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Developing and Applying a Selection Model for Corrugated Box Precision Printing Machine Suppliers

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Abstract: Corrugated box printing machines are precision equipment produced by markedly few manufacturers. They involve high investment cost and risk. Having a corrugated box precision printing machine (CBPPM) supplier with a good reputation enables a corrugated box manufacturer to maintain its competitive advantage. Accordingly, establishing an effective CBPPM supplier selection model is crucial for corrugated box manufacturers. This study established a two-stage CBPPM supplier selection model. The first stage involved the use of a modified Delphi method to construct a supplier selection hierarchy with five criteria and 14 subcriteria. In the second stage, an analytic network process was employed to calculate the weights of criteria and subcriteria and to determine the optimal supplier. According to the results, the five criteria in the model, in descending order of importance, are quality, commitment, cost, service attitude, and reputation. This model can provide insights for corrugated box manufacturers formulating their CBPPM supplier selection strategy.

Keywords: corrugated box printing machine; modified Delphi method; analytic network process (ANP); supplier

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1. Introduction

The global e-commerce market is rapidly developing, with exponential growth in online and TV shopping as well as demand for global shipping. Because most products purchased online or through TV shopping channels (e-commerce) are packaged using corrugated boxes for shipping, the development of e-commerce has contributed to the growth of the corrugated box industry. According to Smithers Pira [1], the global packaging market attained a value of US$917 billion in 2019. Research and Markets (2019) revealed that the corrugated box market reached a value of US$184.377 billion in 2019. Corrugated boxes have become the most adopted packaging materials in the packaging industry. With the continuous and rapid development of the e-commerce market, corrugated boxes, as the main packaging products, will inevitably grow rapidly accompanied with the development of the packaging industry, thus driving the rapid growth of the corrugated box precision printing machine equipment industry. For Tsao (2011) [2], the corrugated box precision printing machine is accompanied by the development of the corrugated box packaging industry. The main manufacturers of the corrugated box precision printing machine industry are currently concentrated in Europe, the United States, Japan, South Korea, Taiwan and China. Manufacturers with advanced production technology in Japan and Taiwan in the Asian region, mainly in the high-tech field, provide the best marketing and after-sales service system in the corrugated box printing machine manufacturers [3].

In the booming Internet and TV shopping consumption era, these consumer packaging have gradually become a visible part of people's lives. The increasing variety of consumer products and complexity of shipping methods have contributed to the importance of corrugated boxes as a packaging material. The demand for corrugated boxes is rapidly growing worldwide, contributing to the development of the corrugated box precision printing machine (CBPPM) industry. The sales value of the global CBPPM industry grew from US$5.499 billion in 2014 to US$7.312 in 2019, and the growth trend is expected to continue (Figure 1). As people's standard of living improves, they expect better appearance and quality of paper boxes rather than just basic paper box packaging. These expectations are closely related to the development of the CBPPM industry and spur market demands for corrugated boxes and for corrugated box precision printing machines.

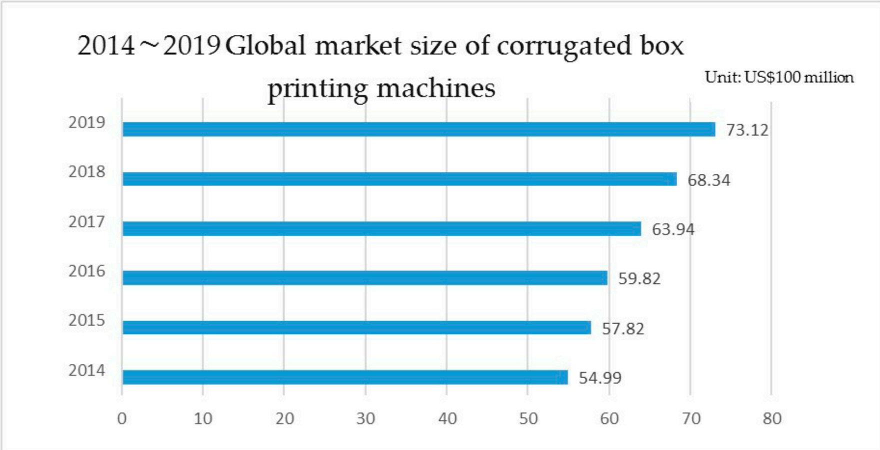

Figure 1. Global market size of corrugated box printing machines [4].

Despite such a large business opportunity in the global CBPPM industry, global manufacturers face challenges such as high investment cost, long research and development (R&D) periods, consumer demand for customization, and high risk. Accordingly, the establishment of a decision-making model for the selection of CBPPM suppliers has become critical for corrugated box manufacturers to maintain their competitive advantage.

The selection of suppliers is a crucial but complex decision-making problem, and its ultimate goal is to find sustainable suppliers with the best potential of providing raw materials and components within a cost budget. According to Ptak and Schragenhiem [5], disruptions in the procurement process can undermine productivity, leading to serious consequences such as bad reputation caused by late delivery or the loss of customers. Therefore, suppliers play a crucial role in procurement activities. In the competitive global environment, most businesses have revisited their procurement strategy and established partnerships with their key suppliers. Despite its recognized importance, cost reduction is not the only critical factor. This study can provide insights into decision making strategies and sustainable operations that can be adopted by the CBPPM industry.

2. Literature Review

2.1. Supplier Selection

The selection of suppliers is critical. Having an appropriate supplier enables a company to offer competitive prices, deliver the correct quantity of products on time, produce high-quality products, and enhance its corporate image and reputation. Labib [6] considered product quality and delivery to be of greater importance than cost. Tam and Tummala [7] argued that the selection criteria for telecommunication service suppliers include quality, cost, problem-solving skills, expertise, delivery time, the ability to satisfy consumer needs, experience, and reputation. Liao and Kao [8] evaluated suppliers with the following criteria: depth of relationship, quality, shipping ability, guaranteed standard, and experience. Basnet [9] suggested that for both local and international businesses, quality, the ability to deliver on time, and performance are the most critical elements in supply chain management.

An excellent supplier satisfies a company's demands for raw materials, products, quality, and services. A company cannot find a high-quality and cost-efficient supplier without having a plan. A critical competency of a procurement specialist is to, by using a rigorous and systematic method, find, evaluate, and select the most suitable supplier for a company [10]. Hsu [11] proposed the following evaluation methods for supplier selection: (a) benchmarking, (b) categorical method, (c) weighted-point method, (d) cost-ratio method, and (e) unit total cost. Considering conflicts among supplier selection indicators, Shirouyehzad [12] employed a strengths–weaknesses–opportunities–threats analysis to evaluate suppliers qualitatively and quantitatively; Shirouyehzad used the technique for order performance by "similarity to the ideal solution" to determine the weights of indicators and adopted a linear planning method to allocate orders. Supplier evaluation methods fall into three major categories: qualitative analyses, quantitative analyses, and methods combining qualitative and quantitative analyses.

Chin [13] defined suppliers as business entities that provide products or services to a buyer and charge the buyer with remuneration in return; such provision encompasses raw materials, equipment, tools, and other resources. The management of suppliers involves active attitudes gradually established in the process of communication and interaction with the suppliers [14]. Shima Aghai [15] proposed a fuzzy multiobjective planning model that incorporates a wide range of factors, namely qualitative, quantitative, risk, and volume discount factors, in supplier selection; this model can be used to select suppliers and optimize supply volume. Supplier selection largely determines subsequent endeavors of establishing buyer–supplier partnerships and increasing supplier capabilities through supplier development programs [16]. The importance of this process for companies is reflected in the final price of products. The price of raw materials, as the main part of the product, is crucial [17,18]. Supplier selection is among the key tasks of supply management [19]. Accordingly, this study constructed a supplier selection model suitable for CBPPM suppliers to help companies maintain competitive advantage.

