furthermore, they evaluate with eight assessment criteria, product quality, delivery, relationship with suppliers, product unit price, flexibility in payment conditions, communication with suppliers, production capacity, and technical competence of suppliers. Li et al. [14] conducted a preliminary analysis to identify the factors that influence the material supplier relationship of the railway project. The indicators refer to two points of view: the supply risk consideration and the evaluation of the potential increase in value considerations.

The selection criteria adopted are often based on literature review and followed by criteria applicable to case study companies [11-14], [17], [27-29]. Other researchers such as [15], [26], [30] use selection criteria resulting from interviews and discussions with experts to determine criteria suitable for industry case studies. The experts also reviewed several criteria from the previous literature. The discussion on what criteria are relevant for model evaluation regarding selecting rolling stock spare parts suppliers for railway companies is still rare. Therefore, this research fills the literature gap. Thus, the selection criteria will adopt the previous literature, then use an expert approach to establish criteria relevant to rail transportation. Table 1 presents the literature review results on selecting alternatives in the supplier selection process and research groups on each alternative criteria.

This study was conducted on a railroad company. Evaluation of the procurement model for the procurement of rolling stock spare

Tabel 1. Alternative Supplier Selection Criteria

Alternative Criteria	**Authors**
Product Price (C1)	[11]-[13], [15]-[16], [18], [20]-[21], [25], [28]-[33], [34], [35], [36], [37]
Product quality (C2)	[11], [14]-[16], [20]-[21], [25]-[35], [38], [39]
Insurance/Warranty (C3)	[11], [16], [20], [28]
Supplier Technical Capability (C4)	[15], [20], [21], [30], [31], [34], [35], [39]
Geographical Location (C5)	[12], [15], [20], [25], [29], [32], [33], [34], [37]
Supplier Capacity (C6)	[12], [15], [21], [33], [39]
Supplier Financial Capability (C7)	[14], [15], [20], [29], [30], [36], [37]
Production capacity (C8)	[14], [20], [30]
Electronic Transaction Capability (C9)	[30]
Company Image (C10)	[38]
Reputation and Position in the Industry (C11)	[14], [16], [20], [27], [33], [36], [37]
Service (C12)	[11], [13], [14], [16], [20], [27]-[29], [32], [36]-[38]
Delivery (C13)	[11], [13]-[15], [20], [21], [25]-[34], [38]
Responsibility for Environmental and Social Issues (C14)	[14], [26], [33], [37]
Buyer-Supplier Relationship (C15)	[16], [21], [33], [36]
Payment Terms (C16)	[12], [16], [21], [33]
Communication with Suppliers (C17)	[21], [14], [29]
Response Speed (C18)	[14], [15]
Supplier Flexibility (C19)	[25], [26], [37]

DOI: 10.25077/josi.v20.n2.p125-135.2021

Table 2. Supplier Poor Performance Records

No.	Supplier	Procurement Category	Problem
1.	Supplier 1	Bogie Parts and Train Interior	Delivery over time
2.	Supplier 2	Electrical Parts	Delivery over time
3.	Supplier 3	Train Interior Parts	Delivery over time and the goods do not meet the specifications
4.	Supplier 4	Filters	Delivery over time and the goods do not meet the specifications
5.	Supplier 5	Custom Items	The goods do not meet the specifications

parts only uses the evaluation of one criterion, namely the product aspect criteria. This study proposes that the supplier evaluation model uses a multi-criteria evaluation so that it can provide additional criteria preferences in addition to evaluating product criteria aspects. Thus, this study is expected to propose decision supports to identify suppliers with better performance, not suppliers who only excel in one aspect of the criteria but are weak compared to other criteria.

Logistics management deals with maintenance scheduling problems [7] and inventory level issues [9]. Therefore, an important issue is an accurate procurement program and acquiring a reliable and quality spare parts supplier. However, problems will arise in the event of an unexpected vendor failure. Vendor failure to deliver ordered goods can affect maintenance scheduling, regularity of the spare parts program in storage, and poor parts quality. Table 2 shows the problem: the poor performance of rolling stock spare parts suppliers for the last three years. This phenomenon is related to delivery problems that exceed the time limit and goods that do not meet specifications. Therefore, the focus of the next problem is how to evaluate the selection model for railroad spare parts suppliers using multiple selection criteria so that the rolling stock maintenance program and logistics management can be appropriately controlled.

Previous researchers have used many methods for supplier selection with multi-criteria decisions. For example, Wen et al. [31] used 2-Tuple Linguistic Representation and VIKOR to select suppliers in the pharmaceutical industry. Biruk et al. [12] using the Analytical Hierarchy Process (AHP) method for supplier selection in the road construction industry. Kumar et al. [13] Using the AHP, Taguchi Loss Function, and Technique for Others Preference by Similarity to Ideal Solutions (TOPSIS) methods in the railway industry. Fu [38] uses the AHP, Additive Ratio Assessment (ARAS), and Multi-Choice Goal Programming (MCGP) methods in industrial aviation.

Sarkar et al. [32] used the DEMATEL-Based Analytic Network Process (DANP), Fuzzy TOPSIS, and Fuzzy Vikor methods for supplier selection in the welding industry. Kumar et al. [27] used the Fuzzy TOPSIS to select suppliers in the iron and steel industry. Cengiz et al. [33] used the Analytic Network Process (ANP) to determine suppliers in construction industry. Luzon and El-Sayegh [20] used the Delphi and AHP to select suppliers in the oil and gas industry. Tavana et al. Tavana et al. [34] used the Adaptive Neuro-Fuzzy Inference System (ANFIS), Artificial neural network (ANN), Multi-Layer Perceptron (MLP) methods to select suppliers in the automotive industry.

Sultana et al. [25] used Fuzzy Delphi, Fuzzy AHP, and Fuzzy TOPSIS in the battery industry; Kar [30 applied Fuzzy AHP and Fuzzy Neural Network (F-NN) in the iron and steel industry; Zang et al. [29] used AHP, Linear Programming, and Information Entropy methods in the iron and steel industry; and Lam et al. [16], who used the Fuzzy Principal Component Analysis (PCA) method to select the property in the building industry.

This study uses the Fuzzy Delphi method (FDM) to select important criteria in selecting rolling stock spare parts suppliers. In this method, unimportant criteria will be eliminated to determine criteria relevant to railway companies. The decision to judge a criterion or not is given a choice in a fuzzy position. That is, the expert can determine within a range of decisions which they think are more appropriate. FDM has several advantages, namely: 1) it can reduce the survey time because the final decision is obtained through one round, unlike the traditional Delphi method, which requires several rounds, 2) it can solve the problem of ambiguity in the general understanding of experts, 3) a combination of provided by FDM can use a small number of samples and offer a complete expression of expert knowledge.

