Received 15 June 2022
Revised 6 September 2022
12 December 2022
21 February 2023
Accepted 28 April 2023

Supplier selection criteria using analytical hierarchy process (AHP)-based approach: a study in refractory materials manufacturers

Gu-Hong Lin and Cheng-An Chuang
Department of Industrial Engineering and Management, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan
Cheng Ling Tan
Graduate School of Business, Universiti Sains Malaysia, Pulau Pinang, Malaysia and Department of Information Technology and Management, Daffodil International University, Dhaka, Bangladesh
Sook Fern Yeo
Faculty of Business, Multimedia University, Melaka, Malaysia and Department of Business Administration, Daffodil International University, Dhaka, Bangladesh, and
Fan-Yi Wu
Department of Industrial Engineering and Management, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan

Abstract

Purpose – Refractory materials are now used in all major industries that demand high-temperature resistance, including petrochemicals, steel, cement and aviation. Businesses must decrease operating costs, enhance product technology, sell well and manage corporate risks in decision-making, notably supplier selection, to be more competitive. The study aims to determine the key criteria and factors of supplier selection and to evaluate the importance of the key factor of the supplier selection criteria for the refractory materials manufacturers in Taiwan.

Design/methodology/approach – Analytical hierarchy process (AHP) is used to rank these factors for the decision maker. The AHP method is suitable for verifying refractory supplier selection criteria and providing references. The weighted loss scores for each supplier are then determined using the relative importance as the weights. Supplier selection criteria are ranked using their aggregate weighted loss scores. The provider with the lowest loss score should be chosen.

Findings – Product quality is the most significant of the five criteria: product quality, production technology, logistics capacity, service capability and supplier background. Professionalism is the most significant aspect of product quality, whereas equipment and capacity are vital in manufacturing techniques. The studies also show that the delivery rate is essential for logistics and service capabilities.

Practical implications – This research has important implications for refractory suppliers in promptly fine-tuning the production and service to enhance customer satisfaction, which is key to business sustainability.

Originality/value – The application of an AHP technique to a real-world industrial issue is what makes this research unique. This research addressed one of the most critical topics in supply chain operations by offering better judgement for supplier selection via the use of suitable quantitative methodologies.

Keywords Refractory, Supplier selection, Analytic hierarchy process, Logistics, Product quality

Paper type Research paper

1. Introduction

The sudden outbreak and surge of the global COVID-19 pandemic have caught many nations off guard. Given the current international economic and trade situation, the global economic

Industrial Management & Data Systems
Vol. 123 No. 6, 2023
pp. 1814-1839

0263-5577
DOI 10.1108/IMDS-06-2022-0370

environment is volatile and the economy is in a continuous downturn. In addition, the advancement of information technology has made information more transparent and globalised. Therefore, enterprises are now facing an era of fierce market competition. In order to effectively enhance competitiveness, enterprises need to not only reduce operating costs, improve and innovate product technology and promote products effectively, but they also cannot neglect the need to reduce and mitigate corporate risks.

Refractory materials are the basic materials for high-temperature technology services, especially closely related to the development of the high-temperature smelting industry. With the continuous development and changes in society, the demand for refractory materials has been growing and has now moved from primary raw materials products in the primary heavy industry to all critical economic sectors requiring high-temperature resistance, such as petrochemicals, steel, cement and aerospace. The refractory industry is booming, and the products are gradually developing from ordinary refractories to high-end quality and new advanced directions. There is a wide range and selection of refractory products available in the market, including high alumina bricks, magnesium bricks, magnesium carbon bricks, sprayed refractories, air-hardened refractory clay, ramming refractory, blast furnace plugging clay, torpedo car refractory, glass kiln refractory, cement rotary kiln refractory, incinerator refractory, etc. They are widely used in the machinery industry, construction industry, consumer goods industry, etc.

Looking back at the past literature, it is not difficult to find that there have been studies on supplier selection factors. Still, there are no relevant studies on supplier selection for refractory manufacturers. Supplier selection is regarded as one of the most important in procurement. As a result, supplier selection is a hotly disputed and researched issue in academic literature and practice (Schotanus *et al.*, 2021). Refractory manufacturers' suppliers have been studied in the past; however, there has been no relevant research on supplier selection for refractory manufacturers. As someone who works in Taiwan's refractory business, the researchers can attest that there is no specific legislation or set of criteria governing suppliers' selection. Given that Taiwan is the second largest exporter of refractory materials in the world, and the majority of Taiwan's refractory materials are exported to India, the Philippines and Vietnam (Volza, 2022). Hence, the research was conducted in the Taiwan region.

This study is based on the important condition that price is not considered. Refractory materials are dangerous due to high-temperature use. There is no convention that "whoever has the lower price automatically wins the bid". Furthermore, minimum safety quality must be achieved. Based on the above research background and motivation, it is clear that finding reliable and trustworthy suppliers is an important part of meeting high expectations and achieving strategic supply chain management. This study found numerous literature gaps in the area of the selection of suppliers. Previous studies on the refractory materials industry were mainly looking at topics related to quality assurance/quality control systems (Álvarez and García, 2021) as well as supply chain management in general (Kharisma and Ernawati, 2021). Additionally, very few studies conducted in the supplier selection area which are very limited to certain industries, such as the semiconductor industry and electrical and electronics industry (Vijayakumar *et al.*, 2019). Besides, previous studies related to the decision-making approach commonly apply Fuzzy DEMATEL, and Fuzzy Delphi methods, which were the preference among the scholars to identify the inter-relationship among multiple criteria (Valahzaghard *et al.*, 2011). Due to a limited reference for the companies in the refractory industry to review their existing supplier selection options and to have an in-depth understanding of the factors that influence procurement and supplier selection through a multicriteria decision-making approach, AHP is viewed as an effective approach applied in this study. The AHP-based approach can help decision-makers to evaluate and compare suppliers based on multiple criteria. The AHP approach also enables decision-makers to set priorities and identify the most critical factors in supplier selection. Using pairwise comparisons in the AHP approach can also help decision-makers to consider the trade-offs between the different criteria and make more informed decisions. Against this backdrop, research questions (RQ) are formulated as follows.

RQ1. What are the key criteria and factors appropriate for the refractory industry's supplier selection?

RQ2. What are the important factors in determining the supplier selection criteria?

In order to address the above-mentioned research questions, the objectives of this research are to (1) determine the criteria and factors of supplier selection for refractory manufacturers; (2) evaluate the importance of the factors influencing supplier selection.

This paper is divided into eight sections. After brief introductory paragraphs, Section 2 provides a detailed study of published works on supplier selection during the previous decades. The following sections outline focuses on AHP-based methods to supplier selection, while Section 4 provides the methodology of the study. The results from the AHP analysis is presented in Section 5. Lastly, this study is concluded with a discussion and several implications in Section 6 and Section 7.

2. Literature review: supplier selection

Supplier selection has long been regarded as a critical issue in supply chain management. Supplier selection models are very common, and these scales may be used to identify which vendors to choose in order to accomplish the Logistics 4.0 objectives (Dallasega *et al.* (2022). Wetzstein *et al.* (2016) point out that supplier selection is becoming increasingly important as supply chains become more global, more operations are outsourced and more criteria make choosing suppliers more difficult. Supplier selection has traditionally been based on suppliers meeting quality and standards such as delivery time; however, as policies and people's environmental awareness grow, sustainability becomes an important requirement in the supply chain, so green supplier selection will include more low-carbon economic indicators (Beiki *et al.*, 2021). Supplier selection has garnered considerable attention in the literature since it is seen as one of the primary success drivers for a business. Selecting the best suppliers for various product items demands a good issue formulation and strategy (Saputro *et al.*, 2022). It is of great significance if proper suppliers can be effectively selected during the procurement process. Managers may improve the quality of corporate shipments by selecting the right suppliers (Nemati *et al.*, 2020). A supplier selection assessment framework for small and medium-sized businesses was developed, as well as an enhanced approach to ensure a sustainable supplier selection process (Tong *et al.*, 2022). Dickson (1966) was the first to propose supplier selection. In a study published in 1966, he listed more than 50 criteria for supplier selection and specified 23 important indicators for supplier selection. Specifically, he identified geographical location, quality, delivery time and rate, past performance, past revenue, financial situation, industry reputation, business relationship, past impressions, management and organisational structure, management control measures, production equipment and capacity, production technology and capability, packaging capability, quality assurance and claims policy, pricing, customer service procedures, communication system, maintenance service, attitude, training assistance, labour relations, interaction and coordination, among other criteria. Dickson (1966) also pointed out that quality, delivery, on-time delivery rates and past performance are the three most critical factors. Since then, most of the studies on supplier selection have been based on these 23 factors.

It was not until the 1990s that quality and service attracted attention. Wilson (1994) compared the evolution of supplier selection criteria from 1974 to 1994. He found that the relationship between suppliers and manufacturers has gradually changed from competitive to cooperative. The change in production strategies has caused the most important factor in supplier selection and has gradually replaced delivery time with quality as the main determining factor. Supplier selection is a critical strategic decision-making process for the acquisition of essential goods or raw materials (Kumar *et al.*, 2022). Correspondingly, Mina *et al.* (2021) stress that it is important to have dependable methods for selecting suppliers, as this choice influences the prices. Other factors, such as on-time delivery and product quality and risk and the like, must be considered when deciding on which suppliers to choose.