2.2. Analytic Network Process

The analytic network process (ANP) involves using pairwise comparisons to reveal the relative importance of decision-making features at each level on a 1–9 ratio scale. Establishing a pairwise comparison matrix, calculating the eigenvalue and eigenvector, and conducting a consistency test can avoid evaluation accuracy being undermined by the decision maker's adoption of multiple criteria. The levels are then aggregated to yield a priority vector of the relative importance of alternatives; subsequently, the optimal alternative is determined according to their relative weights as indicated in the vector. ANP, whose theory and application were introduced by Saaty [20], is derived from the analytical hierarchy process (AHP) and is aimed at solving problems involving dependence and feedback among elements in decision making. Overall, the ANP is a mathematical theory capable of solving dependence and feedback problems systematically.

The ANP comprises four steps: (1) constructing a hierarchical structure of the problem, (2) establishing the pairwise comparison matrix and calculating the eigenvector, (3) obtaining the supermatrices and weights, and (4) determining the optimal alternative.

Step 1: Constructing a Hierarchical Structure of the Problem

Determine the decision-making problem and construct a hierarchical structure for the problem; and describe the problem in detail and divide it into a hierarchical network.

Saaty [21] divided the ANP into two parts. The first part involves evaluating the network relationships between criteria and subcriteria; these relationships affect the relationships within a system. The second part is constituted by the network relationships between elements and clusters. According to a network system can be divided into various clusters to form a complex network structure. Figure 2a,b conceptualizes the AHP and ANP, respectively. Saaty [20] presented the interdependent relationships between clusters and elements in a diagram and used arrows to indicate relationships and interaction between them. For example, Figure 2b depicts interdependent elements.

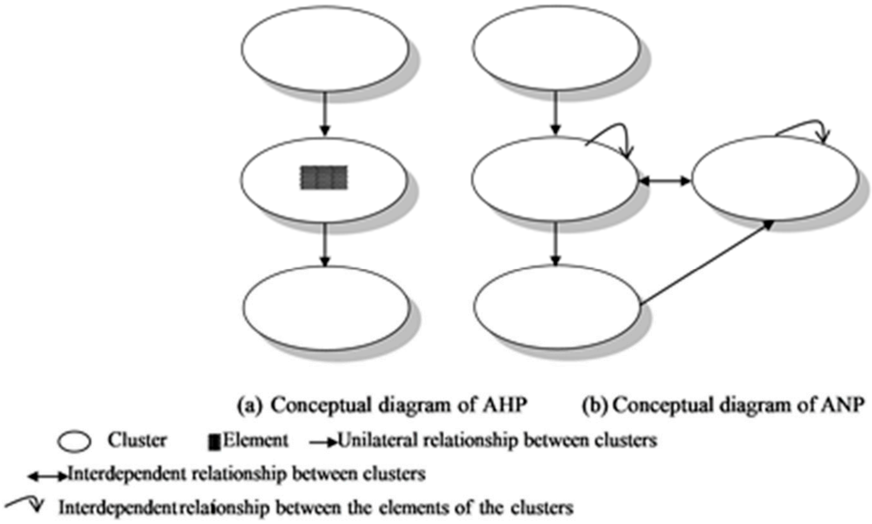

Figure 2. Conceptual diagrams of the analytical hierarchy process (AHP) and analytic network process (ANP) [22].

Step 2: Establishing the Pairwise Comparison Matrix and Calculating the Eigenvector

Saaty [20] recommended the use of the 1–9 ratio scale in pairwise comparison. In ANP pairwise comparisons, the limiting influence of each criterion is calculated to establish the supermatrices.

The pairwise comparison matrix (A) is formed by experts making pairwise comparisons between criteria. Through a hierarchical analysis, the eigenvector (W) of the maximum eigenvalue (λmax) is obtained to satisfy the equation A $\times$ W = λmax $\times$ W. Then, λmax can be used to calculate the consistency index (CI); a satisfactory consistency level is indicated by CI $\leq$ 0.1. According to Saaty [23], a CI < 0.1 suggests the judgments made by experts are consistent. CI and consistency ratio are calculated using the following equations:

$$\mathrm{CI} = \frac{\lambda_{\max} - \mathrm{n}}{n - 1} \tag{1}$$

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{2}$$

RI = random index.

Step 3: Obtaining the Supermatrices and Weights

The supermatrices comprise an unweighted supermatrix, a weighted supermatrix, and a limiting supermatrix, which can be used to obtain the weights of criteria and subcriteria.

A supermatrix is composed of various submatrices, and each ratio scale in the submatrices represents the influence of elements in a cluster on elements in other clusters (i.e., outer dependence) or on other elements in the same cluster (i.e., inner interdependence). Finally, the criteria and subcriteria of all dimensions are listed (respectively) at the left and top of a matrix to form a complete supermatrix, as shown in (3).

Because an unweighted supermatrix (W) may not be column-stochastic (i.e., each column does not sum to (1), it must be converted using the following process. No conversion is needed if the dimension column is stomatic (sum = 1). For nonstochastic columns, relative importance is applied on the submatrix of criteria columns to obtain the weighted supermatrix (W'). Subsequently, the supermatrix is subject to a limiting process, namely raising W' to the power of 2k + 1 (k is an arbitrarily large number) until the interdependent relationships converge, to obtain the relative weights of criteria [20].

$$
W = \begin{array}{cc} & \begin{array}{ccc} \begin{array}{c} C_1 \\ e_{11} \cdots e_{1m_1} \end{array} & \begin{array}{c} C_2 \\ e_{21} \cdots e_{2m_2} \end{array} \cdots\cdots & \begin{array}{c} C_n \\ e_{n_1} \cdots e_{nm_n} \end{array} \end{array} \\
\begin{array}{cc} C1 & \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1m_1} \end{array} \\ C2 & \begin{array}{c} e_{21} \\ e_{22} \\ \vdots \\ e_{2m_2} \end{array} \\ C_n & \begin{array}{c} e_{n_1} \\ e_{n_2} \\ \vdots \\ e_{nm_n} \end{array} \end{array} & \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1n} \\ W_{12} & W_{22} & \cdots & W_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ W_{n1} & W_{n2} & \ldots & W_{nn} \end{bmatrix} \end{array} \quad (3)
$$

As an example, the following is the supermatrix (W_h) of a three-level hierarchical structure [20]:

$$
W_h = \begin{bmatrix} 0 & 0 & 0 \\ W_{21} & 0 & 0 \\ 0 & W_{32} & I \end{bmatrix} \quad (4)
$$

where W_{21} is the eigenvector of criteria under the decision-making goal, W_{32} is the eigenvector of the pairwise comparison matrix between alternatives under each criterion, and I is the identity matrix; a 0 indicates the relationship between identical or two independent elements or criteria without interdependences.

For interdependent criteria, a network structure must be used in place of a hierarchical structure. Accordingly, the supermatrix is updated to W_n in (5), where W_{22} represents the interdependence of the criteria [20].

$$
W_n = \begin{bmatrix} 0 & 0 & 0 \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & W_{33} \end{bmatrix} \quad (5)
$$

This study employed the *ANP* to obtain the weights of elements and weights. Therefore, W_n must be modified as W'_n, as presented in (6).