The AHP method assists the multi-criteria decision selection process through evaluation in determining the criteria's weight so that each criterion's relative importance can be known. TOPSIS is used to assess supplier ratings using weighted criteria considerations that have been determined by the AHP method. The selected supplier is the supplier that has the shortest Euclidean distance from the positive ideal solution and also has the farthest Euclidean distance from the negative ideal solution.

The purposes of this study are (1) to analyze and determine the relevant priority criteria for the selection of suppliers of railway spare parts for railway companies, and (2) to analyze and determine the evaluation model for the selection of suppliers of railway spare parts by considering the selected multi-criteria.

METHOD

This study built a conceptual framework by integrating FDM, AHP, and TOPSIS. The research framework shown in Figure 1 provides an overview of the supplier selection model in order to identify suppliers who have better capabilities to deliver goods according to user expectations.

Fuzzy Delphi Method (FDM)

FDM is a method that was first introduced by [40], where this method is derived from the traditional Delphi technique and Fuzzy Set Theory. The theory of fuzzy sets was first introduced by [41] to deal with ambiguity and uncertainty in human responses. The fuzzy set defines the degree of membership of an item that ranges between values of zero and one. Previous researchers usually used the triangular fuzzy number (TFN), trapezoidal fuzzy number, and Gaussian fuzzy number models. This study uses TFN because many researchers use this model for ease of calculation [42]. Figure 2 illustrates the TFN membership function, where l is the minimum value, m is reasonable, and u is the maximum value.

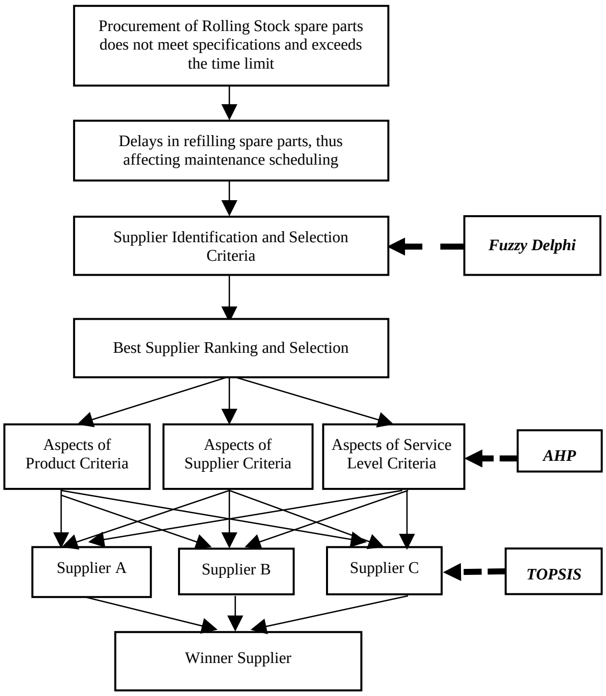

Figure 1. Design of Framework

FDM works in several stages, as follows:

Stage 1.1: Expert Selection

According to [43], experts have experience and knowledge in specific topics. Meanwhile, according to [44], expert opinion is used to assess important criteria for evaluating a particular scheme. According to [45], the recommended number of experts in the Delphi method is 10-50 people. This study uses 20 experts from practitioners who have expertise and experience in planning and procurement of rolling stock spare parts in railway companies. They can make decisions in their work units with a minimum position of Manager level.

Stage 1.2: Collecting Expert Assessment

The expert's assessment using a Likert scale in the form of a linguistic evaluation is then translated into TFN, which has three values that need to be considered, namely the minimum value (l), the most reasonable value (m), and the maximum value (u). Ebrahimi and Bridgelall [42] found that the best approach for evaluating expert judgment in fuzzy triangular sets is to use 5 points. The description of the linguistic assessment and TFN is described in Table 3.

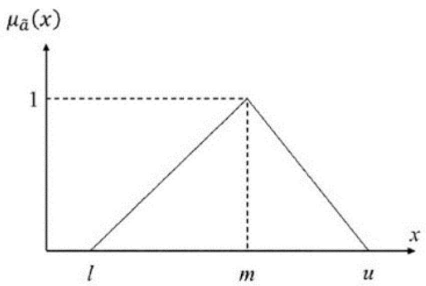

Figure 2. TFN Membership Function

Table 3. Comparison of Likert Scale with Fuzzy Score [48]

Likert Scale	Linguistic Variables	Fuzzy Score
5	Strongly agree	0.6, 0.8, 1.0
4	Agree	0.4, 0.6, 0.8
3	Neutral	0.2, 0.4, 0.6
2	Do not agree	0.0, 0.2, 0.4
1	Strongly Disagree	0.0, 0.0, 0.2

Stage 1.3: Calculating the Average Value of TFN Assessment for Each Criterion

The values of l, m, u are defined as n1, n2, n3, where each is a fuzzy score that expresses the minimum value, the most reasonable value, and the maximum value. The mean values of n1, n2, n3 of all experts are defined as m1, m2, m3.

Stage 1.4: Calculating Threshold Values and Determining Consensus/Expert Opinions

Three conditions must be met as the basis for a construct and item to be accepted. These requirements include (1) threshold value, d-construct ≤ 0.2 [46], (2) expert approval of the item evaluated > 75% [46],[47],[48], and (3) the defuzzification value for each item must be more than the α-cut value = 0.5 [46]. The d-construct threshold value as the first requirement begins with determining the threshold value (d) for each item by calculating the distance between the fuzzy scores (n_1, n_2, n_3) of each item and the fuzzy number average value (m_1, m_2, m_3) as described in equation (1).

$$d(\acute{m}, \tilde{n}) = \sqrt{\frac{1}{3}\left[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)\right]^2} \quad (1)$$

Then, a construct is accepted if the d-construct threshold value (d-const) ≤ 0.2 results from equation (2).

$$\text{d-Const} = \frac{\sum \text{Average threshold Value } (d) \text{ each item}}{\text{Total Expert } \times \text{Total items in Construct}} \quad (2)$$

As a second condition, expert agreement on each item evaluated is also based on the threshold value (d) of each item where (d) ≤ 0.2 will be accepted. The frequency of items received is presented as a percentage. If the item gets approval from the expert, less than 75% will be discarded.