This study also collects relevant research from domestic and foreign scholars in the past 20 years and is divided into the following chronological order. In the early period, most of the studies regarding supplier selection were conducted by foreign researchers. For example, at the end of the 20th century, Swift (1995) conducted a quantitative questionnaire survey for single-supplier and multi-supplier companies and found five important factors for supplier selection: product-related attributes, dependability, experience, price and accessibility. A study by Choi and Hartley (1996) examined the factors considered by the US automotive industry when selecting suppliers and performed a qualitative analysis by combining previously unconsidered factors and summarising eight dimensions such as consistency and affiliation and 26 other factors like flexibility and reliability and technical capability. Pearson and Ellram (1995) compared suppliers of electronic companies in terms of quality, technological foresight, technical capability, design capability, time-to-market, manufacturing process, organisational structure, cost, economic performance, management philosophy compatibility, location and manufacturing plant conditions. It was determined that supplier quality was the most important item in supplier evaluation, followed by cost, technical capability and design capability. Patton (1996) proposed seven supplier evaluation criteria such as quality, price, delivery, equipment and technology, sales support, ordering and financial status in a study that explored the supplier selection decisions of industrial buyers using an artificial judgment model.

In the early 21st century, Choy *et al.* (2002) conducted a benchmarking study on smart supplier management for suppliers in outsourced manufacturing. They concluded that supplier selection should include quality, organisation and culture in addition to the price. Dulmin and Mininno (2003), in a study on the selection of transportation equipment suppliers, proposed seven evaluation criteria, including cost reduction capability, quality system, common design and technology capability, new product development timeline, product design schedule and design change schedule capability. The evaluation criteria where Katsikeas *et al.* (2004) explored the impact of supplier performance on distributor performance for IT products, using competitive price, technical capability, reliability and service as criteria for evaluating the performance of IT product suppliers. The underlying fuzzy set theory is used to manage the fuzziness of customers' views, since qualities are often communicated via language preferences (Yeo *et al.*, 2022). Chen *et al.* (2006) utilised the Fuzzy TOPSIS method to handle the ranking of qualitative and quantitative criteria and to select suitable and effective suppliers. Chan and Kumar (2007) utilised the Fuzzy Extended Analytic Hierarchy Process (FEAHP) to assist business decision-makers in making comparative judgments by utilising triangular fuzzy numbers and the FEAHP method to determine the best supplier based on fixed asset scale, financial situation, cost, management, operational capability, information technology capability, service quality, service diversity, service scope, information sharing and trust, partnership and business reputation. Wadhwa and Ravindran (2007) studied the selection criteria of computer outsourcing suppliers in New York and suggested that quality, delivery and price are the most important factors in selecting suppliers. Alvandi *et al.* (2011) used the Delphi method, fuzzy hierarchical analysis and sliced inverse regression to collate and summarise the top 10 criteria and 27 sub-components of suppliers in terms of quality, delivery, past performance, financial situation, cost, service, flexibility, trust, equipment and location.

In summary, this study found that for supplier selection, both domestic and foreign researchers chose to focus on quantitative research methods and mostly utilised AHP analysis. It can thus be observed that the hierarchical analysis method is more suitable for this study. Therefore, the hierarchical analysis method will be applied to this study. In terms of supplier selection criteria, researchers tend to use the 23 supplier selection criteria proposed by Dickson (1966) as the basis and modify them according to their industry characteristics or the actual needs of an enterprise and then use AHP analysis to obtain the final supplier selection criteria applicable to their industry or a company. Therefore, this study will also draw up supplier selection factors for refractory suppliers, taking into account relevant research conducted by previous researchers, such as the 23 evaluation criteria proposed by Dickson (1966) and based on the subject of this study. An expert interview will finalise the relevant criteria to be used in the questionnaire design subsequently.

3. Analytical hierarchy process (AHP)

The Analytical Hierarchy Process (AHP) was proposed by Professor Thomas L. Saaty of the University of Pittsburgh in 1971. The analytical hierarchy process (AHP), which is based on mathematics and psychology, is a systematic method for organising and evaluating complicated judgments in the theory of decision making. The methodology was developed due to a study conducted in response to the Department of Defense's contingency planning issues at the time. In 1972, the methodology was applied to a study by the National Science Foundation to examine industry contribution to national welfare in determining electricity supply quotas. In 1973, Saaty used AHP analysis as the main framework to lead a logistics system project in Sudan. Certain significant corporations also utilised prioritisation and allocation of resources in the United States between 1974 and 1978. In the 1980s, Saaty proposed the complete AHP methodology in his book "The Analysis Hierarchy Process". The theory was almost mature by that time. Subsequently, the AHP model was further refined in further book revisions. AHP is a strategy that connects decision makers' subjective judgements with objective reasoning using the expertise and knowledge of experts (Cui *et al.* (2022). The weights (or priority) of criteria are often derived in multicriteria decision making (MCDM) through the application of the analytic hierarchy process (Hasan *et al.*, 2019; Wang and Chen, 2021). The AHP may be expanded into an analytical network method in order to directly evaluate the overall performances of several alternatives (Banasik *et al.*, 2018; Wang *et al.*, 2019).

AHP may be seen as a versatile and robust method for understanding and quantifying consumer preferences. AHP is used to evaluate options such as improving public transportation, changing traffic management, encouraging carpooling, introducing specialised bike-sharing systems and encouraging teleworking. Nalmpantis *et al.* (2019) use AHP to evaluate unique public transportation solutions. Damidavičius *et al.* (2020) employ a variety of MCDM approaches to evaluate urban mobility metrics and find that the computed results are very comparable. In Ransikarbum and Khamhong's (2021) evaluation of healthcare apps, fuzzy AHP is utilised to evaluate the most significant criteria. Information is obtained during the examination of preferences from both technical specialists and user groups. Additionally, Kim *et al.* (2022) quantifies the influencing variables and grading system for tunnel collapse risk assessment using the AHP method. However, when Sarraf and McGuire (2020) analyse several approaches for route planning, the findings indicate that AHP and fuzzy AHP perform the best.

Furthermore, the AHP is the most popular and well-known technique (Santos *et al.*, 2019). Indeed, AHP resolves multi-layered decision-making via a hierarchical framework, criteria, sub-criteria and alternatives; and it may be utilised for both individual and group decision-making. According to Zhang *et al.* (2021), the AHP is a multi-criterion method for making judgments based on the relative relevance of factors. Furthermore, the AHP (Ortiz-Barrios *et al.*, 2020) considers the advantages and disadvantages of each criterion based on absolute priority (Eachempati and Srivastava, 2019; Singh *et al.*, 2019) and weightage ranking. It provides flexibility in dealing with decision-making bias by including a consistency ratio to confirm the decision maker's view (Hamidah *et al.*, 2022). The purpose of developing the analytical hierarchical analysis is to systematise complex problems. The specific steps of problem decision making using hierarchical analysis are described as follows.

Step 1: Describe the problem

Before conducting an analytical hierarchical analysis, it is necessary first to clarify where the problem lies. This means that the system framework of the problem is well understood so that the purpose of the decision can be clearly understood and the direction of the problem can be fully grasped so that in the subsequent hierarchical analysis, a hierarchical assessment of the influencing factors can be conducted.

Step 2: List the influencing factors of the problem

The list of influencing factors can be done by group brainstorming or the Delphi method. Firstly, small group discussions among relevant stakeholders are held or integrated with the opinions of experts, scholars and policymakers who have the expertise or accumulated considerable experience. In order to evaluate the issues discussed in the decision, the researchers will have compiled all opinions, listed all the elements that might affect the issue and carefully included them in the analysis.

Step 3: Establishing a hierarchical structure and factor characteristics

The so-called hierarchy should be composed of at least two levels, and the problem is analysed through different hierarchy levels. Through expert opinions, the evaluation criteria and secondary evaluation criteria of factors that may affect the problem are identified in order to establish the hierarchical structure. The goal characteristics of the decision problem are first divided into a hierarchy of upward and downward tree levels; each level is required to include all decision assessment attributes related to the overall goal as much as possible. Each criterion at each level is reviewed to see how it relates to the others and how much of an impact it has on the overall. The factors in each level are different in nature, independent of each other, mutually exclusive and influenced only by the factors in the previous level. The creation of this hierarchy is subject to repeated revisions based on expert opinion.

Step 4: Creating a Pairwise Comparison Matrix

After creating the complete hierarchy chart, a questionnaire design is required to evaluate the hierarchical factors. Any two factors in each level were evaluated based on the factors of the previous level in order to determine the importance of these factors to the factors of the previous level and the influence of the factors between each level. The questionnaires were compared on a scale of 1–9 for each level. The evaluators filled out the questionnaires one by one, giving different scores according to the level of importance to understand their own subjective opinions. After quantifying the pairwise comparisons of factors by scales, a pairwise comparison matrix of the relative importance of the two selected factors is established and used to calculate the eigenvalues and eigenvectors.

Step 5: Calculating the eigenvalues and eigenvectors

Since the results generated by pairwise comparison may be contradictory without being detected, the AHP method can validate whether or not the results obtained are contradictory. Consequently, once the pairwise comparison matrix is complete, the relative weights of the factors in each level can be calculated to obtain the eigenvector of each weight value, which represents the priority order of the factors in the hierarchy, and the eigenvalue can be used to evaluate the consistency of each pairwise comparison matrix. The pairwise comparison matrix's consistency index and consistency ratios are further calculated. Based on these results, the consistency level of the entire hierarchy is evaluated to obtain the weight of each hierarchical factor. Finally, all the related levels are linked to obtain the priority of the lowest level factor in the whole analysis so that the decision-maker can judge the overall priority and make a reasonable and correct decision.

4. Methodology

This study collected a wide range of relevant literature and established a systematic model for refractory supplier selection through a scientific approach. This study is based on 23 evaluation criteria proposed by Dickson (1966) as the reference to design the AHP questionnaire hierarchy.