In (6), W_{22} and W_{33} respectively represent the interdependence weights of the elements and criteria.

$$
W'_n = \begin{bmatrix} 0 & 0 & 0 \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & W_{33} \end{bmatrix} \quad (6)
$$

The exponent of the matrix reaches an extremum where the matrix converges, thus the extremum holds constant. To achieve matrix convergence, the weighted supermatrix is raised to the power of $2k + 1$, where $k \to \infty$, as in (7). This yields a new matrix, the limiting supermatrix (W_{ANP}; [20]), and the finalized weights of criteria and subcriteria can then be obtained.

$$
W_{ANP} = \lim_{k \to \infty} (W'_n)^{2k+1} \quad (7)
$$

Step 4: Determining the Optimal Alternative

According to the limiting supermatrix W_{ANP} in (7), the weights can be obtained through multiple matrix calculations. These weights are then used as the basis for arranging the priority of alternatives.

3. Proposed Model

This study established a two-stage CBPPM supplier selection model. In Stage 1, a modified Delphi method and content validity ratio were used to determine the criteria and subcriteria for supplier selection as well as the interdependence between criteria and subcriteria. In Stage 2, the ANP was used to calculate the weights of criteria and subcriteria.

The two-stage supplier selection model is as follows [24–26]:

3.1. Stage 1: Establish a Hierarchical Network

This stage involves the use of the modified Delphi method comprising four steps, as follows [27,28]:

1. Step 1: Define the criteria.
2. Step 2: Convene an expert panel.
3. Step 3: Conduct a questionnaire survey on the panel.
4. Step 4: Determine the standard of consistency within the panel.

3.2. Stage 2: Select the Optimal Supplier with the ANP

This stage involves the four steps of ANP, as follows [18]:

1. Step 1: Establish the pairwise comparison matrix.
2. Step 2: Calculate the eigenvalue and eigenvector.
3. Step 3: Form the supermatrix and obtain the weights.
4. Step 4: Select the optimal procurement alternative.

4. Results and Discussion

SUNRISE, established in 1996 with a capital of NT$150 million, is a CBPPM manufacturer that sells machines mostly to paper box manufacturers in Taiwan, China, Europe, Southeast Asia, Middle America, and the Middle East. With a revenue of US$36 million in 2019, it is now the largest CBPPM manufacturer in Asia and the second largest in the world. It has thus become the hidden champion of the industry in the Taiwanese market, with patents in various countries. The high-capacity fixed-type CBPPM is its most precise, expensive, and sold machine. This CBPPM (Figure 3), which can print more than 300 color corrugated boxes per minute, contributes nearly 35% of the company's revenue (http://www.sunrisemachinery.com) [29].

Figure 3. High-capacity fixed-type corrugated box precision printing machine (CBPPM) (http://www.sunrisemachinery.com).

The CBPPM industry is relatively closed compared with other industries in Taiwan. Despite the enormous business opportunity in CBPPM manufacturing, no more than 30 CBPPM manufacturers exist in Taiwan. The R&D of CBPPMs involve an extremely high cost and a 3–5-year period (or longer). The R&D and sales expenses for a CBPPM total more than US$3 million. Although a new CBPPM has a product life cycle of more than 10 years on average, its high investment cost and slow return on investment discourage new investors. The industry also has high entry barriers because it involves (1) complex and specialized technologies, (2) specialized assembly technicians who require extensive training, and (3) a high level of working capital. A monthly working capital of more than US$120 million is required for the warehousing of components alone. Accordingly, procurement plays a critical role in the operation of a CBPPM manufacturer, which must establish a collaborative supply chain management system that integrates upstream and downstream suppliers well to shift from the red ocean strategy—which focuses on competition and price cuts—toward the blue ocean strategy, manufacturing products of high value at low cost [30].

This study adopted SUNRISE as an example and optimized its supplier selection process for the five firms that supply the most electronic control components to it. The optimization was conducted using the modified Delphi method and ANP to verify the feasibility of the study's proposed supplier selection model based on these two methods.

This study used the five firms as alternatives to conduct a supplier selection process as follows.

4.1. Stage 1: Establish a Hierarchical Network

Step 1: Define the Criteria

Six key members of SUNRISE (board director, director of plant operations, chief R&D officer, chief procurement officer, junior procurement officer, and procurement specialist) were invited to determine 11 criteria and 64 subcriteria for the supplier selection (Table 1).

Table 1. Criteria and subcriteria determined by six key members of SUNRISE.

Criteria	Definition	Subcriteria
Organization management	Effective process of realizing organizational goals through interaction, coordination, collaboration, and task delegation among all organization members, facilitated by establishing organizational structure, job roles or titles, and clear responsibilities and liabilities	(1) Emergency response (2) Employer–employee relationship (3) Government policy (4) Competitor behavior (5) Competitive analysis of the industry
Financial position	Management of asset purchases (investment), capital loans (financing), operation cash flows (working capital), and profit allocation given the overall goals	(1) Financial stability (2) Property risk management (3) Activity ratio (4) Investment in derivatives
Quality	Whether the product or service conforms to or surpasses the client's expectation	(1) Continuous improvement (2) Product reliability (3) Quality records (4) Solving quality problems (5) Quality management system for substandard products (6) Repair and compensation claims
Delivery	(1) The period between when an order is placed and its delivery by the supplier (2) Delivery = time spent in administrative procedure + procurement + production + shipping + inspection + other operations	(1) Stable supply of orders (2) Commitment to the delivery of orders (3) Accuracy and reliability of supply (4) On-time delivery (5) Ability to deliver orders at short notice (6) Ability to manage inventory
Commitment	A contract made with mutual agreement of all parties	(1) Commitment to orders (2) Stable supply (3) Accuracy and reliability (4) Speed of delivery (5) Commitment to the delivery time

Table 1. *Cont.*

Criteria	Definition	Subcriteria
Cost	All costs incurred during a company's acquisition of products or services and all expenses, which are the cost invested by a company in its business activities to make profit	(1) Procurement cost (2) Reflects real-time prices (3) Transportation cost (4) Price competitiveness (5) Ability to negotiate prices (6) Controlling price with volume (7) Discounts for cash payment
Production capacity	The maximum volume of products produced or raw materials processed by all fixed assets in a company within the contract period and under the given technological conditions	(1) Product stability (2) Production capacity and output value (3) Productivity (4) Expected sales and production capacity (5) Contracting or outsourcing
Technical capability	The level of understanding of and familiarity with a certain activity, particularly interaction with others, in relation to a method, process, program, or technique	(1) Ability to continuously improve (2) Ability to innovate techniques (3) Ability to provide technical support (4) Ability to change designs (5) Core technical skills
Service attitude	An activity or a benefit that is provided by one party to another, is intangible, and does not involve change of rights in remuneration	(1) Continuously reporting back to client (2) Attitude (3) Ability to manage customer complaints (4) Ability to supply spare parts (5) Negotiation with suppliers (6) Ability to conduct training (7) Maintenance of product safety (8) After-sales repair (9) After-sales services
Reputation	The sum of a company's value-creation capabilities generated from its acquisition of recognition by society and then of resources, opportunities, and support	(1) Integrity (2) Value of business reputation (3) Business competitiveness (4) Enhancement of corporate value (5) Improvement of profit (6) Corporate social responsibility (7) Profit increase (8) Financial robustness
Environmental protection product management	Manufacturing, use, and processing of products, conforming to environmental requirements, causing no or very little harm to the environment and conducive to resource circulation and product repurposing	(1) RoHS Regulations on Banned Substances in Components (2) RoHS monitoring and documentation on inbound materials (3) RoHS training (4) Provision of guarantee and a third-party report

Step 2: Convene an Expert Panel

According to Murry and Hammons [28], the appropriate size of an expert panel is more than 10 members, but an excessively large panel (with more than 30 members) can complicate the research work and create difficulty for the panel to reach a conclusion. On this basis and in consideration of feasibility and available research resources, the present study determined that the expert panel size be 23 members from the industry, government, and academia (Table 2).