The third condition is that the defuzzification value of each item must exceed α-cut = 0.5. If the resulting A value is smaller than the α-cut value = 0.5, then the item will be rejected because it shows the approval of the experts in rejecting the item, and vice versa [46]. The defuzzification process is carried out by determining the average fuzzy number's average value (m_1, m_2, m_3) as described in equation (3).

$$A_{max} = \frac{1}{3} X \,(m_1 + m_{2+} m_3) \quad (3)$$

Analytical Hierarchy Process (AHP)

Saaty first developed AHP. It is an MCDM that is commonly used to help solve complex decision problems. This pairwise comparison makes it possible to find the relative weights of the criteria related to the main objective. This pairwise comparison followed the scale of importance suggested by [49], as shown in Table 4. Pairwise comparisons were performed in a matrix format to check the consistency of the ratings.

 DOI: 10.25077/josi.v20.n2.p125-135.2021

The steps below are used to operate the AHP calculation:

1. Identify the main objectives, criteria, and sub-criteria.
2. Determine the experts involved. This study involved six experts in planning rolling stock spare parts procurement.
3. Determine the local weight of the criteria and check the consistency of the expert's assessment using the Consistency Index (CI), Random Index (RI), and Consistency Ratio (CR). If the CR value is < 0.1, the assessment is acceptable, but if the results are otherwise, the pairwise comparison matrix must be modified by reassessing. The formula calculates the CR and CI are shown in equations (4) and (5), respectively:

$$CR = \frac{CI}{RI} = \frac{Consistency\ Index}{Random\ Index} \quad (4)$$

where:

$$CI = \frac{\lambda max - n}{n-1} \quad (5)$$

Technique for Others Preference by Similarity to Ideal Solutions (TOPSIS)

TOPSIS proposed by [50], the basic principle of this method is that the chosen alternative has the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. The positive ideal solution is to maximize the benefit criteria and minimize the cost criteria. The negative ideal solution is to maximize the cost criteria and minimize the benefit criteria. This technique can be applied if the criteria are numeric and have equivalent units. The TOPSIS procedure can be explained with the following stages:

Stage 2.1: Build a decision matrix

The decision matrix structure is formulated based on equation (6) as follows:

$$A = \begin{matrix} & C_1 & C_2 & C_n \\ A_1 & X_{11} & X_{12} & X_{1n} \\ A_2 & X_{21} & X_{22} & X_{2n} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ A_m & X_{m1} & X_{m2} & X_{mn} \end{matrix} \quad (6)$$

where A_i defines alternative supplier i, i = 1,…., *m*, C_i defines the selection criteria, X_{kj} defines the set of performance ratings of each alternative supplier against the selection criteria, k = 1,…, *m* and j = 1,…, *n*.

Stage 2.2: Construct a normalized decision matrix, defined as r_{kj}.

The normalized value (r_{kj}) is calculated using equation (7) as follow:

$$r_{kj}(x) = \frac{x_{kj}}{\sqrt{\sum_{k=1}^{n} x_{kj}^2}}, k = 1, \dots, n, j = 1, \dots, m. \quad (7)$$

Stage 2.3: Build a weighted normalized matrix

Normalized and weighted matrices are calculated using equation (8):

$$V_{kj}(x) = w_j \times r_{kj}(x),\ k = 1,..,m; j = 1,..,n \quad (8)$$

w_j is the weights from the *j*-th criteria, while r_{kj} is the normalized value.

Step 2.4: Determine the ideal positive point (A^+) and ideal negative point (A^-)

This step begins with first identifying the benefit and cost criteria from the list of available criteria. The benefit criteria category applies to the criteria where the largest V_{kj} value shows positive and better results. On the other hand, the cost criteria category applies if the smallest V_{kj} value shows positive and better results. Furthermore, the ideal positive point (A^+) and negative (A^-) are derived in equations (9) and (10).

$$\begin{aligned} A^+ &= \{V_1^+(x), V_2^+(x), \dots, V_j^+(x), \dots, V_m^+(x) \\ &= \{(\max_k v_{kj}(x) |\ j \in J_1), (\min_k v_{kj} |\ j \in J_2) \mid k = 1,..,n\} \end{aligned} \quad (9)$$

$$\begin{aligned} A^- &= \{V_1^-(x), V_2^-(x), \dots, V_j^-(x), \dots, V_m^-(x) \\ &= \{(\min_k v_{kj}(x) |\ j \in J_1), (\max_k v_{kj} |\ j \in J_2) \mid k = 1,..,n\} \end{aligned} \quad (10)$$

where J_1 is the criterion of benefit and J_2 is the criterion of cost.

Step 5: Calculate the distance of all alternatives from the ideal positive point (A^+) and the ideal negative point (A^-)

Calculates the distance between the ideal positive point (A^+) and the ideal negative point (A^-) between the alternative criteria using the separator value measured using the Euclidean distance as described in equations (11) and (12):

$$D_k^* = \sqrt{\sum_{j=1}^{m}[v_{kj}(x) - v_j^+(x)]^2}, k = 1, \dots, n \quad (11)$$

Table 4. The Scale of Factor Importance in Pairwise Comparison

The Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	Activity is strongly favored, and its dominance is demonstrated in practice
9	Extremely importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	An intermediate value	When compromise is needed

Table 5. Value of Random Consistency Index with *n* Criteria

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,51

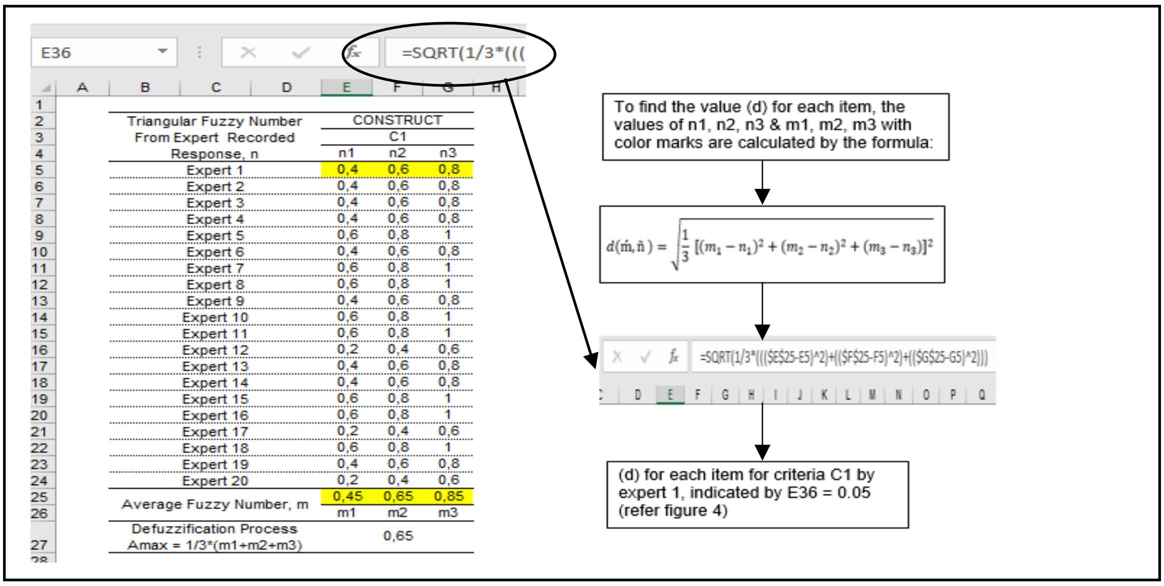

Figure 3. Illustration of Calculating the Fuzzy Number of Each Item (n_1, n_2, n_3) and the Average Value of the Fuzzy Number (m_1, m_2, m_3)

$$D_k^- = \sqrt{\sum_{j=1}^{m}[\, v_{kj}(x) - v_j^-(x)]^2}, k = 1,...., n \tag{12}$$

Step 6: Calculate the relative closeness of each alternative supplier to the ideal solution and ranking.