4.1 AHP questionnaire hierarchy design

In light of the fact that supplier selection is a multi-criteria decision-making process, this study was conducted by means of on-site interviews to develop the hierarchy with two experts, with one holding a PhD's degree attached in a public university as a Professor in a relevant field, and one master's degree who has more than 15 years of relevant working experience in procurement and purchasing department in refractory industry. The questionnaire design of this study was combined with the theme of this study and finally, five evaluation criteria and 25 evaluation factors were finalised as presented in Table 1.

4.2 AHP questionnaire instruments

The research instruments used in this study are mainly comprised of questionnaire participation instructions, basic information and AHP questionnaires. Instructions for questionnaire participation are used as a guide in recruiting the experts. At this stage, experts will be briefed on the specific purpose, time, method and content of the questionnaire for this study. Once the experts agreed, the researcher conducted a survey with them within the scheduled time and restated the purpose and method of this study. The basic information of the questionnaire is used to statistically distinguish the respondents from different backgrounds so that it can be used as a reference factor in the later analysis of the study if discrepancies are found. The AHP questionnaire for this study was designed after a

Table 1. Scale meaning and explanation table

Evaluation scale	Definition	Description
1	Equally important	The degree of contribution of the two factors is of equal importance
3	Slightly important	By experience and judgment, one factor is slightly preferred over another
5	Quite important	By experience and judgment, one factor is highly preferred over another
7	Extremely important	Obvious and strong preference for one factor over another
9	Absolutely important	There is sufficient evidence to confirm an absolute preference for one factor over another
2, 4, 6, 8	Median of adjacent scales	Between two judgments

Source(s): Teng and Tzeng (1989)

discussion with two experts and the selection criteria and factors for the AHP questionnaire were finalised. Through this questionnaire, the real sentiments and real experiences of the expert participants are further explored and it is utilised as a tool for data collection in this study.

4.3 AHP questionnaire collection and analysis

The sample of 20 experts was selected by purposive sampling approach. These individuals included current senior executives, managers and other department heads with extensive industry experience (more than 15 years) with the refractory supplier in business development, production and R&D departments. A total of 20 questionnaires were distributed to these experts, of which 20 were useable samples. These useable questionnaires were collected for further analysis to explore the correlation and weighting of the factors.

This study utilises AHP analysis software to determine the relative weights and consistency of each level of supplier selection factors using data that meets the applicable scope of the AHP analysis method, as well as to investigate and explain the results of the analysed data in order to determine the key factor weights and priorities of the factors that influence refractory supplier selection. Then, key factors that influence the selection of refractory suppliers were selected and ranked in order of weighting to draw conclusions and make specific recommendations. The final conclusion of this study was thus completed.

4.4 Supplier evaluation hierarchical determination

By leveraging the AHP method, the researchers expect to systematise the complex issues of refractory supplier selection and, at the same time, through the establishment of the hierarchy, quantify its evaluation to help decision-makers select the most appropriate direction and reduce the risk of decision errors. The key factors are ranked according to their weight values to explore the key evaluation criteria. The AHP questionnaire for this study will be based on earlier literature and combined with the theme of this study to select the factors with greater influence and conduct the AHP expert questionnaire. The descriptions of implementation of each step of the AHP-based analysis are described as follows.

Step 1: Establishment of a hierarchical structure

To adopt the AHP method, it is necessary to establish a hierarchical structure for the problem to be evaluated, starting from the objective to be analysed and then extending the decision factors of the next layer down to the bottom layer, forming a network tree structure (Figure 1). The deciding factor depends on the factors that need to be considered for the decision objective, depending on the complexity of the factors to be considered. However, based on the suggestion of Saaty (1980), the inventor of the AHP theory.

(1) The highest level represents the ultimate goal of the evaluation.

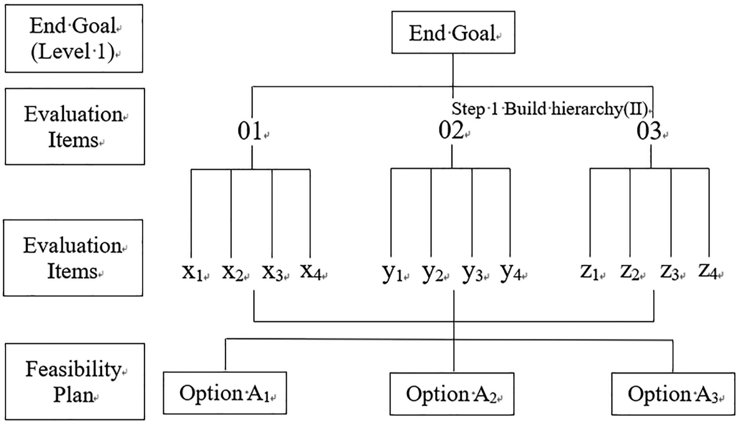
(2) Do not create more than seven decision factors in a single hierarchy.

(3) Each level of the hierarchy should be independent of each other.

(4) Decompose the key factors affecting the system into several groups, each group is further divided into several corresponding sub-groups, and so on, layer by layer, the entire hierarchy can be built.

Step 2: Setting the evaluation scale

The logic of analytic hierarchical analysis is that "consistency in ranking the relative importance of factors must be maintained." Failure in the sequencing of the answers will result in the regrettable "ineligibility" of the questionnaire. In order to derive the relative importance of



Source(s): Teng (2005)

Figure 1. Hierarchical structure for the problem to Be evaluated

the factors, it is necessary to compare the factors with each other. The AHP method suggests using the Ratio Scale as a criterion for comparison, ranging from 1 to 9 (and the reciprocal of 1–9, i.e. 1/1 to 1/9), with 9 representing “greatest influence”, 1 representing “least influence” and 8, 6, 4 and 2 in between, respectively. 1. If the respondent thinks A is more important than B, check Absolutely important, Very important, Quite important, Slightly important or Equally important columns, to the best of knowledge. 2. If the respondent thinks that although not Absolutely Important, it is slightly more than Important, please check the compromise column between the two columns. 3. If the respondent thinks A is more important than B, check Absolutely important, Very important, Quite important, Slightly important and Equally important columns, to the best of the knowledge. 4. If the respondents think A is equally important as compared to B, please check the equally important (1:1) column. Priority of importance is ranked according to number; the larger the number, the more important it is, and the smaller the number, the less important it is. The analyst only needs to use their judgment on a single issue to choose the level of importance (see below Table 2).

Step 3: Establishing a relative inverse-positive matrix

Once the analyst has listed all the decision factors in the same hierarchical structure as a matrix, the pairwise comparison process can commence. The pairwise comparison method takes out two different factors and uses one of them as a benchmark. Then, the evaluation scale identifies the degree of determination that the analyst considers more important than another factor. For example, in the case of the number 2, the scale is slightly important, and the importance of a factor to another factor is two times the weight value. In the process of filling in the pairwise comparison matrix, the following points need to be noted as identical factors are not compared with each other and are labelled with a weight of 1 in the matrix, meaning the factors are equally important.

Table 2. Coefficients of random indices

N	1	2	3	4	5	6	7	8	9	10	11	12	13
R.I.	0.0	0.0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.48	1.49	1.51	1.56

Source(s): Saaty (1980)

Two different factors are compared with each other only once. In contrast, the corresponding matrix on the other side is the inverse of the matrix filled by the earlier analyst, for example. if the pairwise comparison results between A and B are entered as a triple weight. The comparison results between B and A will be automatically changed to a 1/3 weight.

This is expressed in mathematical form as follows.

$$A = \begin{bmatrix} 1 & A_{12} & \cdots & A_{1n} \\ A_{21} & 1 & \cdots & A_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & A_{12} & \cdots & A_{1n} \\ 1/A_{12} & 1 & \cdots & A_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/A_{1n} & 1/A_{2n} & \cdots & 1 \end{bmatrix}$$

$$= \begin{bmatrix} W_1/W_1 & W_1/W_2 & \cdots & W_1/W_n \\ W_2/W_1 & W_2/W_2 & \cdots & W_2/W_n \\ \vdots & \vdots & \ddots & \vdots \\ W_n/W_1 & W_n/W_2 & \cdots & W_n/W_n \end{bmatrix}$$

W_i: is the weight of element i; i = 1, 2, 3, ..., n.

a_{ij}: is the ratio between two elements; i, j = 1, 2, 3, ..., n.

Step 4: Calculating the maximum eigenvalue and eigenvector

After establishing a pairwise comparison matrix, the researchers can determine the weights of the main factors of each level of the hierarchy, which is generally the eigenvalue solution commonly used in numerical analysis to find the eigenvectors, and then normalise them based on the followings.

(1) First, find the geometric mean of the row vectors.

(2) Then find the sum T of the geometric mean of the row vectors.

(3) Find the weight W_i.

(4) Calculate the AW value.

(5) Obtain λ_{max}.

Eigenvector W_i (where m is the number of decision factors)

$$W_i = \left(\prod_{j=1}^{m} a_{ij}\right)^{1/m} \Big/ \sum_{i=1}^{m}\left(\prod_{j=1}^{m} a_{ij}\right)^{1/m}$$

Maximum eigenvalue

$$\begin{bmatrix} 1 & a_{12} & \cdots & a_{1m} \\ a_{21} & 1 & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & 1 \end{bmatrix} \times \begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ \vdots \\ W_m \end{bmatrix} = \begin{bmatrix} W_1'' \\ W_2'' \\ W_3'' \\ \vdots \\ W_m'' \end{bmatrix}$$

$$\lambda_{max} = (1/m) \times \left(W_1''/W_1 + W_2''/W_2 + \cdots + W_m''/W_m \right)$$

Step 5: Consistency test

In addition to evaluating the decision-maker's judgment, the purpose of consistency testing is to verify that the results of the analysis are logical. As the priority of each level varies, the overall framework should be tested for consistency, and Saaty (1980) recommends a consistency index value of around 0.1 to pass the consistency test, regardless of whether or not it is a measure of the decision maker's judgment or a test of the overall hierarchical structure. In determining the consistency ratio, the following equation is utilised:

$$C.I. = (\lambda_{max} - n) / (n - 1)$$

C.I.: Consistency Index.

