

Supplier Selection for Bamboo Product Using AHP, ANP, CPI, PROMETHEE, and TOPSIS Methods (Case Study)

Dwiky Valeryan¹, Marihot Nainggolan², Kinley Aritonang³

valeryandwiky@gmail.com

¹²³) Faculty of Industrial Technology, Department of Industrial Engineering, Parahyangan Catholic University
Jl. Ciumbuleuit 94, Bandung 40141

Abstract

PT X serves as a bamboo supplier for the Semarang – Demak toll road project. The bamboo provided must meet specific standards and offer competitive pricing for cost efficiency. To meet these criteria, PT X engages three bamboo suppliers: supplier A, supplier B, and supplier C, each with unique strengths and weaknesses. However, frequent returns of bamboo during implementation have caused significant delays in the project. Thus, finding the most suitable supplier is crucial to meet the bamboo requirements promptly.

This research employs five different methods to determine the most suitable supplier based on their individual characteristics. The methods used are the Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Composite Performance Index (CPI), PROMETHEE, and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). PROMETHEE and TOPSIS methods integrate with AHP and ANP to derive decision outcomes. Data for the research includes interview results and questionnaire responses from PT X decision-makers. From these interviews, five criteria and twelve sub criteria are identified for the bamboo supplier selection process. The collected data undergoes processing using each method, followed by a ranking process to determine PT X's most suitable supplier.

Comparisons of the results obtained from each method offer insights into user preferences. In AHP, ANP, AHP-TOPSIS, and ANP-TOPSIS methods, supplier B is ranked first. However, in the AHP PROMETHEE I and ANP-PROMETHEE I methods, supplier A takes the top position. Conversely, the CPI method ranks supplier C as the primary supplier. Considering the supplier ranking results, supplier B emerges as the primary bamboo supplier for PT X.

Keywords: AHP, ANP, CPI, PROMETHEE, TOPSIS

1.1 Introduction

The swift pace of development in today's era demands prompt responses to fulfill the requirements of national progress. Among the sectors witnessing substantial growth is the infrastructure sector. As per Grigg (1988), infrastructure constitutes a tangible system crafted to facilitate the construction of buildings, irrigation, transportation, and various public facilities, thereby supporting human life socially and economically. According to Surbakti and Harefa (2017), the priority level of supplier criteria needs to be considered in determining the supplier. It is necessary to conduct an evaluation of the company's suppliers to ascertain their continued relevance for use (Abidi et al, 2019).

The correlation of each factor of supplier can influence the outcomes of a decision when analyzing a model (Chang et al, 2020). Yitmen et al (2021) present the research criteria and weights can be utilized as guidelines to evaluate system performance during the planning and design phases. Institutions and governments play a crucial role in effecting change to attain a better model

Indonesia's recent infrastructure development has been noteworthy, encompassing the establishment of airports, ports, railways, dams, and highways that interconnect diverse cities and districts. According to data from the State Secretariat Ministry of the Republic of Indonesia, the infrastructure development budget in Indonesia surged to IDR 384.8 trillion in 2022. This marks a positive trend, although the distribution of infrastructure across Indonesia remains unequal. One focal point frequently debated among the general public pertains to the government's substantial allocation of funds for infrastructure, particularly toll roads. According to Law No. 38 of 2004, toll roads denote public roads typically linear in design, serving as national routes where users are required to pay for access. Constructing toll roads offers manifold advantages, including ameliorating traffic conditions, facilitating goods distribution, enhancing people's mobility, and economizing on travel costs and time.

The ongoing government-led construction project involves the Semarang - Demak toll road. As per information from the Ministry of Public Works and People's Housing, this toll road necessitates a land area spanning 1,887,000 square meters. Once completed, it will interconnect the cities of Semarang, Demak, Gresik, and Surabaya. The construction timeline for this toll road is estimated at two years, backed by a government investment of IDR 15.3 trillion. The Semarang - Demak toll road itself will comprise two sections: the first situated within Semarang city and the second in Demak Regency.

Constructing toll roads demands a robust foundation capable of accommodating the weight of passing vehicles. Given the soil conditions along the Semarang - Demak toll road, categorized as very soft soil, reinforcing the soil becomes imperative to enhance its stability. Information sourced from the Ministry of Public Works and People's Housing suggests that one effective method for reinforcing such soil conditions involves utilizing bamboo as a support system, effectively transforming bamboo into a matting system.



Figure 1. Bamboo Mat Construction

Figure 1 illustrates the implementation of bamboo mat construction on the Semarang - Demak toll road. These bamboo mats are positioned over pre-installed stakes and are subsequently fastened securely together using ropes throughout the construction phase. For a comprehensive understanding of the bamboo mat utilization, a detailed explanation is available in Figure 2.