The relative proximity of the alternative supplier A_i to the ideal positive point (A^+) is derived in Equation 13.

$$C_k^* = \frac{D_k^-}{(D_k^* + D_k^-)}\,,\; k = 1, \dots, n \tag{13}$$

where the index value of C_k^* is between 0 and 1. Alternative suppliers who get the largest index value are suppliers who have good performance values.

RESULTS AND DISCUSSION

The FDM method in this study was used to filter alternative criteria. These criteria are screened based on the importance of a criterion and its relevance in evaluating suppliers in railway companies. The experts involved have more than 20 years of experience in railroad companies in rolling stock maintenance and master procurement issues, and 75% of them have bachelor's and master's education backgrounds. From the questionnaires given, 20 experts gave their feedback.

Next, the expert judgment using the Likert scale is converted into TFN numbers.The results of the calculation of the average TFN

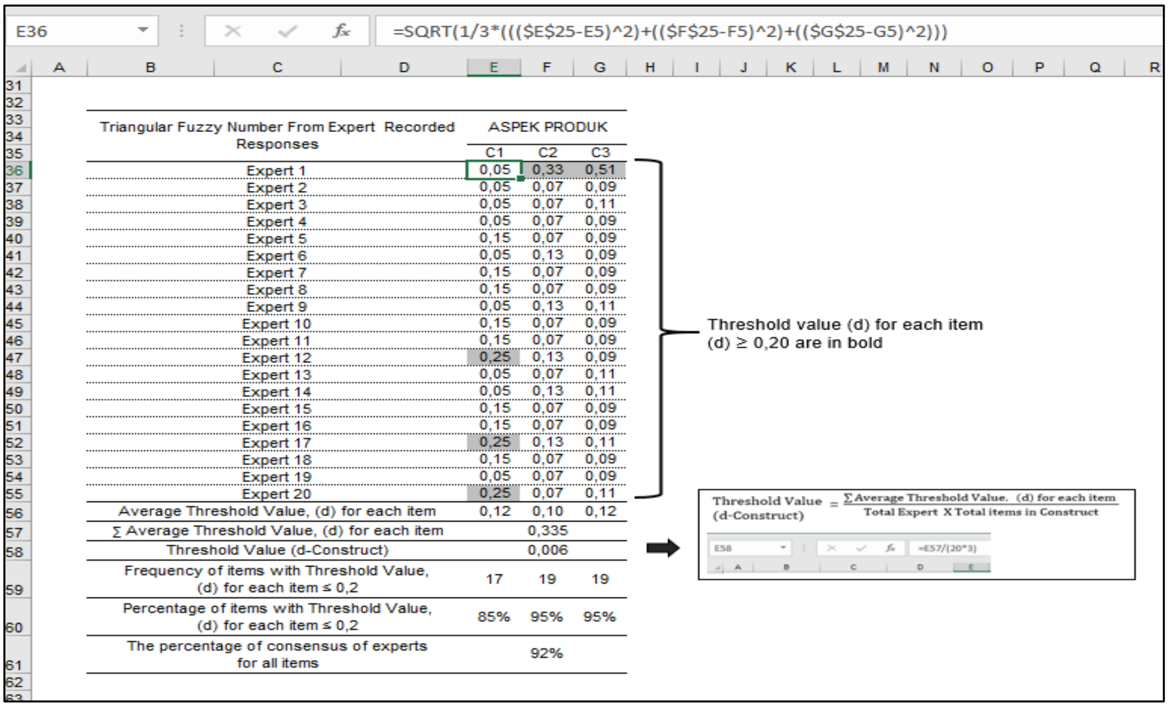

Figure 4. Illustration of *d*-construct Calculation and Determination of Expert Agreement Value

DOI: 10.25077/josi.v20.n2.p125-135.2021

Table 6. Summary of Expert Assessment for DFM

No.	Criteria	Fuzzy Evaluation				TFN Requirement		Conclusion
		m_1	*m_2*	*m_3*	Defuzzi-fication	*d-const*	% of Items with TV*)	
1	Product Price (C1)	0.45	0.65	0.85	0.65	0.12	85	Accepted
2	Product quality (C2)	0.53	0.73	0.93	0.73	0.10	95	Accepted
3	Insurance/Warranty (C3)	0.51	0.71	0.91	0.71	0.12	95	Accepted
4	Supplier Technical Capability (C4)	0.50	0.70	0.90	0.70	0.11	95	Accepted
5	Geographical Location (C5)	0.44	0.64	0.84	0.64	0.13	80	Accepted
6	Supplier Capacity (C6)	0.41	0.61	0.81	0.61	0.15	75	Rejected
7	Supplier Financial Capability (C7)	0.43	0.63	0.83	0.63	0.12	80	Accepted
8	Production capacity (C8)	0.45	0.65	0.85	0.65	0.14	85	Accepted
9	Electronic Transaction Capability (C9)	0.38	0.58	0.78	0.58	0.15	65	Rejected
10	Company Image (C10)	0.45	0.65	0.85	0.65	0.12	90	Accepted
11	Reputation and Position in the Industry (C11)	0.38	0.58	0.78	0.58	0.11	75	Rejected
12	Service (C12)	0.48	0.68	0.88	0.68	0.10	100	Accepted
13	Delivery (C13)	0.53	0.73	0.93	0.73	0.10	95	Accepted
14	Responsibility for Environmental and Social Issues (C14)	0.36	0.56	0.76	0.56	0.17	60	Rejected
15	Buyer-Supplier Relationship (C15)	0.47	0.67	0.87	0.67	0.12	95	Accepted
16	Payment Terms (C16)	0,34	0,54	0,74	0,54	0,16	65	Rejected
17	Communication with Suppliers (C17)	0,51	0,71	0,91	0,71	0,12	95	Accepted
18	Response Speed (C18)	0,48	0,68	0,88	0,68	0,13	90	Accepted
19	Supplier Flexibility (C19)	0,40	0,60	0,80	0,60	0,12	45	Rejected

*) TV = Threshold value

value for each criterion (m_1, m_2, m_3) and the results of the defuzzification of TFN numbers carried out using Microsoft Excel software are illustrated in Figure 3. Assessment of the threshold value requirements (*d*) for each criterion item, the threshold value d-constructs, and expert agreement on the value (*d*) of criteria items (≤ 0.2), which must be able to exceed 75% of the number of experts is illustrated in Figure 4. The results of the calculation of the three threshold conditions can be summarized in Table 6.