Table 2. Composition of the expert panel.

Expert Category	Place of Employment	Number of People	Percentage (%)
Industry	Manufacturers specializing in the design, production, and sale of CBPPMs (each with over 20 years of experience in selling and manufacturing CBPPMs [note 1])	12	52.17
Government	Bureau of Foreign Trade (Ministry of Economic Affairs); Industrial Development Bureau (Ministry of Economic Affairs); Taiwan External Trade Development Council; National Taiwan Bureau of Taipei (Ministry of Finance)	5	21.74
Academia	Five from academic institutions; one from The Global Logistics & Commerce Council of Taiwan	6	26.09
	Total	23	100

Six manufacturers were interviewed; four completed a questionnaire.

Step 3: Conduct a Questionnaire Survey on the Panel

The first survey was administered to 23 experts who expressed their willingness to participate through mail; 20 questionnaire responses were returned for a response rate of 86.96%. Subsequently, a second survey was administered to the 20 experts (i.e., excluding the three who did not return a response) along with statistical charts for the first survey. In the second survey, 20 questionnaires were distributed, and all were returned. This study employed a two-round modified Delphi method, repeating the administration of the survey until consensus was established (Table 3).

Table 3. Comparison of survey response rates in the two-round modified Delphi method.

Category	First Round	Second Round
Number of copies distributed	23	20
Number of responses	20	20
Response rate (%)	86.96	100

Step 4: Determine the Standard of Consistency within the Panel

After a preliminary version of the questionnaire was created, the modified Delphi method was used to verify its content. A total of 20 experts from industry, government, and academia were recruited to determine the validity of the items. The experts were asked to rate each item on a 5-point Likert scale (1 = *Very dissatisfied* to 5 = *Very satisfied*) according to its appropriateness and relevance to the research topic as well as to determine the importance of each criterion and subcriterion. The content validity ratio (CVR) formula proposed by Lawshe [31] was employed to calculate the level of agreement among the experts. The ratings were used to calculate the CVR; in this study, a rating = 5 was determined to be the standard. Specifically, the CVR for each expert was calculated by dividing the number of items rated as 5 points by the total number of items. The CVRs for the 20 experts ranged between 0.7 and 1.00. This indicated the content validity of the questionnaire, with an average CVR ≥ 0.7 [32].

After deleting criteria and subcriteria with a CVR < 0.7, five criteria and 14 subcriteria remained. The five criteria were quality, commitment, cost, service attitude, and reputation. The 14 subcriteria were product reliability, quality management system for substandard products, commitment to orders, stable supply, accuracy and reliability, on-time delivery, price reduction, price competitiveness, attitude, ability to manage customer complaints, negotiation with suppliers, after-sales services, integrity, and profit increase. On the basis of the experts' input, the criteria were interdependent (Figure 4); inner interdependence was present between subcriteria (Table 4). According to these results, the CBPPM supplier selection hierarchical network was established (Figure 5).

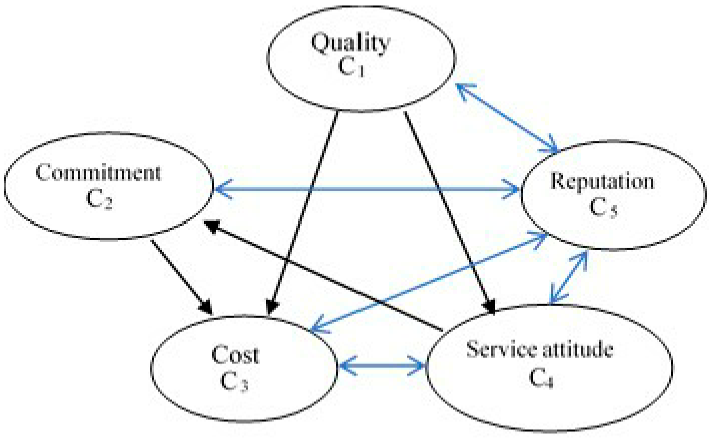

Figure 4. Relationships among CBPPM supplier selection criteria.

Table 4. Relationships among CBPPM supplier selection subcriteria.

Criteria	Subcriteria	Relationship
Quality (C_1)	Product reliability (C_{11})	Interdependent with C_{21}, C_{22}, C_{23}, C_{24}, C_{31}, and C_{32}
	Quality management system for substandard products (C_{12})	Interdependent with C_{21}, C_{22}, C_{23}, C_{24}, C_{31}, and C_{32}
Commitment (C_2)	Commitment to orders (C_{21})	Interdependent with C_{11}, C_{12}, C_{31}, and C_{32}
		Unilaterally dominant over C_{51} and C_{52}
	Stable supply (C_{22})	Interdependent with C_{11}, C_{12}, C_{31}, and C_{32}
		Unilaterally dominant over C_{51} and C_{52}
	Accuracy and reliability (C_{23})	Interdependent with C_{11}, C_{12}, C_{31}, and C_{32}
		Unilaterally dominant over C_{43} and C_{44}
	On-time delivery (C_{24})	Interdependent with C_{11}, C_{12}, C_{31}, and C_{32}
		Unilaterally dominant over C_{41}, C_{42}, and C_{43}
Cost (C_3)	Price reduction (C_{31})	Interdependent with C_{11}, C_{12}, C_{21}, C_{22}, C_{23}, C_{24}, C_{43}, and C_{52}
	Price competitiveness (C_{32})	Interdependent with C_{11}, C_{12}, C_{21}, C_{22}, C_{23}, C_{24}, C_{42}, and C_{51}
Service attitude (C_4)	Attitude (C_{41})	Unilaterally dominant over C_{11}, C_{12}, C_{31}, C_{32}, and C_{51}
	Ability to manage customer Complaints (C_{42})	Interdependent with C_{32} and C_{51}
		Unilaterally dominant over C_{11}, C_{12}, C_{31}, and C_{52}
	Negotiation with suppliers (C_{43})	Interdependent with C_{31} and C_{51}
		Unilaterally dominant over C_{11}, C_{12}, and C_{32}
	After-sales services (C_{44})	Unilaterally dominant over C_{11}, C_{12}, C_{31}, C_{32}, and C_{51}
Reputation (C_5)	Integrity (C_{51})	Interdependent with C_{32}, C_{43}, and C_{52}
		Unilaterally dominant over C_{11}, C_{12}, C_{31}, and C_{42}
	Profit increase (C_{52})	Interdependent with C_{31} and C_{51}
		Unilaterally dominant over C_{11}, C_{12}, and C_{32}