λ_{max}: Maximum eigenvalue

n: Number of evaluation factors

C.I. is the consistency index. The consistency index value is obtained by applying the vector of eigenvalues derived from the matrix to the above formula to obtain the consistency index value, ideally C.I. = 0. However, as the number of decision factors and evaluation schemes increases, a small numerical error will arise in the calculation, making it necessary to adjust the weight values in the matrix. When C.I. = 0, it indicates that the previous and subsequent judgments are identical.

According to Saaty (1980), C.I. $\leqq$ 0.1 is an allowable bias and the weight allocation is reasonable; assuming that C.I. > 0.1, the evaluators' judgment is inconsistent and should be rectified immediately. After obtaining the consistency index, the next step is to determine the consistency ratio for the consistency of the hierarchy. The consistency ratio value is obtained by applying the previously obtained consistency index value to the following equation:

$$C.R. = C.I. / R.I.$$

C.R.: Consistency Ratio.

C.I.: Consistency Index

R.I.: Random Index

The R.I. value in the formula is called a Random Index, which is the consistent value of the randomly generated matrix of positive and negative values. The corresponding R.I. value can be found according to the matrix order, as Table 3 shows the coefficient table of R.I. value. When the calculated result of C.R. value is less than 0.1, it means that the matrix achieves logical consistency.

Step 6: Overall Hierarchy Consistency Determination

The consistency ratio of the hierarchy (C.R.H.) can be used to determine and calculate the integrated weighting and consistency assessment of the hierarchy. This study conducted AHP analysis by utilising the decision analysis software Power Choice.

$$C.R.H. = C.I.H./R.I.H.$$

C.I.H. = the sum of (priority weight per level) × (C.I. per level).

Criteria	Factors
Product quality	Quality reliability
	Quality professionalism
	Quality control
	Price evaluation and bargaining power
	Safety regulation and environmental protection capability
Production technology	Technical support capability
	Production equipment and capacity
	Inspection reliability
	New product development capability
Logistics capacity	Delivery Rate
	Flexible deployment contingency
	Delivery and storage reliability
	Historical delivery performance
Service capability	Information control capability
	Customer complaint handling response capability
	Customer communication system
	After-sales service
	Service attitude
Supplier background	Financial status
	Historical sales
	Quality management framework and process
	Labor relations
	Staff training and auditing
	Geographic location
	Industry reputation and status

Source(s): Author's own work

Table 3. Criteria and factors for supplier selection

C.I.H.: consistency index of the hierarchy

R.I.H. = the sum of (priority weight per level) × (R.I. per level).

R.I.H.: Random index of the hierarchy

C.R.H. values should be < 0.1 for acceptable overall hierarchical consistency.

Saaty (1980) considered that when C.R.H. < 0.1, it indicates that the overall hierarchical consistency is acceptable. It is assumed that the smaller the value of consistency ratio C.R. and overall consistency ratio C.R.H., the more the matrix conforms to mathematical transitive relations, which also means that the matrix is suitable for applying AHP to find the critical factors, C.R. < 1 and C.R.H. < 0.1, in order to ensure consistency.

5. Results

Based on the AHP analysis, this study was conducted with a clear target population and distributed questionnaires to experts. Twenty questionnaires were distributed, and Twenty questionnaires were validly collected, with a 100% response rate. After the questionnaires were collected, the study was analysed through the analytic hierarchy process (AHP). The software Power Choice was utilised to find each factor's comparative matrix and weight at each level. The ultimate goal was to determine the relative importance of each weighting factor by collecting experts' opinions and confirming that the consistency index between the comparison matrix of each level was less than 0.10. The key criteria for decision making to improve management performance were determined. The analysis is divided into two parts, the first part is the main criteria, and the second part is the factors that influence decision making.

5.1 Weighting analysis of the main criteria for refractory materials supplier selection

The main criteria of this study are refractory supplier selection, which consists of five, namely product quality, production technology, logistics capability, service capability and supplier background. After gathering the responses from the 20 experts, the results were then tabulated with standardised weights. It can be observed that C.R. = 0.046 < 0.1; this shows that the pairwise ratio of the main criteria is consistent. Table 4 and Figure 2 show the key factors for refractory suppliers' selection are in the following order of weight.

Product quality (L = 0.468) > Production technology (L = 0.271) > Service capability (L = 0.174) > Logistics capability (L = 0.054) > Supplier background (L = 0.032).

This means that the main critical criteria for refractory supplier selection are the product quality provided by the supplier (46.8%), followed by the production technology offered by the supplier (27.1%), with the least influence derived from the supplier's background (3.2%).

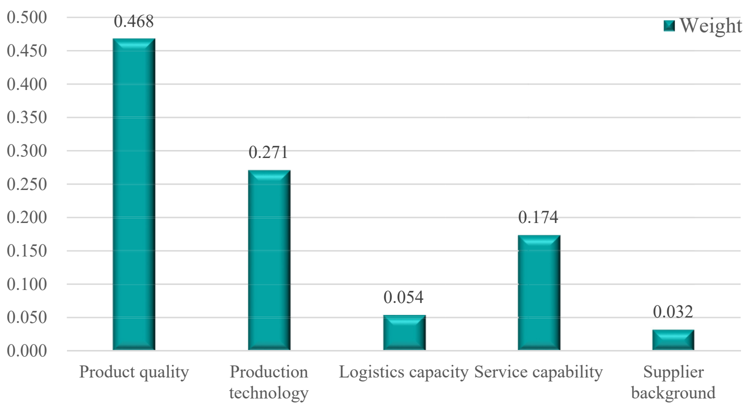
5.2 Weighting analysis of refractory supplier selection criteria

5.2.1 Product quality weighting analysis. There are five key factors under the product quality criteria namely, quality reliability, quality professionalism, quality control, price evaluation and bargaining power, safety regulation and environmental protection capability (see

Table 4. Pairwise comparative matrix of key factors for refractory supplier selection and priority factors

Key factors	Product quality	Production technology	Logistics capacity	Service capability	Supplier background	Weight	Order
Product quality	1	2.324	6.134	4.406	8.303	0.468	1
Production technology	0.430	1	6.077	2.166	7.754	0.271	2
Logistics capacity	0.163	0.165	1	0.185	2.457	0.054	4
Service capability	0.227	0.462	5.403	1	6.839	0.174	3
Supplier background	0.120	0.129	0.407	0.146	1	0.032	5
Consistency test		λ_{max} = 5.281, C.I. = 0.070, R.I. = 1.12, C.R. = 0.063 < 0.1					

Source(s): Author's own work



Source(s): Author's own work

Figure 2. Ranking of weighting of refractory supplier selection by key factors

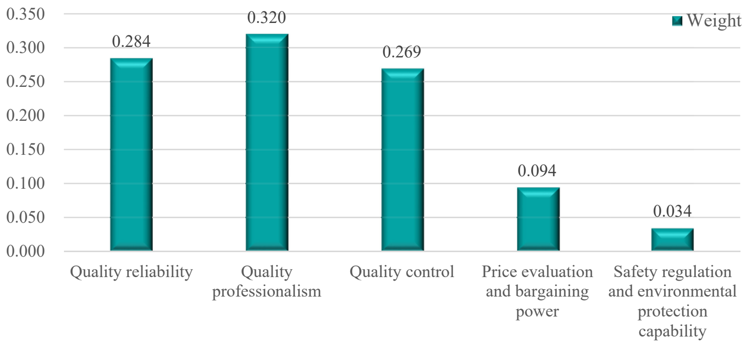
Figure 3). After completing the questionnaire with 20 experts and calculating the standardised weights, it can be observed that C.R. = 0.031 < 0.1 indicates consistency in the pairwise ratio of product quality criteria. The two-by-two comparison of each factor of product quality results is shown in Table 5. Table 5 shows that the key factors under product quality criteria are ranked in the following order of weight:

Quality professionalism (L = 0.320) > Quality reliability (L = 0.284) > Quality control (L = 0.269) > Price evaluation and bargaining power (L = 0.094) > Safety regulations and environmental protection capability (L = 0.034).

It shows that quality professionalism (32.0%) is the main key factor of product quality criteria, followed by quality reliability (28.4%). In comparison, safety regulation and environmental protection capability are slightly less influential (3.4%).

5.2.2 Production technology weighting analysis. There are four factors under the production technology criteria, namely technical support capability, production equipment and capacity, monitoring reliability and new product development capability (as shown in Figure 4). After the questionnaire and standardised weight calculation of responses from 20 experts, it can be observed that C.R. = 0.014 < 0.1 indicates consistency in the comparison of production technology factors. Table 6 shows the results of the two-by-two comparison of the factors of production technology criteria. It can be observed that the key factors of production technology criteria have the following order of importance:

Production equipment and capacity (L = 0.434) > monitoring reliability (L = 0.257) > technical support capability (L = 0.212) > new product development capability (L = 0.097).