FDM was able to determine the importance of the multi-criteria collection in this study. Fuzzy set theory can assess a case in a gray decision range position making it easier for experts to determine their assessment. Finally, Table 6 shows 13 criteria were successfully selected and used to select rolling stock spare parts suppliers considering the required threshold value. While the other six criteria must be eliminated because they do not meet the threshold, the expert agrees that they do not have sufficient importance for the procurement of rolling stock spare parts in railway companies.

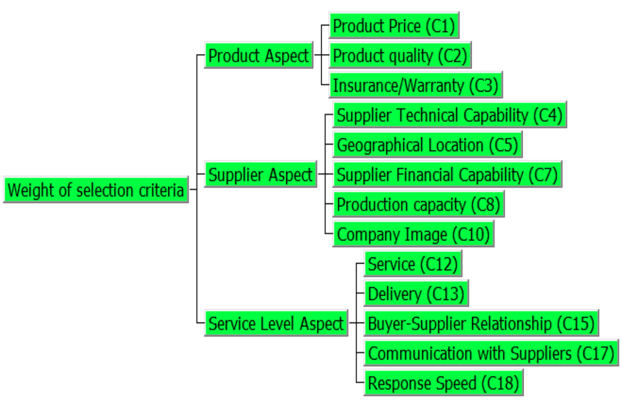

Figure 5. Hierarchy of Selection Criteria

Six experts were involved at this stage. They were asked to rate the importance of one criterion over other criteria. The thirteen selected criteria were grouped into three dimensions: product aspects, supplier aspects, and service level aspects. Figure 5 illustrates a hierarchy consisting of level one as a decision-making objective, level two as a criterion dimension, and level three as evaluation criteria.

This study uses the AHP method to determine the weight of a criterion. The results of the AHP analysis are shown in Table 7-10. Table 7 shows examples of pairwise comparison matrices by six experts for the criterion dimension. Table 8 displays the

Table 7. Pairwise Comparison of Criteria Dimensions

	Expert 1			Expert 2		
Criteria	**Prod.**	**Suppl.**	**Servl.**	**Prod.**	**Suppl.**	**Servl.**
Prod.	1	7	7	1	1	3
Suppl.	1/7	1	1/2	1	1	2
Servl.	1/7	2	1	1/3	1/2	1
	Expert 3					
	Prod.	**Supl.**	**Servl.**	**Prod.**	**Suppl.**	**Servl.**
Prod.	1	7	5	1	2	1
Suppl.	1/7	1	1/3	1/2	1	1/5
Servl.	1/5	3	1	1	5	1
	Expert 5			**Expert 6**		
	Prod.	**Supl.**	**Servl.**	**Prod.**	**Suppl.**	**Servl.**
Prod.	1	5	5	1	1/3	1
Suppl.	1/5	1	1	3	1	2
Servl.	1/5	1	1	1	1/2	1

Prd. = Product; Supl. = Supplier; Servl. = Service Level

Table 8. Aggregated Pairwise Comparison for Dimension of Criteria

	Product	Supplier	Service Level
Product	1	2,34	2,84
Supplier	0,43	1	0,71
Service Level	0,35	1,40	1

Table 9. Local weight of Criteria Dimension

Criteria Dimension	Weight
Product	0,560
Supplier	0,203
Service Level	0,238

geometric mean of the assessments of all experts in the previous table. Table 9 shows the final results of the criteria weights plus the results of testing the CR values that meet the consistency. Finally, Table 10 displays the local weight and global weight analysis results of all selection criteria.

Quality criteria are criteria that have the highest weight. The logical reason is that the quality of the supply goods must match the demands of the users. As explained earlier, the safety and reliability factors are the goals of maintenance. Thus the need for quality spare parts support for rolling stock maintenance. Quality can be defined as the supplier's ability to consistently meet product specifications such as material, dimension, design, or durability issues, thereby preventing product rejection due to these quality problems.

The weighting of the price criteria illustrates different views. From the calculation above, the price criterion is not the criterion that is the most important. Even the weight value is only 0.141, which means it is much smaller than the highest criteria (quality criteria). This result illustrates that the experts do not require the price criteria as the priority criteria. This is understandable because the prevailing procurement system requires all prospective suppliers to offer prices below the ceiling funds. Therefore, the findings of this data will significantly influence the selection of suppliers because the previous selection model used price criteria as a determinant of supplier selection.

The spare parts procurement method uses the direct selection method where the procurement planner has determined the potential suppliers. The procurement stages follow the rules that apply in the company. Announcements and invitations are given to prospective bidders. They are asked to attend the procurement explanation meeting, where at this stage, the procurement employee provides information on administrative requirements, technical requirements, price requirements, and other matters related to procurement activities. Next, prospective suppliers are asked to submit Bidding Documents in sealed envelopes containing administrative documents, technical documents, and price documents, and then the procurement employee evaluates this bid document.

TOPSIS starts from building an assessment matrix. The assessment matrix is determined based on the evaluation results of the Bid Documents from alternative suppliers. Each alternative supplier is assessed for its performance based on 13 selection criteria that have been previously determined by FDM and AHP calculations. Furthermore, the assessment results are calculated in a weighted manner with the weighted value of each criterion. TOPSIS works by checking the value of the shortest distance of alternative suppliers to the ideal positive point, and at the same time, having the farthest distance from the negative ideal solution. The positive ideal solution is to maximize the benefit criteria and minimize the cost criteria. The negative ideal solution is to maximize the cost criteria and minimize the benefit criteria.

Table 12 shows the normalized decision matrix for selecting alternatives for suppliers of rolling stock spare parts based on the evaluation results of the Bidding Documents shown in Table 11. The relative weights shown in Table 12 (second row) are the weights of the pairwise comparison results to determine the importance of a criterion. Table 13 shows the Weighted normalized decision matrix accompanied by the calculation of the distance of alternative suppliers to the positive ideal solution (D_k^+) and negative ideal solution (D_k^-). Table 14 shows the results of selecting alternative suppliers based on the relative closeness of the alternative to the ideal solution. Supplier A has the highest relative closeness value (0.591), which means that Supplier A was ranked first. Followed by Supplier B with a value of 0.545, the lowest was Supplier C with 0.282.