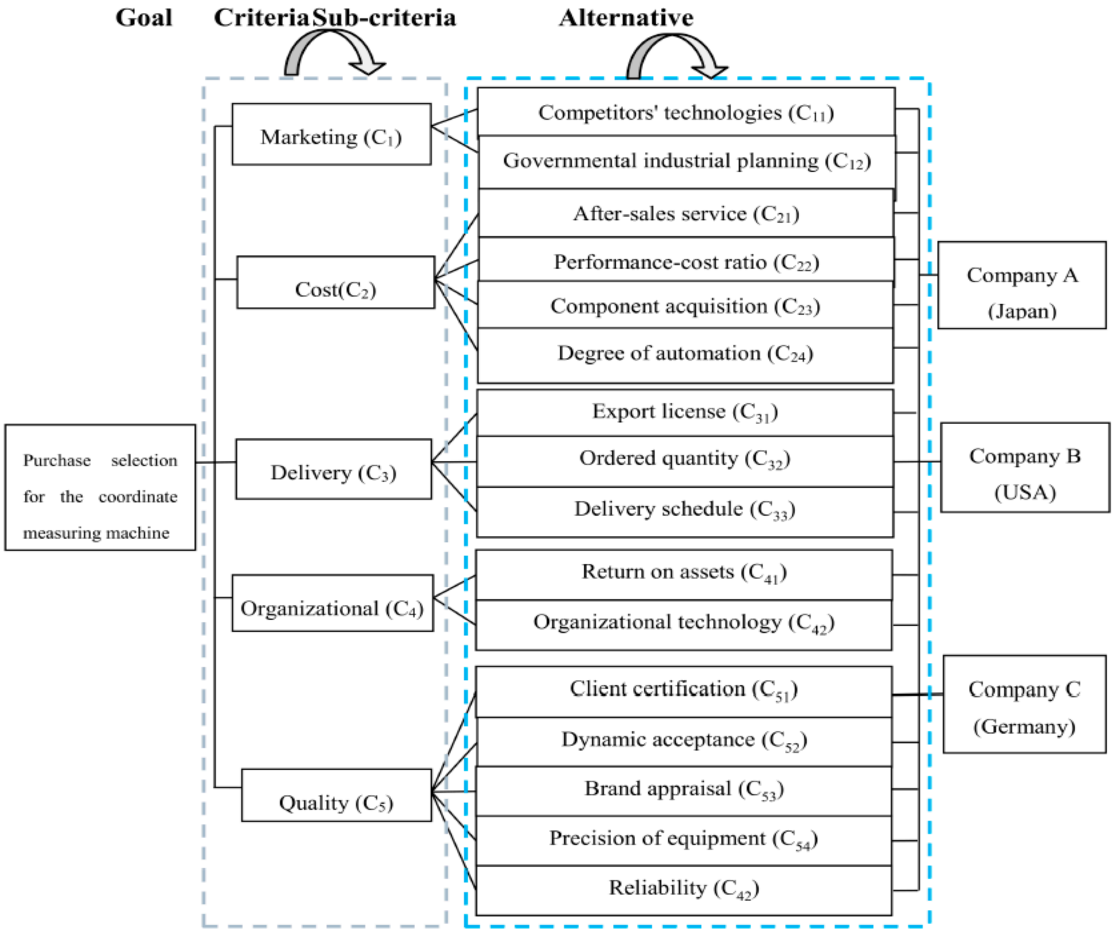

Figure 5. Hierarchical network for CBPPM supplier selection.

4.2. Stage 2: Select the Optimal Supplier with the ANP

Step 1: Establish the Pairwise Comparison Matrix

A panel of 20 experts was convened to determine the relative importance of each criterion in the ANP questionnaire. Table 5 depicts the resulting pairwise comparison matrix W_{21}.

Table 5. Pairwise comparison matrix W_{21} and the eigenvector.

Criteria	Quality (C_1)	Commitment (C_2)	Cost (C_3)	Service Attitude (C_4)	Reputation (C_5)	Eigenvector
Quality C_1	1	2	5	5	3	0.4206
Commitment C_2	0.5000	1	4	3	3	0.2827
Cost C_3	0.2000	0.2500	1	3	0.5000	0.0985
Service attitude C_4	0.2000	0.3333	0.3333	1	0.5000	0.0655
Reputation C_5	0.3333	0.3333	2	2	1	0.1327

(1) λmax = 5.2394; (2) CI = 0.0598 and consistency ratio (CR) = 0.0534 $\leq$ 0.1.

Step 2: Calculate the Eigenvalue and Eigenvector

Super Decisions software was used to calculate the maximum eigenvalue λ_{max} = 5.2394 and corresponding eigenvector x = (0.4206, 0.2827, 0.0985, 0.0655, 0.1327, rightmost column of Table 5) for the pairwise comparison matrix.

Equations (1) and (2) were used to obtain CI = 0.0598 and CR = 0.0534, both of which indicate satisfactory consistency.

Step 3: Form the Supermatrix and Obtain the Weights

After calculating the weights for W_{21}, the eigenvector matrix W_{32} was formed. For example, the pairwise comparison matrix and eigenvector for subcriteria C_{11} and C_{12} under criterion C_1 are presented in Table 6. Table 7 compiles W_{21} and W_{32}.

Table 6. Pairwise comparison matrix and eigenvector for subcriteria under criterion C_1.

Subcriteria Under C_1	Product Reliability (C_{11})	Quality Management System for Substandard Products (C_{12})	Eigenventor
Product reliability (C_{11})	1	4	0.8000
Quality management system for substandard products (C_{12})	0.2500	1	0.2000

(1) λmax = 2.0000; (2) CI = 0 and CR = 0 $\leq$ 0.1.

Table 7. Weights for criteria and subcriteria.

Criteria	Criteria Weight (W_{21})	Subcriteria	Subcriteria Weight (W_{32})
Quality (C_1)	0.4206	Product reliability (C_{11})	0.8000
		Quality management system for substandard products (C_{12})	0.2000
Commitment (C_2)	0.2827	Commitment to orders (C_{21})	0.0493
		Stable supply (C_{22})	0.2075
		Accuracy and reliability (C_{23})	0.2701
		On-time delivery (C_{24})	0.4731
Cost (C_3)	0.0985	Price reduction (C_{31})	0.1111
		Price competitiveness (C_{32})	0.8889
Service attitude (C_4)	0.0655	Attitude (C_{41})	0.6642
		Ability to manage customer complaints (C_{42})	0.0903
		Negotiation with suppliers (C_{43})	0.0957
		After-sales services (C_{44})	0.1498
Reputation (C_5)	0.1327	Integrity (C_{51})	0.7500
		Profit increase (C_{52})	0.2500

Matrix W_{22} represents the pairwise comparison results for the five criteria with the presence of inner interdependence. The eigenvector matrix formed with the eigenvectors is shown in (8). Matrix W_{33} is the eigenvector matrix representing the pairwise comparison results for the 14 subcriteria with the presence of inner interdependence, as presented in (10).

An unweighted supermatrix is formed by combining matrices W_{21}, W_{22}, W_{32}, and W_{33}, as expressed in (9). Table 8 reveals the details of the supermatrix. In this study, matrices W_{22} and W_{32} are each assigned a weight of 0.5 to obtain the weighted supermatrix (Table 9).

Table 10 illustrates the limiting supermatrix, and Equation (11) provides the weights of all subcriteria (W_{ANP}) [33].

Table 8. Unweighted supermatrix.