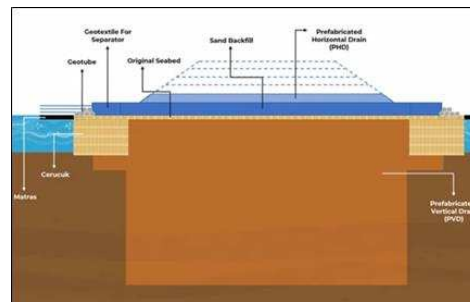


Figure 2. Bamboo Technology Illustration

Figure 2 depicts the use of stakes and bamboo mats as reinforcement for soft soil conditions. Bamboo is employed to bolster the road's structure that will be constructed atop it. The installed bamboo will undergo a Prefabricated Vertical Drain (PVD) process to expedite soil consolidation by eliminating groundwater. Following the PVD process, the subsequent step involves the construction of Geotubes. This process creates Low Crested Weir Breakwaters (LCWB) to mitigate erosion or abrasion caused by ocean waves. Subsequently, after the Geotube construction, the structure will be filled with sand to fortify its strength and support the anticipated load.

PT X serves as a vendor responsible for ensuring the availability of bamboo used in the Semarang - Demak toll road construction. They are tasked with providing bamboo that meets specified standards at a competitive price to optimize project costs. Meeting these requirements and adhering to the established schedule poses a challenge for the company. The standard specifications for bamboo are detailed in Table 1.

Table 1. Standard Bamboo Specifications

Standard Bamboo Specifications		
No.	Specifications	Description
1.	Center Diameter	8 – 10 cm
2.	Base Diameter	8 – 12 cm
3.	Minimum Length	8 m
4.	Condition	Straight and cut to sections

In the table above, each specification size with its specified range is provided. The center diameter, situated in the middle between the two ends of the bamboo, is described as the central diameter. This central diameter primarily acts as support for the bamboo and significantly influences its strength, preventing it from easily breaking or splitting into two parts. Conversely, the base diameter refers to the bamboo's diameter at its end. Both aspects of the diameter, as outlined in the standard, are crucial factors to consider when placing an order for bamboo. Figure 3 represents a segment of the standard bamboo specifications, where circular markings labeled with number 1 indicate the central diameter, and number 2 signifies the base diameter of the bamboo.



Figure 3. Standard Bamboo Specifications

PT X collaborates with multiple suppliers to fulfill their bamboo requirements promptly. Yet, interviews with the head of the procurement division unveiled recurring issues concerning these suppliers. The prevalent problems revolve around bamboo not meeting the specified standards. Two contributing factors to this issue were identified. Firstly, the initial condition of the bamboo might not adhere to standards due to issues during the harvesting process or transportation. Secondly, bamboo often sustains damage during the unloading process.

During unloading, bamboo is dropped directly onto the surface, frequently resulting in bending or breakage due to the substantial impact incurred during this process. This outcome is inevitable due to ingrained habits and practices developed over time. Moreover, this method is chosen for its speed, considering the large quantity and weight of bamboo needing unloading. Beyond the unloading process, bamboo returns also stem from instances where bamboo fails to meet standard specifications, resulting in a higher return rate. This issue significantly impacts the company, impeding the progress of the Semarang – Demak toll road project. Provided below is the data concerning the total number of returns.

Table 2. Standard Bamboo Specifications

Bamboo Returns Semarang – Demak Toll Road in 2022				
No.	Month	Return Quantity	Total Bamboo Orders (Month)	Percentage
1.	February	5.504	17.200	32%
2.	March	4.128	17.200	24%
3.	April	5.160	17.200	30%
4.	May	4.644	17.200	27%
5.	June	3.784	17.200	22%
6.	July	3.096	17.200	18%
7.	Total Returns	26.316	103.200	25,5%

The data in the table 2 highlights February as the month with the highest return percentage compared to other months. Despite subsequent decreases each month after February, the ultimate goal remains achieving a 0% return rate, signifying no bamboo returns at all. Over the past six months, the recorded data on bamboo returns specifically relates to bamboo utilized in the trial embankment process. This process serves as a test phase to evaluate the bamboo's load-bearing capacity for supporting construction on soft soil.

Given the substantial number of returns, PT X faces the imperative task of selecting the most suitable supplier to ensure the smooth progression of the Semarang - Demak toll road project. The total number of returns in the last six months amounts to 26,316 pieces, accounting for 25.5% of the total bamboo orders. The reasons for bamboo return primarily encompass instances where the bamboo fails to meet standard specifications and issues arising from the unloading process. Table 3 below provides a breakdown of return data attributed to each factor over the past six months.