The integration of the FDM-AHP-TOPSIS method results in selected suppliers according to the needs of the railway company based on relevant evaluation criteria and accompanied by their weighting. The results of supplier selection using multi-criteria

Table 10. Global Weight of Supplier Selection Criteria

No.	Dimension		Criteria		Global Weight
	Type	**Local Weight**	**Type**	**Local Weight**	
1.	Product	0,562	Product Price (C1)	0,141	0,079
			Product quality (C2)	0,661	0,370
			Insurance/Warranty (C3)	0,199	0,111
2.	Supplier	0,202	Supplier Technical Capability (C4)	0,370	0,075
			Geographical Location (C5)	0,072	0,015
			Supplier Financial Capability (C7)	0,188	0,038
			Production capacity (C8)	0,239	0,048
			Company Image (C10)	0,131	0,027
2.	Supplier	0,202	Service (C12)	0,189	0,045
			Delivery (C13)	0,254	0,060
			Buyer-Supplier Relationship (C15)	0,084	0,020
			Communication with Suppliers (C17)	0,176	0,042
			Response Speed (C18)	0,297	0,070

DOI: 10.25077/josi.v20.n2.p125-135.2021

Table 11. Decision Matrix for Bidding Evaluation

Supplier *i*	**C1**	**C2**	**C3**	**C4**	**C5**	**C7**	**C8**	**C10**	**C12**	**C13**	**C15**	**C17**	**C18**
Supplier A	197.708.100	4	4	4	22	4	3	3	4	45	4	5	5
Supplier B	197.731.850	4	3	5	155	1	2	3	4	60	4	5	5
Supplier C	195.320.572	4	3	5	781	5	3	2	4	60	4	5	5

Table 12. Decision Matrix for Selection of Alternatives for Rolling Stock Spare Part Suppliers

	C1	**C2**	**C3**	**C4**	**C5**	**C7**	**C8**	**C10**	**C12**	**C13**	**C15**	**C17**	**C18**
Weight Alternative	0,079	0,37	0,111	0,075	0,015	0,038	0,048	0,027	0,045	0,060	0,020	0,042	0,070
Supplier A	0,580	0,577	0,686	0,492	0,028	0,617	0,640	0,640	0,577	0,469	0,577	0,577	0,577
Supplier B	0,580	0,577	0,514	0,615	0,195	0,154	0,426	0,640	0,577	0,625	0,577	0,577	0,577
Supplier C	0,573	0,577	0,514	0,615	0,980	0,772	0,640	0,426	0,577	0,625	0,577	0,577	0,577

Table 13. Weighted Normalized Decision Matrix

	C1	**C2**	**C3**	**C4**	**C5**	**C7**	**C8**	**C10**	**C12**	**C13**	**C15**	**C17**	**C18**	D_k^*	D_k^-
Supplier A	0,046	0,214	0,076	0,037	0,0004	0,023	0,031	0,017	0,026	0,028	0,012	0,024	0,040	0,0199	0,0288
Supplier B	0,046	0,214	0,057	0,046	0,003	0,006	0,020	0,017	0,026	0,037	0,012	0,024	0,040	0,0237	0,0284
Supplier C	0,045	0,214	0,057	0,046	0,015	0,029	0,031	0,012	0,026	0,037	0,012	0,024	0,040	0,0352	0,0138

decisions give different results when compared to the current supplier selection method. The current selection method only evaluates price comparisons between suppliers, so supplier C is the winning supplier. However, this study shows different results where supplier C is not selected even has the lowest value. These results support the initial premise that suppliers who excel in one aspect of the criteria can potentially be weak against other aspects of the criteria, thus potentially selecting suppliers who have poor performance.

CONCLUSIONS

This study discusses procurement in the rail transportation industry. The findings and discussions described in the previous section contributed to the achievement of the objectives of this study. A total of 13 selection criteria have been selected and simultaneously eliminated six other criteria. According to the results of expert consensus, the criteria that have been selected are relevant to railway companies, especially those related to the procurement of rolling stock spare parts. Furthermore, the weighting results illustrate the priority level of each of these criteria, where the quality criterion is the most important, and the location criterion is the least important.

The evaluation model for the supplier of rolling stock spare parts illustrated in the previous section illustrates the role of the TOPSIS method in evaluating the selection of rolling stock spare parts suppliers. TOPSIS calculation results in evaluating alternative suppliers based on multiple weighted criteria have supported the initial premise that the selected supplier must have advantages in several aspects of the assessment to provide a broader view of the potential of each supplier. Based on the TOPSIS calculation, Supplier A is the selected supplier with the highest relative closeness value of 0.591, followed by Supplier B in the second position with a value of 0.545, and Supplier C as the last rank with a value of 0.282.

Table 14. Weighted Normalized Decision Matrix

Alternative	C_k^*	**Rank**
Supplier A	0,591	1
Supplier B	0,545	2
Supplier C	0,282	3

Future research on the selection of rail suppliers and rail logistics is still wide open. For example, the idea of calculating the company's loss for suppliers who do not meet the criteria requirements optimally can still be developed. Of course, if this loss analysis is integrated, it will produce a more comprehensive supplier evaluation analysis. In addition, the analysis of the inventory management of the railway spare parts warehouse can still be explored and developed by calculating the need for the procurement of railway spare parts by considering the pattern of replacement parts and logistics efficiency.

REFERENCES

[1] L. Li, M. Liu, W. Shen, and G. Cheng, "An improved stochastic programming model for supply chain planning of MRO spare parts," Appl. Math. Model., vol. 47, pp. 189–207, 2017, doi: 10.1016/j.apm.2017.03.031.

[2] Bierer, U. Götze, S. Köhler, and R. Lindner, “Control and Evaluation Concept for Smart MRO Approaches,” Procedia CIRP, vol. 40, pp. 699–704, 2016, doi: 10.1016/j.procir.2016.01.157.

[3] M. Seitz, T. Lucht, C. Keller, C. Ludwig, R. Strobelt, and P. Nyhuis, "Improving MRO order processing by means of advanced technological diagnostics and data mining approaches," Procedia Manuf., vol. 43, pp. 688–695, 2020, doi: 10.1016/j.promfg.2020.02.121.

[4] D. Dinis, A. Barbosa-Póvoa, and Â. P. Teixeira, "A supporting framework for maintenance capacity planning and scheduling: Development and application in the aircraft MRO industry," Int. J. Prod. Econ., vol. 218, pp. 1–15, 2019, doi: 10.1016/j.ijpe.2019.04.029.