Unweighted Super Matrix	***Goal***	**(C_1)**	**(C_2)**	**(C_3)**	**(C_4)**	**(C_5)**	**(C_{11})**	**(C_{12})**	**(C_{21})**	**(C_{22})**	**(C_{23})**	**(C_{24})**	**(C_{31})**	**(C_{32})**	**(C_{41})**	**(C_{42})**	**(C_{43})**	**(C_{44})**	**(C_{51})**	**(C_{52})**
Goal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_1)	0.4206	0.4296	0	0	0	0.1779	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_2)	0.2827	0	0.4806	0	0.1093	0.1982	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_3)	0.0985	0.0784	0.1140	0.1655	0.1093	0.1402	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_4)	0.0655	0.0820	0	0.6098	0.5725	0.2043	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_5)	0.1327	0.4100	0.4054	0.2247	0.2090	0.2793	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_{11})	0	0.8	0	0	0	0	0.2808	0	0.2936	0.4116	0.1736	0.0479	0.2522	0.2176	0.3302	0.3702	0.3495	0.2489	0.0561	0.0466
(C_{12})	0	0.2	0	0	0	0	0	0.4158	0.1587	0.0454	0.0645	0.0520	0.0442	0.0942	0.2869	0.2201	0.2409	0.0986	0.0346	0.0440
(C_{21})	0	0	0.25	0	0	0	0.0292	0.0430	0.0497	0	0	0	0.1451	0.0725	0	0	0	0	0	0
(C_{22})	0	0	0.25	0	0	0	0.1200	0.0459	0	0.1593	0.0341	0	0.1937	0.1582	0	0	0	0	0	0
(C_{23})	0	0	0.25	0	0	0	0.3515	0.0853	0	0	0.1691	0	0.1535	0.1617	0	0	0	0	0	0
(C_{24})	0	0	0.25	0	0	0	0.1004	0.1071	0	0	0.0545	0.1278	0.0921	0.1608	0	0	0	0	0	0
(C_{31})	0	0	0	0.5	0	0	0.0586	0.1324	0.2257	0.0340	0.0447	0.0591	0.0257	0	0.0437	0.0253	0.0286	0.0339	0.0466	0.1211
(C_{32})	0	0	0	0.5	0	0	0.0595	0.1706	0.1849	0.0533	0.0436	0.0513	0	0.0263	0.0437	0.0317	0.0534	0.0427	0.0581	0.2903
(C_{41})	0	0	0	0	0.25	0	0	0	0	0.1261	0	0.1474	0	0	0.1143	0	0	0	0	0
(C_{42})	0	0	0	0	0.25	0	0	0	0	0	0	0.3575	0	0.0420	0	0.0869	0	0	0.1663	0
(C_{43})	0	0	0	0	0.25	0	0	0	0	0.1702	0.1860	0.1570	0.0339	0	0	0	0.0800	0	0.2076	0
(C_{44})	0	0	0	0	0.25	0	0	0	0	0	0.2299	0	0	0	0	0	0	0.2475	0	0
(C_{51})	0	0	0	0	0	0.5	0	0	0.0624	0	0	0	0	0.0666	0.1812	0.1449	0.2476	0.3284	0.3273	0.2687
(C_{52})	0	0	0	0	0	0.5	0	0	0.0250	0	0	0	0.0596	0	0	0.1210	0	0	0.1033	0.2294

Table 9. Weighted supermatrix.

Weighted Super Matrix	***Goal***	**(C_1)**	**(C_2)**	**(C_3)**	**(C_4)**	**(C_5)**	**(C_{11})**	**(C_{12})**	**(C_{21})**	**(C_{22})**	**(C_{23})**	**(C_{24})**	**(C_{31})**	**(C_{32})**	**(C_{41})**	**(C_{42})**	**(C_{43})**	**(C_{44})**	**(C_{51})**	**(C_{52})**
Goal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_1)	0.4206	0.2148	0	0	0	0.0889	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_2)	0.2827	0	0.2403	0	0.0546	0.0991	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_3)	0.0985	0.0392	0.0570	0.0828	0.0546	0.0701	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_4)	0.0655	0.0410	0	0.3049	0.2862	0.1022	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_5)	0.1327	0.2050	0.2027	0.1123	0.1045	0.1397	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_{11})	0	0.4	0	0	0	0	0.2808	0	0.2936	0.4116	0.1736	0.0479	0.2522	0.2176	0.3302	0.3702	0.3495	0.2489	0.0561	0.0466
(C_{12})	0	0.1	0	0	0	0	0	0.4158	0.1587	0.0454	0.0645	0.0520	0.0442	0.0942	0.2869	0.2201	0.2409	0.0986	0.0346	0.0440
(C_{21})	0	0	0.1250	0	0	0	0.0292	0.0430	0.0497	0	0	0	0.1451	0.0725	0	0	0	0	0	0
(C_{22})	0	0	0.1250	0	0	0	0.1200	0.0459	0	0.1593	0.0341	0	0.1937	0.1582	0	0	0	0	0	0
(C_{23})	0	0	0.1250	0	0	0	0.3515	0.0853	0	0	0.1691	0	0.1535	0.1617	0	0	0	0	0	0
(C_{24})	0	0	0.1250	0	0	0	0.1004	0.1071	0	0	0.0545	0.1278	0.0921	0.1608	0	0	0	0	0	0
(C_{31})	0	0	0	0.25	0	0	0.0586	0.1324	0.2257	0.0340	0.0447	0.0591	0.0257	0	0.0437	0.0253	0.0286	0.0339	0.0466	0.1211
(C_{32})	0	0	0	0.25	0	0	0.0595	0.1706	0.1849	0.0533	0.0436	0.0513	0	0.0263	0.0437	0.0317	0.0534	0.0427	0.0581	0.2903
(C_{41})	0	0	0	0	0.1250	0	0	0	0	0.1261	0	0.1474	0	0	0.1143	0	0	0	0	0
(C_{42})	0	0	0	0	0.1250	0	0	0	0	0	0	0.3575	0	0.0420	0	0.0869	0	0	0.1663	0
(C_{43})	0	0	0	0	0.1250	0	0	0	0	0.1702	0.1860	0.1570	0.0339	0	0	0	0.0800	0	0.2076	0
(C_{44})	0	0	0	0	0.1250	0	0	0	0	0	0.2299	0	0	0	0	0	0	0.2475	0	0
(C_{51})	0	0	0	0	0	0.25	0	0	0.0624	0	0	0	0	0.0666	0.1812	0.1449	0.2476	0.3284	0.3273	0.2687
(C_{52})	0	0	0	0	0	0.25	0	0	0.0250	0	0	0	0.0596	0	0	0.1210	0	0	0.1033	0.2294

Table 10. Limiting supermatrix.