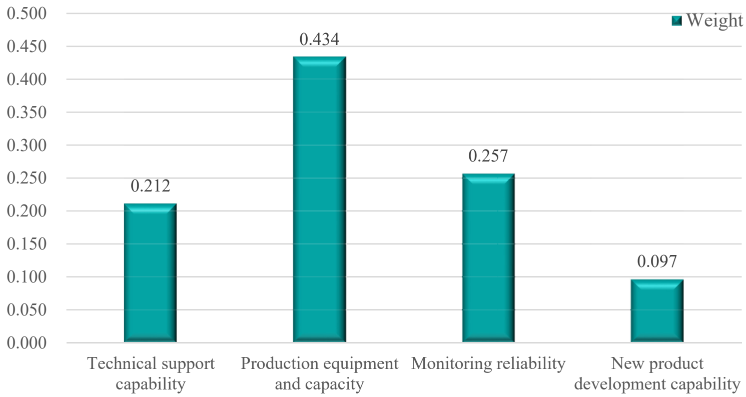
Source(s): Author's own work

Figure 3. Weighting of factors of product quality criteria

Evaluation factors	A1	A2	A3	A4	A5	Weight	Order
A1	1	0.973	1.097	3.683	6.530	0.284	2
A2	1.027	1	1.441	4.131	7.515	0.320	1
A3	0.912	0.694	1	4.039	7.422	0.269	3
A4	0.272	0.242	0.248	1	4.905	0.094	4
A5	0.153	0.133	0.135	0.204	1	0.034	5
Consistency test	λ_{max} = 5.140, C.I. = 0.035, R.I. = 1.12, C.R. = 0.031 < 0.1						

Note(s): A1: quality reliability; A2: quality professionalism; A3: quality control; A4: price evaluation and bargaining power; A5: safety regulation and environmental protection capability
Source(s): Author's own work

Table 5. Pairwise comparison matrix and priority factors for the evaluation of product quality factors



Source(s): Author's own work

Figure 4. The weighting of the factors of the intra-company adjustment factors

Table 6. Pairwise comparison matrix and priority factors for the evaluation of production technology factors

Evaluation factors	B1	B2	B3	B4	Weight	Order
B1	1	0.477	1.025	1.781	0.212	3
B2	2.096	1	1.755	4.400	0.434	1
B3	0.976	0.570	1	3.399	0.257	2
B4	0.561	0.227	0.294	1	0.097	4
Consistency test	$\lambda_{max} = 4.038$, C.I. = 0.013, R.I. = 0.89, C.R. = 0.014 < 0.1					

Note(s): B1: Technical support capability; B2: Production equipment and capacity; B3: Monitoring stability; B4: New product development capability
Source(s): Author's own work

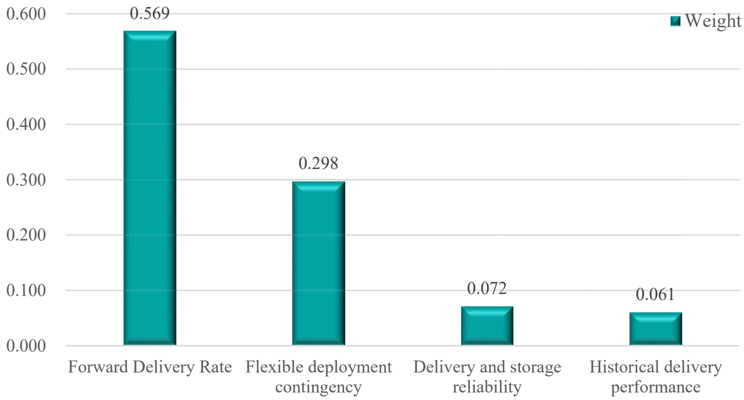
This indicates that the key factor of the production technology is production equipment and capacity (43.4%), followed by monitoring reliability (25.7%), while new product development capability (9.7%) is the least influential.

5.2.3 Logistics capability weighting analysis. There are four factors under the logistics capability criteria namely, delivery rate, flexible deployment contingency, delivery and storage reliability rate and historical delivery performance (as shown in Figure 5). Further to the calculation of the standardised weights, it can be observed that C.R. = 0.041 < 0.1 indicates consistency in the pairwise comparison ratio of logistics capability criteria. The results of the two-by-two comparison of the factors of logistics capability criteria. From Table 7, the key factors of logistics capability criteria are in the following order of importance:

Delivery rate (L = 0.569) > Flexible deployment contingency (L = 0.298) > delivery and storage reliability rate (L = 0.072) > Historical delivery performance (L = 0.061).

Results indicate that the delivery rate (56.9%) is the main key factor, followed by flexibility in deployment contingency (29.8%), and historical delivery performance (6.1%) has the least impact.

5.2.4 Service capability weighting analysis. There are five factors under the service capability criteria namely, information control capability, customer complaint handling response capability, customer communication system, after-sales service and service attitude (as shown in Figure 6). The findings from this observation found that the C.R. = 0.075 < 0.1 indicates that there is consistency in the pairwise comparison of service capability criteria. The results of the two-by-two comparison of the factors of service capability support criteria (Table 8).



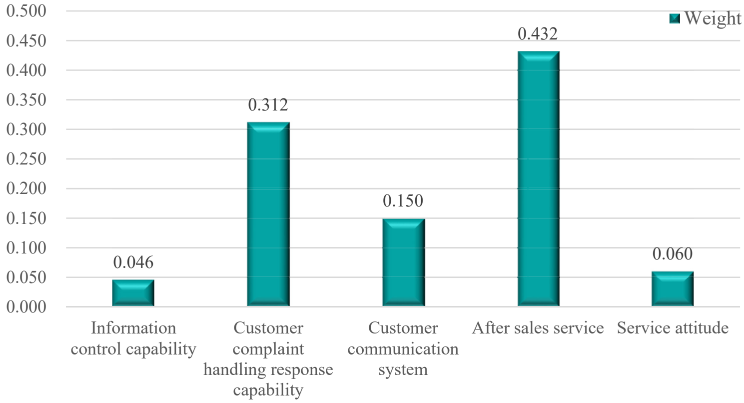
Source(s): Author's own work

Figure 5. Weighting of logistics capability criteria

Evaluation factors	C1	C2	C3	C4	Weight	Order
C1	1	3.013	6.128	7.129	0.569	1
C2	0.332	1	5.195	5.961	0.298	2
C3	0.163	0.192	1	1.231	0.072	3
C4	0.140	0.168	0.813	1	0.061	4
Consistency test	λ_{max} = 4.110, C.I. = 0.037, R.I. = 0.89, C.R. = 0.041 < 0.1					

Note(s): C1: Delivery Rate; C2: Flexible Deployment Contingency; C3: Delivery and Storage Reliability Rate; C4: Historical Delivery Performance
Source(s): Author's own work

Table 7. Pairwise comparison matrix and priority factors for the evaluation of logistics capability factors



Source(s): Author's own work

Figure 6. Service capability factors of factor weighting

After-sales service (L = 0.432) > Customer complaint handling response capability (L = 0.312) > Customer communication system (L = 0.150) > Service attitude (L = 0.060) > Information control capability (L = 0.046).

Service capability is a criteria, and after-sales service (43.2%) is the main key factor. This is followed by the customer complaint handling response capability (31.2%) and sound information control capability (4.6%), which is relatively lower in influence.

5.2.5 Weighting analysis of supplier background factors. In regards to the supplier background criteria, it was noted that there are seven factors namely, financial status, historical revenue, quality management framework and process, labour relations, employee training and auditing, geographic location and industry reputation and status (as shown in Figure 7). Results from the calculation of the standardised weight found that C.R. = 0.076 < 0.1 indicates that the pairwise ratio of supplier background factors is consistent. The results of the two-by-two comparison of each factor of supplier background criteria are shown in Table 9, and it can be observed that the key factors of supplier background criteria are ranked in the following order:

Quality management framework and process (L = 0.400) > Employee training and auditing (L = 0.279) > Financial status (L = 0.091) > Historical revenue (L = 0.088) > Industry reputation and status (L = 0.077) > Labour relations (L = 0.038) > Geographic location (L = 0.027).

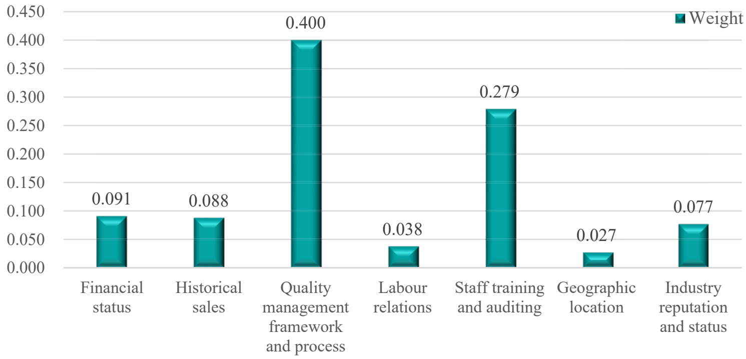
That indicates that the primary key factor of supplier background criteria is quality management framework and process (40.0%), followed by employee training and auditing (27.9%) and geographic location (2.7%), which is relatively less influential.