[5] M. Le Sueur and B. G. Dale, "The procurement of maintenance, repair, and operating supplies: A study of the

key problems," Eur. J. Purch. Supply Manag., vol. 4, no. 4, pp. 247–255, 1998, doi: 10.1016/S0969-7012(98)00016-1.

[6] M. Basak, "Achieving E-procurement Benefits in an Aviation MRO Environment," Oper. Supply Chain Manag. An Int. J., vol. 9, no. 1, pp. 50–60, 2015, doi: 10.31387/oscm0230160.

[7] H. H. Turan, M. Atmis, F. Kosanoglu, S. Elsawah, and M. J. Ryan, "A risk-averse simulation-based approach for a joint optimization of workforce capacity, spare part stocks and scheduling priorities in maintenance planning," Reliab. Eng. Syst. Saf., vol. 204, no. March, p. 107199, 2020, doi: 10.1016/j.ress.2020.107199.

[8] S. Van Der Auweraer and R. Boute, "International Journal of Production Economics Forecasting spare part demand using service maintenance information," Intern. J. Prod. Econ., vol. 213, no. April 2018, pp. 138–149, 2019, doi: 10.1016/j.ijpe.2019.03.015.

[9] S. Van Der Auweraer, R. N. Boute, and A. A. Syntetos, "Forecasting spare part demand with installed base information : A review," Int. J. Forecast., vol. 35, no. 1, pp. 181–196, 2019, doi: 10.1016/j.ijforecast.2018.09.002.

[10] S. Zhu, W. Van Jaarsveld, and R. Dekker, "Spare parts inventory control based on maintenance planning," Reliab. Eng. Syst. Saf., vol. 193, no. January 2019, p. 106600, 2020, doi: 10.1016/j.ress.2019.106600.

[11] C. N. Liao and H. P. Kao, "Supplier selection model using Taguchi loss function, analytical hierarchy process and multi-choice goal programming," Comput. Ind. Eng., vol. 58, no. 4, pp. 571–577, 2010, doi: 10.1016/j.cie.2009.12.004

[12] S. Biruk, P. Jaskowski, and A. Czarnigowska, "Fuzzy AHP for selecting suppliers of construction materials," IOP Conf. Ser. Mater. Sci. Eng., vol. 603, no. 3, 2019, doi: 10.1088/1757-899X/603/3/032093.

[13] R. Kumar, S. S. Padhi, and A. Sarkar, "Supplier selection of an Indian heavy locomotive manufacturer: An integrated approach using Taguchi loss function, TOPSIS, and AHP," IIMB Manag. Rev., vol. 31, no. 1, pp. 78–90, 2019, doi: 10.1016/j.iimb.2018.08.008.

[14] A. M. Li, G. Q. Wang, and J. J. Zhang, "The research on railway construction project materials supplier selection model," Adv. Mater. Res., vol. 919–921, pp. 1503–1508, 2014, doi: 10.4028/www.scientific.net/AMR.919-921.1503.

[15] O. Kilincci and S. A. Onal, "Fuzzy AHP approach for supplier selection in a washing machine company," Expert Syst. Appl., vol. 38, no. 8, pp. 9656–9664, 2011, doi: 10.1016/j.eswa.2011.01.159.

[16] K. C. Lam, R. Tao, and M. C. K. Lam, "A material supplier selection model for property developers using Fuzzy Principal Component Analysis," Autom. Constr., vol. 19, no. 5, pp. 608–618, 2010, doi: 10.1016/j.autcon.2010.02.007.

[17] R. Wang, X. Li, and C. Li, "Optimal selection of sustainable battery supplier for battery-swapping station based on Triangular fuzzy entropy -MULTIMOORA method," J. Energy Storage, vol. 34, no. October, p. 102013, 2021, doi: 10.1016/j.est.2020.102013.

[18] A. Kumar, M. A. Kaviani, A. Hafezalkotob, and E. K. Zavadskas, "Evaluating innovation capabilities of real estate firms: a combined fuzzy Delphi and DEMATEL approach," Int. J. Strateg. Prop. Manag., vol. 21, no. 4, pp. 401–416, 2017, doi: 10.3846/1648715X.2017.1409291.

[19] G. W. Dickson, "An Analysis Of Vendor Selection Systems And Decisions," J. Purch., vol. 2, no. 1, pp. 5–17, 1966, doi: 10.1111/j.1745-493X.1966.tb00818.x.

[20] B. Luzon and S. M. El-Sayegh, "Evaluating supplier selection criteria for oil and gas projects in the UAE using AHP and Delphi," Int. J. Constr. Manag., vol. 16, no. 2, pp. 175–183, 2016, doi: 10.1080/15623599.2016.1146112.

[21] G. Polat and E. Eray, "An Integrated Approach using AHP-ER to Supplier Selection in Railway Projects," Procedia Eng., vol. 123, pp. 415–422, 2015, doi: 10.1016/j.proeng.2015.10.068.

[22] M. Marzouk and M. Sabbah, "AHP-TOPSIS social sustainability approach for selecting supplier in construction supply chain," Clean. Environ. Syst., vol. 2, no. March, p. 100034, 2021, doi: 10.1016/j.cesys.2021.100034

[23] M. Oroojeni, M. Javad, M. Darvishi, A. Oroojeni, and M. Javad, "Green supplier selection for the steel industry using BWM and fuzzy TOPSIS : A case study of Khouzestan steel company," Sustain. Futur., vol. 2, no. October 2019, p. 100012, 2020, doi: 10.1016/j.sftr.2020.100012.

[24] H. Selcuk and A. Selcuk, "Modified two-phase fuzzy goal programming integrated with IF-TOPSIS for green supplier selection," Appl. Soft Comput. J., vol. 93, p. 106371, 2020, doi: 10.1016/j.asoc.2020.106371.

[25] I. Sultana, I. Ahmed, and A. Azeem, "An integrated approach for multiple criteria supplier selection combining Fuzzy Delphi, Fuzzy AHP and Fuzzy TOPSIS," J. Intell. Fuzzy Syst., vol. 29, no. 4, pp. 1273–1287, 2015, doi: 10.3233/IFS-141216.

[26] R. K. Mavi, "Green supplier selection: A fuzzy AHP and fuzzy ARAS approach," Int. J. Serv. Oper. Manag., vol. 22, no. 2, pp. 165–188, 2015, doi: 10.1504/IJSOM.2015.071528.

[27] S. Kumar, S. Kumar, and A. G. Barman, "Supplier selection using fuzzy TOPSIS multi criteria model for a small scale steel manufacturing unit," Procedia Comput. Sci., vol. 133, pp. 905–912, 2018, doi: 10.1016/j.procs.2018.07.097.