Limit Super Matrix	***Goal***	**(C_1)**	**(C_2)**	**(C_3)**	**(C_4)**	**(C_5)**	**(C_{11})**	**(C_{12})**	**(C_{21})**	**(C_{22})**	**(C_{23})**	**(C_{24})**	**(C_{31})**	**(C_{32})**	**(C_{41})**	**(C_{42})**	**(C_{43})**	**(C_{44})**	**(C_{51})**	**(C_{52})**
Goal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_1)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_2)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_3>)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_4)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_5)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C_{11})	0.2094	0.2094	0.2094	0.2094	0.2094	0.2094	0.2094	0.2094	0.2094	0.2094	0.2094	0.2094	0.2094	0.2094	0.2094	0.2094	0.2094	0.2094	0.2094	0.2094
(C_{12})	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139
(C_{21})	0.0257	0.0257	0.0257	0.0257	0.0257	0.0257	0.0257	0.0257	0.0257	0.0257	0.0257	0.0257	0.0257	0.0257	0.0257	0.0257	0.0257	0.0257	0.0257	0.0257
(C_{22})	0.0675	0.0675	0.0675	0.0675	0.0675	0.0675	0.0675	0.0675	0.0675	0.0675	0.0675	0.0675	0.0675	0.0675	0.0675	0.0675	0.0675	0.0675	0.0675	0.0675
(C_{23})	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244	0.1244
(C_{24})	0.0647	0.0647	0.0647	0.0647	0.0647	0.0647	0.0647	0.0647	0.0647	0.0647	0.0647	0.0647	0.0647	0.0647	0.0647	0.0647	0.0647	0.0647	0.0647	0.0647
(C_{31})	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578
(C_{32})	0.0692	0.0692	0.0692	0.0692	0.0692	0.0692	0.0692	0.0692	0.0692	0.0692	0.0692	0.0692	0.0692	0.0692	0.0692	0.0692	0.0692	0.0692	0.0692	0.0692
(C_{41})	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204
(C_{42})	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424	0.0424
(C_{43})	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680
(C_{44})	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380	0.0380
(C_{51})	0.0763	0.0763	0.0763	0.0763	0.0763	0.0763	0.0763	0.0763	0.0763	0.0763	0.0763	0.0763	0.0763	0.0763	0.0763	0.0763	0.0763	0.0763	0.0763	0.0763
(C_{52})	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222

$$
W_{22} = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \end{array} \begin{array}{ccccc} C_1 & C_2 & C_3 & C_4 & C_5 \\ \end{array}
\left[\begin{array}{ccccc} 0.4296 & 0 & 0 & 0 & 0.1779 \\ 0 & 0.4806 & 0 & 0.1093 & 0.1982 \\ 0.0784 & 0.1140 & 0.1655 & 0.1093 & 0.1402 \\ 0.0820 & 0 & 0.6098 & 0.5725 & 0.2043 \\ 0.4100 & 0.4054 & 0.2247 & 0.2090 & 0.2793 \end{array} \right] \quad (8)
$$

$$
W_n = \begin{bmatrix} 0 & 0 & 0 \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & W_{33} \end{bmatrix} \quad (9)
$$

$W_{33} =$ (10)

	C_{11}	C_{12}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{41}	C_{42}	C_{43}	C_{44}	C_{51}	C_{52}
C_{11}	0.2808	0	0.2936	0.4116	0.1736	0.0479	0.2522	0.2176	0.3302	0.3702	0.3495	0.2489	0.0561	0.0466
C_{12}	0	0.4158	0.1587	0.0454	0.0645	0.0520	0.0442	0.0942	0.2869	0.2201	0.2409	0.0986	0.0346	0.0440
C_{21}	0.0292	0.0430	0.0497	0	0	0	0.1451	0.0725	0	0	0	0	0	0
C_{22}	0.1200	0.0459	0	0.1593	0.0341	0	0.1937	0.1582	0	0	0	0	0	0
C_{23}	0.3515	0.0853	0	0	0.1691	0	0.1535	0.1617	0	0	0	0	0	0
C_{24}	0.1004	0.1071	0	0	0.0545	0.1278	0.0921	0.1608	0	0	0	0	0	0
C_{31}	0.0586	0.1324	0.2257	0.0340	0.0447	0.0591	0.0257	0	0.0437	0.0253	0.0286	0.0339	0.0466	0.1211
C_{32}	0.0595	0.1706	0.1849	0.0533	0.0436	0.0513	0	0.0263	0.0437	0.0317	0.0534	0.0427	0.0581	0.2903
C_{41}	0	0	0	0.1261	0	0.1474	0	0	0.1143	0	0	0	0	0
C_{42}	0	0	0	0	0	0.3575	0	0.0420	0	0.0869	0	0	0.1663	0
C_{43}	0	0	0	0.1702	0.1860	0.1570	0.0339	0	0	0	0.0800	0	0.2076	0
C_{44}	0	0	0	0	0.2299	0	0	0	0	0	0	0.2475	0	0
C_{51}	0	0	0.0624	0	0	0	0	0.0666	0.1812	0.1449	0.2476	0.3284	0.3273	0.2687
C_{52}	0	0	0.0250	0	0	0	0.0596	0	0	0.1210	0	0	0.1033	0.2294

$$
W_{ANP} = \begin{array}{c} \\ (C_{11}) \\ (C_{12}) \\ (C_{21}) \\ (C_{22}) \\ (C_{23}) \\ (C_{24}) \\ (C_{31}) \\ (C_{32}) \\ (C_{41}) \\ (C_{42}) \\ (C_{43}) \\ (C_{44}) \\ (C_{51}) \\ (C_{52}) \end{array} \left[\begin{array}{c} \textit{Goal} \\ 0.2094 \\ 0.1139 \\ 0.0257 \\ 0.0675 \\ 0.1244 \\ 0.0647 \\ 0.0578 \\ 0.0692 \\ 0.0204 \\ 0.0424 \\ 0.0680 \\ 0.0380 \\ 0.0763 \\ 0.0222 \end{array} \right] \quad (11)
$$

Table 11 lists the weights of the five alternatives calculated according to the pairwise comparison matrix for subcriterion C_{12} (quality management system for substandard products).

Table 11. Weights of the five alternatives calculated using the pairwise comparison matrix for subcriterion C_{12}.

(C_{12})	**Company A**	**Company B**	**Company C**	**Company D**	**Company E**	**Weight**
Company A	1	3	0.5	0.5	0.3333	0.1470
Company B	0.3333	1	1	0.3333	0.3333	0.1024
Company C	2	1	1	1	1	0.2154
Company D	2	3	1	1	1	0.2538
Company E	3	3	1	1	1	0.2814

(1) λmax = 5.3250; (2) CI = 0.0598 and CR = 0.0534 $\leq$ 0.1.

Table 12 presents the weights of the five alternatives calculated using the pairwise comparison matrices of all subcriteria.

Table 12. Eigenvectors of five alternatives under each criterion.

Alternatives	**(C_{11})**	**(C_{12})**	**(C_{21})**	**(C_{22})**	**(C_{23})**	**(C_{24})**	**(C_{31})**	**(C_{32})**	**(C_{41})**	**(C_{42})**	**(C_{43})**	**(C_{44})**	**(C_{51})**	**(C_{52})**
Company A	0.3274	0.1470	0.2346	0.2183	0.2086	0.2909	0.1033	0.0957	0.0787	0.1421	0.0566	0.0718	0.1688	0.0877
Company B	0.1299	0.1024	0.1660	0.0986	0.2630	0.1470	0.1818	0.1599	0.1814	0.1459	0.1308	0.1388	0.1601	0.1498
Company C	0.1331	0.2154	0.1978	0.0888	0.0947	0.1062	0.1377	0.1733	0.1814	0.0878	0.1218	0.0988	0.1217	0.2148
Company D	0.2383	0.2538	0.1694	0.2730	0.2881	0.2479	0.2256	0.2428	0.3149	0.4103	0.5491	0.2862	0.2435	0.2739
Company E	0.1714	0.2814	0.2321	0.3213	0.1457	0.2080	0.3515	0.3283	0.2435	0.2139	0.1417	0.4045	0.3059	0.2739