Table 3. Percentage of Return Causes

Bamboo Return Causes Semarang – Demak Toll Road in 2022					
No.	Month	Specification Not Meeting Standards		Unloading Process	
		Return Quantity	%	Total Returns	%
1.	February	5.009	91	495	9
2.	March	3.839	93	286	7
3.	April	4.592	89	568	11
4.	May	4.272	92	372	8
5.	June	3.594	95	190	8
6.	July	2.911	94	185	6
7.	Total Returns	24.217	92	2.096	8

Table 3 illustrates the number of returns attributed to the two primary factors causing bamboo returns. Notably, the factor of bamboo failing to meet standard specifications exhibits a higher percentage compared to issues stemming from the unloading process. Consequently, the foremost concern with suppliers revolves around bamboo not meeting specified standards, necessitating a comprehensive analysis for selecting the right supplier crucial to the construction of the Semarang - Demak toll road.

Through direct observations and previous interviews with the head of the procurement division, it was determined that PT X engages three bamboo suppliers for the Semarang - Demak toll road project: supplier A, supplier B, and supplier C. Each supplier possesses distinct strengths and weaknesses, forming the criteria for selecting the permanent supplier supporting the project's progress. In the last six months, PT X allocated its bamboo orders from the total requirements, distributing 30% to supplier A, 40% to supplier B, and 30% to supplier C. Consequently, supplier A fulfilled a total bamboo order of 30,960 pieces, supplier B received 41,280 pieces, and supplier C received 30,960 pieces.

The focus remains on evaluating the performance of the bamboo suppliers engaged by PT X for the Semarang - Demak toll road project. Supplier A stands as the largest supplier with extensive land coverage and the highest production capacity among the three. Supplier B exhibits the lowest return rate but charges the highest price per bamboo piece. Conversely, supplier C offers the lowest price per bamboo piece but operates with significantly lower production capacity. The table below compares each criterion for evaluating the performance of each supplier.

Table 4. Comparison of Bamboo Suppliers

Comparison of Bamboo Suppliers			
Consideration Factors	Supplier		
	Supplier A	Supplier B	Supplier C
Price			
Price per Bamboo (IDR)	19.000	21.000	18.000
Payment Terms	DP 20% Payment Term 1 Month	DP 10% of Total Payment	Cash Deposit 50% Upfront
Quality and Quantity			
Total Number of Returns (In 6 Months)	18.156	4.737	3.420
Bamboo Quality	Fairly Good	Very Good	Good
Production Capacity/week	24.500	8.400	6.300
Services			
Return Procedure	Difficult	Easy	Fairly Easy
Response Time (Hours)	Slow (2-4)	Fairly Fast (1-2)	Fast (<1)
Distance from Bamboo Forest to Drop-off Location (km)	Temanggung (90) Purworejo (134) Boyolali (93) Salatiga (70)	Magelang (91) Muntilan (106)	Pekalongan (186) Kendal (53)

Table 4 presents an overview of the strengths and weaknesses of each bamboo supplier, considering three primary factors: price, quality, quantity, and service. These criteria are interconnected. For instance, there exists a correlation between price and bamboo quality; a higher price often signifies superior bamboo quality offered by the supplier. Additionally, the quality of bamboo supplied correlates with the frequency of returns experienced.

Furthermore, regarding bamboo price and return procedures, a higher price offered by the supplier might streamline return procedures. Additionally, bamboo production capacity is directly associated with the number and proximity of bamboo forests owned by the supplier. The greater the number of bamboo forests a supplier possesses, and the closer they are to the unloading location, the higher production capacity they can offer.

In Table 4, the quality of bamboo from each supplier is classified into three levels: quite good, good, and very good. Bamboo categorized as 'quite good' typically aligns with the lower limit of the specified standard bamboo sizes. For instance, supplier A's bamboo quality is classified as 'quite good' because most of its bamboo exhibits a central and base diameter around 8 cm. Supplier C offers 'good' quality bamboo, with sizes falling within the mid-range of approximately 9 to 10 cm. Meanwhile, supplier B provides 'very good' quality bamboo as the majority boasts a central diameter of 10 cm and a base diameter of 11 to 12 cm. Larger diameters of bamboo are crucial as they offer optimal strength.

Considering the outlined strengths and weaknesses, a decision-making method becomes imperative to select PT X's primary supplier for the Semarang - Demak toll road project. Urgency arises due to the project's requirement for a 0% return rate to ensure smooth progress. Moreover, with an increasing project budget, cost efficiency becomes pivotal in bamboo selection. Additionally, nearing the project deadline necessitates prompt identification of the primary supplier to meet the bamboo demand.