[28] S. Sharma and S. Balan, "An integrative supplier selection model using Taguchi loss function, TOPSIS and multi criteria goal programming," J. Intell. Manuf., vol. 24, no. 6, pp. 1123–1130, 2013, doi: 10.1007/s10845-012-0640-y.

[29] Y. Zhang, X. Liu, and H. Bo, "An integrated AHP-entropy approach for spare parts supplier evaluation and order quantity allocation," Adv. Mater. Res., vol. 452–453, pp. 768–772, 2012, doi: 10.4028/www.scientific.net/AMR.452-453.768.

[30] A. K. Kar, "A hybrid group decision support system for supplier selection using analytic hierarchy process, fuzzy set theory and neural network," J. Comput. Sci., vol. 6, pp. 23–33, 2015, doi: 10.1016/j.jocs.2014.11.002.

[31] T. C. Wen, K. H. Chang, and H. H. Lai, "Integrating the 2-tuple linguistic representation and soft set to solve supplier selection problems with incomplete information," Eng. Appl. Artif. Intell., vol. 87, no. August 2019, p. 103248, 2020, doi: 10.1016/j.engappai.2019.103248.

[32] S. Sarkar, D. K. Pratihar, and B. Sarkar, "An integrated fuzzy multiple criteria supplier selection approach and its

 DOI: 10.25077/josi.v20.n2.p125-135.2021

application in a welding company," J. Manuf. Syst., vol. 46, pp. 163–178, 2018, doi: 10.1016/j.jmsy.2017.12.004.

[33] A. E. Cengiz, O. Aytekin, I. Ozdemir, H. Kusan, and A. Cabuk, "A Multi-criteria Decision Model for Construction Material Supplier Selection," Procedia Eng., vol. 196, no. June, pp. 294–301, 2017, doi: 10.1016/j.proeng.2017.07.202.

[34] M. Tavana, A. Fallahpour, D. Di Caprio, and F. J. Santos-Arteaga, "A hybrid intelligent fuzzy predictive model with simulation for supplier evaluation and selection," Expert Syst. Appl., vol. 61, pp. 129–144, 2016, doi: 10.1016/j.eswa.2016.05.027.

[35] E. Plebankiewicz and D. Kubek, "Multicriteria Selection of the Building Material Supplier Using AHP and Fuzzy AHP," J. Constr. Eng. Manag., vol. 142, no. 1, p. 04015057, 2016, doi: 10.1061/(ASCE)CO.1943-7862.0001033.

[36] G. N. Yücenur, Ö. Vayvay, and N. Ç. Demirel, "Supplier selection problem in global supply chains by AHP and ANP approaches under fuzzy environment," Int. J. Adv. Manuf. Technol., vol. 56, no. 5–8, pp. 823–833, 2011, doi: 10.1007/s00170-011-3220-y.

[37] R. Gupta, A. Sachdeva, and A. Bhardwaj, "Selection of 3pl Service Provider using Integrated Fuzzy Delphi and Fuzzy TOPSIS," Lect. Notes Eng. Comput. Sci., vol. 2187, no. 1, pp. 1092–1097, 2010.

[38] Y. K. Fu, "An integrated approach to catering supplier selection using AHP-ARAS-MCGP methodology," J. Air Transp. Manag., vol. 75, no. July 2018, pp. 164–169, 2019, doi: 10.1016/j.jairtraman.2019.01.011

[39] M. Zeydan, C. Çolpan, and C. Çobanoğlu, "A combined methodology for supplier selection and performance evaluation," Expert Syst. Appl., vol. 38, no. 3, pp. 2741–2751, 2011, doi: 10.1016/j.eswa.2010.08.064.

[40] A. Ishikawa, M. Amagasa, T. Shiga, G. Tomizawa, R. Tatsuta, and H. Mieno, "The max-min Delphi method and fuzzy Delphi method via fuzzy integration," Fuzzy Sets Syst., vol. 55, no. 3, pp. 241–253, 1993, doi: 10.1016/0165-0114(93)90251-C.

[41] L. A. Zadeh, "Fuzzy sets," Inf. Control, vol. 8, no. 3, pp. 338–353, 1965, doi: 10.1016/S0019-9958(65)90241-X. 10.1016/S0019-9958(65)90241-X

[42] S. Ebrahimi and R. Bridgelall, "A fuzzy Delphi analytic hierarchy model to rank factors influencing public transit mode choice: A case study," Res. Transp. Bus. Manag., no. May, p. 100496, 2020, doi: 10.1016/j.rtbm.2020.10049696.

[43] T. Y. Pham, H. M. Ma, and G. T. Yeo, "Application of Fuzzy Delphi TOPSIS to Locate Logistics Centers in Vietnam: The Logisticians' Perspective," Asian J. Shipp. Logist., vol. 33, no. 4, pp. 211–219, 2017, doi: 10.1016/j.ajsl.2017.12.004.

[44] C. Lin, "Application of fuzzy Delphi method (FDM) and fuzzy analytic hierarchy process (FAHP) to criteria weights for fashion design scheme evaluation," Int. J. Cloth. Sci. Technol., vol. 25, no. 3, pp. 171–183, 2013, doi: 10.1108/09556221311300192.

[45] H. Jones and B. C. Twiss, "Forecasting technology for planning decisions," 1978. doi: 10.1007/978-1-349-03134-4.

[46] N. K. Ismail, S. Mohamed, and M. I. Hamzah, "The Application of the Fuzzy Delphi Technique to the Required Aspect of Parental Involvement in the Effort to Inculcate Positive Attitude among Preschool Children," Creat. Educ., vol. 10, no. 12, pp. 2907–2921, 2019, doi: 10.4236/ce.2019.1012216.

[47] P. L. Chang, C. W. Hsu, and P. C. Chang, "Fuzzy Delphi method for evaluating hydrogen production technologies," Int. J. Hydrogen Energy, vol. 36, no. 21, pp. 14172–14179, 2011, doi: 10.1016/j.ijhydene.2011.05.045.

[48] S. K. Manakandan, R. Ismai, M. R. M. Jamil, and P. Ragunath, "Pesticide applicators questionnaire content validation: A fuzzy delphi method," Med. J. Malaysia, vol. 72, no. 4, pp. 228–235, 2017.

[49] T. L. Saaty, "How to make a decision: The analytic hierarchy process," Eur. J. Oper. Res., vol. 48, no. 1, pp. 9–26, 1990, doi: 10.1016/0377-2217(90)90057-I.

[50] C. L. Hwang and K. Yoon, "Multiple Attributes Decision Making Methods and Applications, spring," New York, 1981. doi: 10.1007/978-3-642-48318-9_3.