5.2.6 Refractory supplier selection factor weighting analysis. Refractory supplier selection and the comparison results are shown in Table 7 with twenty-five factors. As shown in Table 10, it can be observed that the factors of refractory supplier selection are evaluated in order of decreasing weight:

Table 8. Pairwise comparison matrix and priority factors of serviceability factor

Evaluation factors	D1	D2	D3	D4	D5	Weight	Order
D1	1	0.211	0.205	0.157	0.608	0.046	5
D2	4.747	1	4.164	0.545	4.627	0.312	2
D3	4.889	0.240	1	0.217	4.260	0.150	3
D4	6.385	1.836	4.619	1	5.607	0.432	1
D5	1.644	0.216	0.235	0.178	1	0.060	4
Consistency test	λ_{max} = 5.336, C.I. = 0.089, R.I. = 1.12, C.R. = 0.075 < 0.1						

Note(s): D1: Information control capability; D2: Customer complaint handling response capability; D3: Customer communication system; D4: After-sales service; D5: Service attitude
Source(s): Author's own work



Source(s): Author's own work

Figure 7. Ranking of factor weights of supplier background criteria

Quality Professionalism(L = 0.149) > Quality Reliability (L = 0.133) > Quality Control (L = 0.126) > Production Equipment and Capacity (L = 0.118) > After-sales Service (L = 0.075) > Inspection Reliability (L = 0.070) > Technical Support Capability (L = 0.057) > Customer Complaint Handling Response Capability (L = 0.054) > Price Evaluation and Bargaining Capability (L = 0.044) > Delivery Rate (L = 0.031) > New Product

Evaluation factors	E1	E 2	E 3	E 4	E 5	E6	E7	Weight	Order
E1	1	1.470	0.167	4.627	0.226	4.437	0.637	0.091	3
E2	0.680	1	0.201	4.926	0.193	4.599	0.929	0.088	4
E3	5.989	4.984	1	7.122	2.776	7.414	5.485	0.400	1
E4	0.216	0.203	0.140	1	0.147	1.487	0.973	0.038	6
E5	4.426	5.173	0.360	6.807	1	6.579	5.332	0.279	2
E6	0.225	0.217	0.135	0.673	0.152	1	0.259	0.027	7
E7	1.570	1.076	0.182	1.027	0.188	3.868	1	0.077	5
Consistency test	λ_{max} = 7.619, C.I. = 0.103, R.I. = 1.36, C.R. = 0.076 < 0.1								

Note(s): E 1: Financial status; E 2: Historical revenue; E 3: Quality management framework and process; E 4: Labour relations; E 5: Employee training and auditing; E 6: Geographic location; E 7: Industry reputation and status
Source(s): Author's own work

Table 9. Pairwise comparison matrix and priority factors for the evaluation of supplier background factors

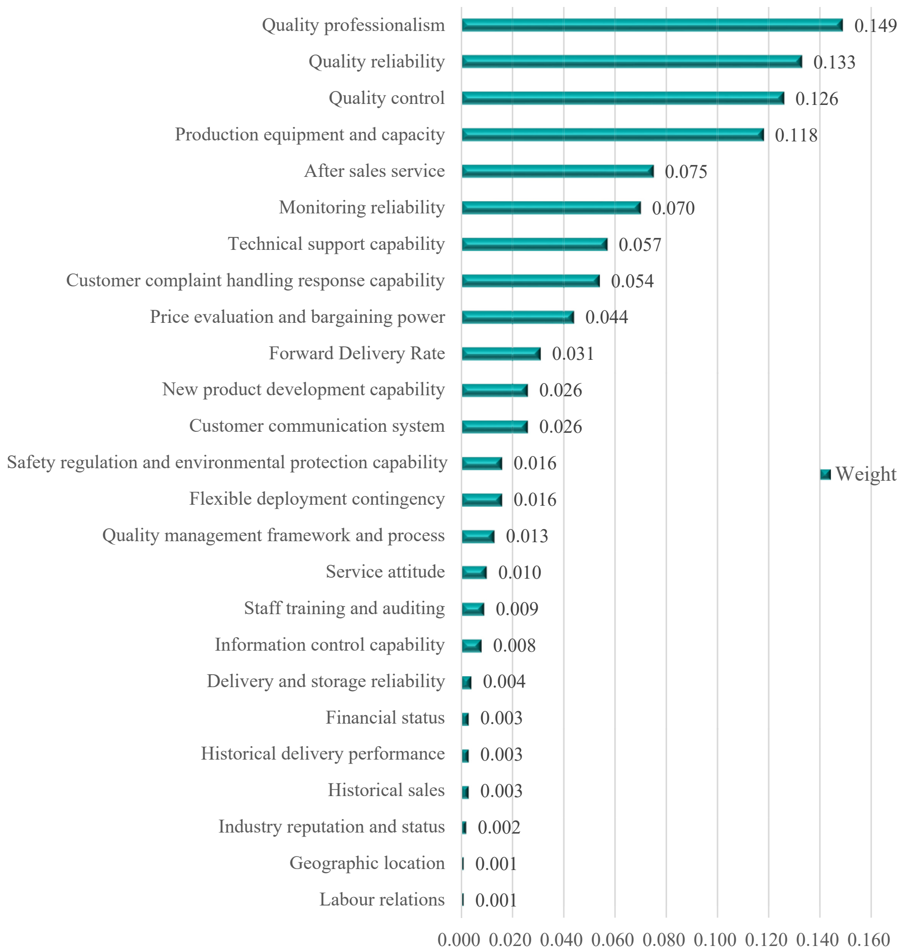
Main criteria	Main criteria ranking	Factors	Weight	Overall ranking of sub-factors
Product quality	1	Quality professionalism	0.149	1
		Quality reliability	0.133	2
		Quality control	0.126	3
		Production equipment and capacity	0.118	4
		After-sales service	0.075	5
Production technology	2	Monitoring reliability	0.07	6
		Technical support capability	0.057	7
		Customer complaint handling response capability	0.054	8
		Price evaluation and bargaining power	0.044	9
		Delivery Rate	0.031	10
Service capability	3	Customer communication system	0.026	11
		New product development capability	0.026	12
		Flexible deployment contingency	0.016	13
		Safety regulation and environmental protection capability	0.016	14
		Quality management framework and process	0.013	15
Logistics capacity	4	Service attitude	0.010	16
		Staff training and auditing	0.009	17
		Information control capability	0.008	18
		Delivery and storage reliability	0.004	19
		Historical sales	0.003	20
Supplier background	5	Historical delivery performance	0.003	21
		Financial status	0.003	22
		Industry reputation and status	0.002	23
		Labour relations	0.001	24
		Geographic location	0.001	25

Source(s): Author's own work

Table 10. Refractory supplier selection factor weighting

Development Capability (L = 0.026) > Safety Regulation and Environmental Protection Capability (L = 0.016) = Flexible Deployment Response (L = 0.016) > Quality Management Structure and Process (L = 0.013) > Service Attitude (L = 0.010) > Employee Training and Audit (L = 0.009) > Information Control Capability (L = 0.008) > Delivery and Storage Reliability (L = 0.004) > Historical Delivery Performance (L = 0.003) = Financial Status (L = 0.003) = Historical Revenue (L = 0.003) > Industry Reputation and Status (L = 0.002) > Labour Relations (L = 0.003) = Geographic Location (L = 0.003) (as shown in Figure 8).

Findings indicate that the main factor weighting for refractory supplier selection is the quality professionalism of product quality (14.9%), followed by the quality reliability of product quality (13.3%), which falls under the main criterion of product quality. It further posits that product quality is the main selection criterion for choosing refractory suppliers.



Source(s): Author's own work

Figure 8.
Factor weighting of refractory suppliers

6. Discussion and conclusion

With industry development, refractories have become an important basic material for heavy industry, mostly used in steel, cement, petrochemicals, incinerators, power plants and other industries involving high thermal production processes. Different industries have different applications for refractory materials and need to overcome different adverse conditions due to the differences in the composition of refractory materials and the ensuing diversity in properties and features. Thus manufacturers target specific applications in various industries, and with the development of technology, refractory materials are constantly being developed to meet market requirements. Since the refractory industry is demand-driven, suppliers must provide and meet any customer needs. Therefore, it is important to utilise proper supplier evaluation to select the right supplier. Supplier selection can empower companies to eliminate unsuitable suppliers and select suitable suppliers, which can help companies reduce operational risks and costs.

Therefore, to investigate the criteria of refractory supplier selection, this study was conducted by a questionnaire survey to collect pertinent data. After undergoing AHP analysis to determine the refractory supplier selection criteria, the study implications are discussed.

The weighted indices for each of the refractory supplier selection criteria were ranked according to the level of each criterion's selection criteria. The main criterion is product quality (46.8%), followed by production technology (27.1%) and service capability (17.4%). Other important factors in decreasing order include the quality professionalism of product quality (14.9%), the quality reliability of product quality (13.3%) and the quality control of product quality. Additionally, this indicates that product quality is a key factor in selecting suppliers, and quality is one of the most critical factors in the early selection of suppliers. In today's highly competitive market, product quality has become a key factor in the consideration and selection of suppliers and further showcases the competitiveness and performance of suppliers. The production technology of suppliers is the basis for developing new products, and new products are continuously developed to meet customer needs to gain more market share.

Next, in this study, there are five factors affecting product quality, namely quality professionalism (32.0%), quality reliability (28.4%), quality control (26.9%), price evaluation and bargaining power (9.4%) and safety regulation and environmental protection (3.4%). One of the main influences on product quality is quality professionalism, quality reliability and quality control. Product quality is realised by having a dedicated person in charge of product quality, hiring technical professionals and applying management knowledge, techniques, tools and methods to the product to achieve quality requirements. Product quality is affected by personnel competence, cooperation, attitude, supervision and other aspects, and strong quality expertise can address these difficulties. Therefore, quality expertise is more vital to product quality. Reliability and consistency of quality ensure high-quality products and customer recognition.

Besides, this study found that the most critical factors affecting production technology are production equipment and production capacity. There are four factors affecting production technology, namely, production equipment and capacity (43.4%), monitoring stability (25.7%), technical support capability (21.2%) and new product development capability (9.7%). Production equipment is the essential tool of production, and its quality and advanced technology directly affect the quality, precision, output and production efficiency of products. Factors such as capacity, quality, maintainability, completeness, flexibility, impact on the environment and investment cost of the equipment can be considered for selecting production equipment. Admittedly, the delivery rate is the percentage of on-time deliveries in a certain period of time compared to the total number of deliveries. The delivery rate is a manifestation of the logistics capability. A high delivery rate of a supplier indicates its high production capability and production management standards. Four factors affect logistics capability, namely, delivery rate (56.9%), flexibility in deployment contingency (29.8%), delivery and storage reliability rate (7.2%) and historical delivery performance (6.1%). Dickson (1966) noted that quality, delivery time and rate and past performance were the most critical factors.