Step 4: Select the Optimal Procurement Alternative

On the basis of (11) and Table 12, the priority vector of the five alternatives is obtained, as shown in (12).

$$\begin{array}{c} \\ \mathbf{A} \\ \mathbf{B} \\ \mathbf{C} \\ \mathbf{D} \\ \mathbf{E} \end{array}
\begin{array}{c}
\begin{array}{cccccccccccccc} C_{11} & C_{12} & C_{21} & C_{22} & C_{23} & C_{24} & C_{31} & C_{32} & C_{41} & C_{42} & C_{43} & C_{44} & C_{51} & C_{52} \end{array} \\
\begin{bmatrix}
0.3274 & 0.1470 & 0.2346 & 0.2183 & 0.2086 & 0.2909 & 0.1033 & 0.0957 & 0.0787 & 0.1421 & 0.0566 & 0.0718 & 0.1688 & 0.0877 \\
0.1299 & 0.1024 & 0.1660 & 0.0986 & 0.2630 & 0.1470 & 0.1818 & 0.1599 & 0.1814 & 0.1459 & 0.1308 & 0.1388 & 0.1601 & 0.1498 \\
0.1331 & 0.2154 & 0.1978 & 0.0888 & 0.0947 & 0.1062 & 0.1377 & 0.1733 & 0.1814 & 0.0878 & 0.1218 & 0.0988 & 0.1217 & 0.2148 \\
0.2383 & 0.2538 & 0.1694 & 0.2730 & 0.2881 & 0.2479 & 0.2256 & 0.2428 & 0.3149 & 0.4103 & 0.5491 & 0.2862 & 0.2435 & 0.2739 \\
0.1714 & 0.2814 & 0.2321 & 0.3213 & 0.1457 & 0.2080 & 0.3515 & 0.3283 & 0.2435 & 0.2139 & 0.1417 & 0.4045 & 0.3059 & 0.2739
\end{bmatrix}
\end{array}
\begin{bmatrix} 0.2094 \\ 0.1139 \\ 0.0257 \\ 0.0675 \\ 0.1244 \\ 0.0647 \\ 0.0578 \\ 0.0692 \\ 0.0204 \\ 0.0424 \\ 0.0680 \\ 0.0380 \\ 0.0763 \\ 0.0222 \end{bmatrix}
= \begin{bmatrix} 0.1923 \\ 0.1532 \\ 0.1356 \\ 0.2801 \\ 0.2388 \end{bmatrix} \quad (12)$$

According to (12), in the supplier selection process, the companies were ranked as follows: Company D (0.2801), Company E (0.2388), Company A (0.1923), Company B (0.1532), and Company C (0.1356; Figure 6).

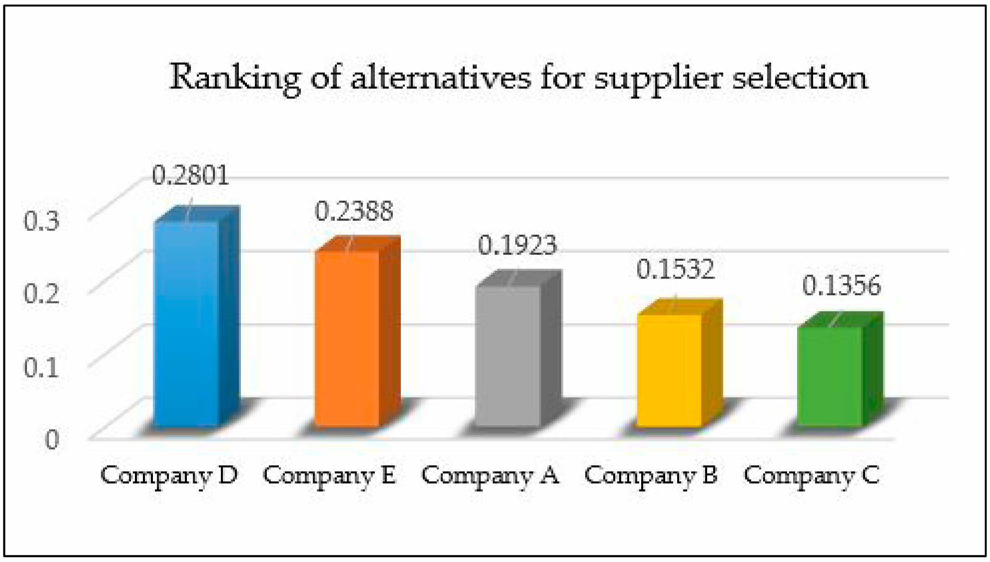

Figure 6. Ranking of alternatives for supplier selection.

5. Conclusions

The continuous, rapid development of the e-commerce market has contributed to fast growth in the packaging industry and is allowing the CBPPM industry to thrive. Accordingly, the establishment of an appropriate CBPPM supplier selection decision-making model has become critical for corrugated box manufacturers to maintain their competitive advantage.

According to the empirical results, Labib [6] considered product quality and delivery to be of greater importance than cost. Basnet [9] suggested that for both local and international businesses, quality, the ability to deliver on time, and performance are the most critical elements in supply chain management. Tam and Tummala [7] argued that the selection criteria for telecommunication service suppliers include quality, cost, problem-solving skills, expertise, delivery time, the ability to satisfy consumer needs, experience, and reputation. Four of the criteria obtained in this study are quality, commitment, cost and reputation, which is the same as Tam and Tummala [7], the new model is of high practical value and enables enterprises to consider and evaluate alternative solutions from multiple perspectives, thus facilitating sustainable operation and development. A quality-oriented company has an influence from higher managers to the employees of different functional departments. It not only can prevent the problems facing the products but also improve the current situation continuously. A corporate culture of having quality as the first priority has always been regarded as one of the main elements of a successful implementation of total quality management.

Through a rigorous research design, this study formed a panel of experts to build a CBPPM supplier selection model, offering insight for the corrugated box industry. The following conclusions were drawn:

1. This study convened a panel comprising 20 experts and scholars from the industry, government, and academia and employed the ANP to determine the weights of criteria as follows: quality (0.4206), commitment (0.2827), reputation (0.1327), cost (0.0985), and service attitude (0.0655).
2. The three subcriteria assigned the most weight were product reliability (0.2094), accuracy and reliability (0.1244), and quality management system for substandard

products (0.1139), two of which belonged to the "quality" criteria. A CBPPM manufacturer can face an enormous loss if it manufactures products using substandard components. Scrupulous product inspection and component control practices guarantee a long, useful life and high quality of machines, which in turn enhances the manufacturer's commitment, service attitude, and reputation.

3. The proposed CBPPM supplier selection model was verified to be feasible. Additionally, the robustness of this two-stage model was tested using the ranking of alternative suppliers. The ranking remained the same according to a sensitivity analysis of the five suppliers, which indicates the robustness of the model and its suitability for adoption by companies for supplier selection.
4. A corporate culture emphasizing quality is commonly considered a main factor for successful total quality management [34,35]. Quality orientation is the extent to which companies emphasize quality, their attitude toward quality, and the effort they make to enhance quality. The establishment of a quality-oriented philosophy within a company creates a top-down drive for quality problem prevention and continuous improvement among company members at all levels. Forza and Filippini [36] researched total quality management practice in companies and observed that companies improved the consistency of product quality as well as customer satisfaction through emphasis on quality, maintained raw material quality by strengthening connections with suppliers, obtained improvement plans initiated by employees through employee education and training, and elevated the overall process control by enhancing communication with suppliers and employees.

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