This present study prescribed that after-sales service is the most important aspect influencing service capability. There are five factors affecting service capability, namely after-sales service (43.2%), customer complaint handling response capability (31.2%), customer communication system (15.0%), service attitude (6.0%) and information control capability (4.6%). Excellent after-sales service can provide customers with an excellent product experience, which helps to enhance customer dependence and stickiness, maintains good customer relationships, improves market reputation and lays a good foundation for expanding market share by word -of mouth. Outstanding after-sales service to new customers can effectively dispel their doubts about new products and new suppliers, enhance trust and promote their determination to buy offered products. At the same time, suppliers with excellent after-sales service often have an advantage in facilitating transactions based on the same quality of products compared to peers. Therefore, having a comprehensive and efficient after-sales service system is the most direct manifestation of a company's service capability.

Most importantly, this study found that the key influence of supplier background is the quality management framework and process. An excellent management structure and a strict quality management process are the highest requirements of a company for its products. Through standard operating procedures and quality control-related information, enterprises can build their own distinct corporate culture and reputation and further enhance competitiveness. The seven factors that influence the background of suppliers are quality management framework and process (40.0%), staff training and audit (27.9%), financial status (9.1%), historical revenue (8.8%), industry reputation and status (7.7%), labour relations (3.8%) and geographic location (2.7%).

7. Implications and future research directions

Based on the study results, the following recommendations are made to refractory suppliers and future research. It is found that the primary factor affecting the selection criteria of refractory suppliers is product quality, followed by production technology, service capability, logistics capability and lastly, supplier background. There are managerial implications for both the organisation using the approach and the suppliers participating in the processes. In terms of the firm, on the one hand, the use of the AHP method for the organisation of the decision-making model has made it feasible for the company. AHP helps in structuring complex decision-making problems into a hierarchy of factors, which can be evaluated and prioritised based on their relative importance. This can lead to more informed and consistent decisions in the selection of suppliers, which can improve the overall performance of the refractory material manufacturers. Given the necessity to incorporate the organisation's stated common objectives and priorities, the set of calculated relevance criteria weights has been unique for all decision-makers. It has been demonstrated that the presented AHP model can significantly reduce the time and effort required by managers during the decision-making process, partly because it does not require complex mathematical operations and can be easily transferred to a spreadsheet for easy computations and obtain the ranking order of alternatives automatically. The research is theoretically based on an approach to analysing the key factors in the selection of suppliers by refractory materials manufacturers in Taiwan. AHP helps in identifying the key factors that contribute the most to the selection of suppliers. This enables manufacturers to focus their resources on improving these critical factors, which enhance the overall effectiveness of supplier selection. Various variables linked to product quality, production technology, logistics capability, service capability and supplier background were evaluated and carefully studied in this method. The research adds to the expanding literature on the selection of suppliers by refractory materials manufacturers by delving into several facets. Multiple criteria and factors in the decision-making process contribute to the advancement of decision-making theory and practice by providing a more holistic and comprehensive approach to decision-making. By analysing the outcomes of supplier selection decisions, manufacturers can identify areas for improvement and make adjustments to the decision-making process that can lead to better outcomes over time. The study's findings are useful in developing a theoretically driven framework in other emerging economies. Furthermore, the work adds to the current literature by using the fuzzy AHP in selecting suppliers by refractory materials manufacturers, which has not been investigated before.

In fact, when considering the managerial implications for the suppliers, the chosen decision framework and evaluation tree can be a useful tool to pinpoint their advantages and disadvantages, choose the best operational approaches and put the necessary corrective measures in place to enhance their performance, the quality of their goods and the level of customer satisfaction. The improvement of the continuing support and maintenance is a crucial feature that must be tracked and improved for this goal. Additionally, the developed methodological approach has impressed the company's managers as being so strong and adaptable that they have recommended encouraging its adoption to other multi-criteria strategic decision problems within various divisions and areas of the business. Therefore, it is recommended that refractory suppliers should clarify the direction of development: take product quality as the foundation of their development and growth, improve their production technology, ensure stable production capacity and product yield, continuously strengthen new product development capabilities, ensure the technological advancement of their products, provide good product service, optimise logistics capabilities, introduce advanced logistics management technology, ensure inventory turnover rate, reduce costs and enhance competitiveness. Of course, according to the results of the weighting analysis of the factors in this study, each supplier should still pursue development according to its business model and customer traits. For example, some companies emphasise usability over quality, but some focus on meeting standards and paying attention to after-sales service. Therefore, fine-tuning production and service on time to enhance customer satisfaction is key to business sustainability. Consequently, it is recommended that refractory suppliers fully explore the characteristics and differences of their operations according to the results of this study and implement respective strategies according to their needs.

The hybrid technique has a lower degree of computational complexity than models from Yeh and Chang (2009), which enables its practical use. The hybrid model presented and evaluated in this work differs from what is shown in the literature in that it combines the method for determining criterion weights characteristic of the AHP approach with results obtained. The AHP application's computing complexity is lowered as a result, and the practical application is made easier. Although AHP is well-established techniques, the application suggested in this work adds something new since, to the best of our knowledge, it has never been suggested in research of a similar kind for service selection. Following a meticulous comparison study of ISO/IEC rules, service and supplier selection issues and business drivers of the organisation, the suggested model clearly identifies the criteria for refractory supplier selection and structures the problem in a methodical manner. Finally, this paper sets out also to discover, use and report the best decision-making strategy for concurrently solving both elements of a refractory service selection problem.

In terms of research methodology, this study utilises literature as the basis for research and adopts a hierarchical analysis to establish its research framework. It may also be suggested that subsequent researchers use fixed and specific product criteria to collect relevant data on key factors for refractory supplier selection. Since the scope of refractory materials used is too large and complex, it is more realistic and apt to select a few common or mainstream product types as the condition for supplier selection. The selection of key factors for supplier evaluation should avoid too much repetition and redundancy, making the number of constructs too high, causing difficulties for respondents and reducing the accuracy of the study.

References

Alvandi, M., Fazli, S. and Memarzade, M. (2011), "E-supplier selection using Delphi, Fuzzy AHP and SIR", *European Journal of Scientific Research*, Vol. 66 No. 4, pp. 481-509.

Álvarez, D. and García, M. (2021), "Development of a quality control system for the supply of silica refractory material from China", *IOP Conference Series: Materials Science and Engineering*, Vol. 1193 No. 1, doi: 10.1088/1757-899x/1193/1/012071.

Banasik, A., Bloemhof-Ruwaard, J.M., Kanellopoulos, A., Claassen, G.D.H. and van der Vorst, G.A.J. (2018), "Multi-criteria decision making approaches for green supply chains: a review", *Flexible Services and Manufacturing Journal*, Vol. 30 No. 3, pp. 366-396.

Beiki, H., Mohammad Seyedhosseini, S., Ponkratov, V.V., Olegovna Zekiy, A. and Ivanov, S.A. (2021), "Addressing a sustainable supplier selection and order allocation problem by an integrated approach: a case of automobile manufacturing", *Journal of Industrial and Production Engineering*, Vol. 38 No. 4, pp. 239-253.

Chan, F.T.S. and Kumar, N. (2007), "Global supplier development considering risk factors using fuzzy extended AHP-based approach", *The International Journal of Management Science Omega*, Vol. 35 No. 4, pp. 417-431.

Chen, C.T., Lin, C.T. and Huang, S.F. (2006), "A fuzzy approach for supplier evaluation and selection in supply chain management", *International Journal of Production Economics*, Vol. 102 No. 2, pp. 289-301.

Choi, T.Y. and Hartley, J.L. (1996), "An exploration of supplier selection - practices across the supply chain", *Journal of Operations Management*, Vol. 14, pp. 333-343.

Choy, K.L., Lee, W.B. and Lo, V. (2002), "An intelligent supplier management tool for benchmarking suppliers in outsource manufacturing", *Expert System with Application*, Vol. 22 No. 3, pp. 213-224.

Cui, L., Gao, M., Dai, J. and Mou, J. (2022), "Improving supply chain collaboration through operational excellence approaches: an IoT perspective", *Industrial Management and Data Systems*, Vol. 122 No. 3, pp. 565-591.

Dallasega, P., Woschank, M., Sarkis, J. and Tippayawong, K.Y. (2022), "Logistics 4.0 measurement model: empirical validation based on an international survey", *Industrial Management and Data Systems*, Vol. 122 No. 5, pp. 1384-1409.

Damidavičius, J., Burinskienė, M. and Antuchevičienė, J. (2020), "Assessing sustainable mobility measures applying multicriteria decision making methods", *Sustainability*, Vol. 12, p. 6067.

Dickson, G.W. (1966), "An analysis of vendor selection systems and decisions", *Journal of Purchasing*, Vol. 2 No. 1, pp. 5-17.

Dulmin, R. and Mininno, V. (2003), "Supplier selection using a multicriteria decision aid method", *Journal of Purchasing and Supply Management*, Vol. 9 No. 4, pp. 177-187.

Eachempati, P. and Srivastava, P.R. (2019), "Personalised elective selection: a multicriteria perspective in academia", *International Journal of Strategic Decision Sciences*, Vol. 10 No. 4, pp. 43-63.

Hamidah, M., Hasmadi, I.M., Chua, L.S.L., Yong, W.S.Y., Lau, K.H., Faridah-Hanum, I. and Pakhriazad, H.Z. (2022), "Development of a protocol for Malaysian important plant areas criterion weights using multicriteria decision making-analytical hierarchy process (MCDM-AHP)", *Global Ecology and Conservation*, Vol. 34, e02033.

Hasan, M., Büyüktahtakın, I.E. and Elamin, E. (2019), “A multicriteria ranking algorithm (MCRA) for determining breast cancer therapy”, *Omega*, Vol. 82, pp. 83-101.

Katsikeas, C.S., Paparoidamis, N.G. and Katsikea, E. (2004), “Supply source selection criteria: the impact of supplier performance on distributor performance”, *Industrial Marketing Management*, Vol. 33 No. 8, pp. 755-764.

Kharisma, S. and Ernawati, D. (2021), “Pengukuran kinerja supply chain management (SCM) dengan menggunakan SCOR Model dan Metode Analitycal Hierarchy Process (AHP) di PT. Loka Refractory Wira Jatim”, *JUMINTEN*, Vol. 2 No. 5, pp. 121-132.

Kim, J., Kim, C., Kim, G., Kim, I., Abbas, Q. and Lee, J. (2022), “Probabilistic tunnel collapse risk evaluation model using analytical hierarchy process (AHP) and Delphi survey technique”, *Tunnelling and Underground Space Technology*, Vol. 120, 104262.

Kumar, A., Gupta, A. and Aparna Mehra, A. (2022), “A bilevel game model for ascertaining competitive target prices for a buyer in negotiation with multiple suppliers”, *RAIRO Operations Research*, Vol. 56, pp. 293-330.

Mina, H., Kannan, D., Gholami-Zanjani, S.M. and Biuki, M. (2021), “Transition towards circular supplier selection in petrochemical industry: a hybrid approach to achieve sustainable development goals”, *Journal of Cleaner Production*, Vol. 286, 125273.

Nalmpantis, D., Roukouni, A., Genitsaris, E., Stamelou, A. and Naniopoulos, A. (2019), “Evaluation of innovative ideas for public transport proposed by citizens using multi-criteria decision analysis (MCDA)”, *European Transport Research Review*, Vol. 11 No. 22, pp. 1-16.

Nemati, M., Farzipoor Saen, R. and Matin, R.K. (2020), “A data envelopment analysis approach by partial impacts between inputs and desirable-undesirable outputs for sustainable supplier selection problem”, *Industrial Management and Data Systems*, Vol. 121 No. 4, pp. 809-838.

Ortiz-Barrios, M., Gul, M., Lopez-Meza, P., Yucesan, M. and Navarro-Jimenez, E. (2020), “Evaluation of hospital disaster preparedness by a multicriteria decision making approach: the case of Turkish hospitals”, *International Journal of Disaster Risk Reduction*, Vol. 49, 101748.

Patton, W.E. (1996), “Use of human judgment models in industrial buyers’ vendor selection decisions”, *Industrial Marketing Management*, Vol. 1 No. 25, pp. 135-149.

Pearson, J.N. and Ellram, L.M. (1995), “Supplier selection and evaluation in small versus large electronics firms”, *Journal of Small Business Management*, Vol. 33 No. 4, pp. 53-65.

Ransikarbum, K. and Khamhong, P. (2021), “Integrated fuzzy analytic hierarchy process and technique for order of preference by similarity to ideal solution for additive manufacturing printer selection”, *Journal of Materials Engineering and Performance*, Vol. 30, pp. 6481-6492.

Saaty, T.L. (1980), *The Analytic Hierarchy Process*, McGraw-Hill, New York.

Santos, P.H.D., Neves, S.M., Sant’Anna, D.O., Oliveira, C.H. and Carvalho, H.D. (2019), “The analytic hierarchy process supporting decision making for sustainable development: an overview of applications”, *Journal of Cleaner Production*, Vol. 212, pp. 119-138.

Saputro, T.E., Figueira, G. and Almada-Lobo, B. (2022), “A comprehensive framework and literature review of supplier selection under different purchasing strategies”, *Computers Industrial Engineering*, Vol. 167, 108010.

Sarraf, R. and McGuire, M.P. (2020), “Integration and comparison of multi-criteria decision-making methods in safe route planner”, *Expert Systems with Applications*, Vol. 154, 113399.

Schotanus, F., van den Engh, G., Nijenhuis, Y. and Telgen, J. (2021), “Supplier selection with rank reversal in public tenders”, *Journal of Purchasing and Supply Management*, Vol. 28, 100744.

Singh, T., Patnaik, A., Fekete, G., Chauhan, R. and Gangil, B. (2019), “Application of hybrid analytical hierarchy process and complex proportional assessment approach for optimal design of brake friction materials”, *Polymer Composites*, Vol. 40 No. 4, pp. 1602-1608.

Swift, C.O. (1995), "Preferences for single sourcing and supplier selection criteria", *Journal of Business Research*, Vol. 32, pp. 105-111.

Teng, J.Y. and Tzeng, G.H. (1989), "The analytic hierarchy process: concepts, techniques and applications (I)", *Journal of the Chinese Statistical Association*, Vol. 27, pp. 5-22.

Tong, L.Z., Wang, J. and Pu, Z. (2022), "Sustainable supplier selection for SMEs based on an extended PROMETHEE II approach", *Journal of Cleaner Production*, Vol. 330, 129830.

Valahzaghard, M.K., Mozaffari, M.M., Valahzaghard, H.K. and Memarzade, M. (2011), "Supplier selection by using fuzzy Delphi, fuzzy AHP, and SIR VIKOR", *American Journal of Scientific Research*, Vol. 35, pp. 24-45.

Vijayakumar, Y., Rahim, S.A., Ahmi, A. and Rahman, N.A. (2019), "Investigation of supplier selection criteria that leads to buyer-supplier long term relationship for semiconductor industry", *International Journal of Supply Chain Management*, Vol. 8 No. 3, pp. 982-993.

Volza (2022). *Refractory materials exports from Taiwan*. Export data with price, buyer, supplier, HSN code, available at: https://www.volza.com/p/refractory-materials/export/export-from-taiwan/

Wadhwa, V. and Ravindran, A.R. (2007), "Vendor selection in outsourcing", *Computers and Operations Research*, Vol. 34 No. 12, pp. 3725-3737.

Wang, Y.C. and Chen, T. (2021), "A Bi-objective AHP-MINLP-GA approach for flexible alternative supplier selection amid the covid-19 pandemic", *Soft Computing Letters*, Vol. 3, 100016.

Wang, Y.C., Chen, T. and Yeh, Y.L. (2019), "Advanced 3D printing technologies for the aircraft industry: a fuzzy systematic approach for assessing the critical factors", *The International Journal of Advanced Manufacturing Technology*, Vol. 105 No. 10, pp. 4059-4069.

Wetzstein, A., Hartmann, E., Benton, W.C. and Hohenstein, N.O. (2016), "A systematic assessment of supplier selection literature – state-of-the-art and future scope", *International Journal of Production Economics*, Vol. 182, pp. 304-323.

Wilson, E.J. (1994), "The relative importance of supplier selection criteria: a review and update", *International Journal of Purchasing and Materials Management*, Vol. 30 No. 3, pp. 35-41.

Yeh, C.H. and Chang, Y.H. (2009), "Modeling subjective evaluation for fuzzy group multicriteria decision making", *European Journal of Operational Research*, Vol. 194 No. 2, pp. 464-473.

Yeo, S.F., Tan, C.L., Tseng, M.-L., Tam, S. and San, W.K. (2022), "Factors influencing organic food purchase decision: fuzzy DEMATEL approach", *British Food Journal*, Vol. 124 No. 12, pp. 4567-4591, doi: 10.1108/BFJ-05-2021-0509.

Zhang, J.Z., Srivastava, P.R. and Eachempati, P. (2021), "Evaluating the effectiveness of drones in emergency situations: a hybrid multicriteria approach", *Industrial Management and Data Systems*, Vol. 123 No. 1, pp. 302-323, doi: 10.1108/IMDS-01-2021-0064.

Further reading

Lin, Y.T., Lin, L., Yu, H.C. and Tzeng, G.H. (2010), "A novel hybrid MCDM approach for outsourcing vendor selection: a case study for a semiconductor company in Taiwan", *Expert Systems with Applications*, Vol. 37 No. 7, pp. 4796-4804.

O'Neil, B.F. and Iveson, J.L. (1991), "An operational procedure for prioritising customer service elements", *Journal of Business Logistics*, Vol. 12 No. 2, pp. 157-191.

Ramanathan, R. (2007), "Supplier selection problem: integrating DEA with the approaches of total cost of ownership and AHP", *Supply Chain Management*, Vol. 12 No. 4, pp. 258-261.

Roux, H.J. (1982), *A Discussion of Fire Risk Assessment. Fire Risk Assessment*, ASTM STP762, USA, pp. 16-27.

Sen, C.G., Sen, S. and Baslgil, H. (2010), "Pre-selection of suppliers through an integrated fuzzy analytic hierarchy process and max-min methodology", *International Journal of Production Research*, Vol. 48 No. 6, pp. 1603-1625.

Shaw, K., Shankar, R., Yadav, S.S. and Thakur, L.S. (2012), "Supplier selection using fuzzy AHP and fuzzy multi-objective linear programming for developing low carbon supply chain", *Expert Systems with Applications*, Vol. 39 No. 9, pp. 8182-8192.

Spring, M. and Boaden, R. (199), "One more time: how do you win order?: a critical reappraisal of the Hill manufacturing strategy framework", *International Journal of Operations and Production Management*, Vol. 17 No. 8, pp. 757-779.

Tagaras, G. and Lee, H.L. (1996), "Economic models for vendor selection with quality cost analysis", *Management Science*, Vol. 42 No. 11, pp. 1531-1543.

Weber, C.A. (1991), "Vendor selection criteria and methods", *European Journal of Operational Research*, Vol. 50 No. 1, pp. 2-18.

Corresponding author
Cheng Ling Tan can be contacted at: tanchengling@usm.my