The selection of bamboo suppliers involves evaluating various criteria, warranting the implementation of the Multi-Criteria Decision Making (MCDM) method. This method aids in determining the best-suited supplier options for the company. The MCDM method encompasses specific approaches such as the Analytical Hierarchy Process (AHP), Analytical Network Process (ANP), Composite Performance Index (CPI), Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), and Technique for Others Preference by Similarity to Ideal Solution (TOPSIS).

These methods serve the same function in multi-criteria decision-making for supplier selection but vary in their advantages and disadvantages. Consequently, this research will delve deeper into each method employed to identify the most suitable bamboo supplier for PT X. With the previously identified issues in mind, the research questions pertaining to the selection of bamboo suppliers are detailed below.

1. What are the criteria and sub-criteria for selecting bamboo suppliers at PT X?
2. How is the model for selecting bamboo suppliers at PT X using the AHP, ANP, CPI, PROMETHEE, and TOPSIS methods?
3. What is the priority for selecting bamboo suppliers at PT X based on the comparison of the AHP, ANP, CPI, PROMETHEE, and TOPSIS methods?

1.2 Literature Review

Bamboo Mattress

According to Keswara (2012), bamboo matting serves to enhance soil strength, preventing settlement and bolstering soil bearing capacity. This method expedites soil consolidation and has long been utilized to reinforce soft soil conditions. Reports from the Railway Enthusiast Digest highlight the use of bamboo matting as a soil reinforcement component for railway tracks in the Semarang Tawang – Alastua section, prone to frequent tidal flooding. Bamboo matting, placed atop marshes during construction, has proven its durability over time.

The construction process for bamboo matting is relatively straightforward, involving binding three bamboo stalks together using nylon rope. These bound bamboo stalks are then stacked in 17 layers to form a mat-like structure. This 17-layer configuration has been selected for its optimal reinforcement capacity for soft soil, supported by two conducted tests: tensile and flexural. While these tests were initially conducted by the toll road constructor to assess the suitability of bamboo matting as a soil reinforcement system for the Semarang - Demak toll road construction, PT X doesn't consider them as criteria or sub-criteria.

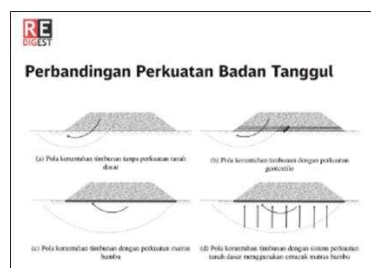


Figure 4. The Benefits of Bamboo Mat Technology

Figure 4 compares the failure patterns between embankments with and without bamboo matting reinforcement. The inclusion of bamboo matting in the soil leads to a more uniform distribution of the embankment load. Beyond this, bamboo matting offers buoyancy and proves remarkably effective in soft soil near water bodies. Additionally, owing to bamboo's inherent stiffness, it stabilizes soil movement, reducing the foundation's susceptibility to cracks.

Supplier Selection

Suppliers play a pivotal role in a company's operations or project execution. As per Solihin (2012), a supplier denotes a party providing essential resources—be it raw materials, services, or labor—to a company. They remain indispensable for meeting consumer needs and form integral components within the supply chain's functionality.

In this context, suppliers must meet specified requirements aligned with the company's standards. According to Dickson (1996), supplier selection involves several criteria, comprising 23 distinct factors, each with its assigned priority level. Below is a table outlining the priority levels for these criteria in supplier selection

Table 5. Kriteria Pemilihan Supplier

No.	Priority Level	Criteria
1.	Slight Importance	Reciprocal Arrangements
2.	Average Importance	Training Aids
3.		Amount of Past Business
4.		Geographical Location
5.		Labor Relation Record
6.		Packaging Ability
7.		Impression
8.		Attitude
9.		Repair Service
10.	Average Importance	Operating Control
11.		Management & Organization
12.		Desire of Business
13.		Reputation & Position
14.		Communication System
15.		Procedural Compliance
16.	Considerable Importance	Financial Position
17.		Technical Capabilities
18.		Price
19.		Production Facilities & Capacities
20.		Warranties & Claim Products
21.		Performance History
22.	Extreme Importance	Quality
23.		Delivery

(Source: Dickson, 1996)

Table 5 delineates four priority levels in supplier selection: slight importance, average importance, considerable importance, and extreme importance. Supplier selection significantly influences a company's future performance, as highlighted by Fauzi (2004). There are five critical criteria to consider when selecting a supplier:

1. Offered Price

This pertains to the supplier's quoted price to the company. The competitiveness of this price is pivotal, as the company seeks bamboo at the lowest feasible cost.

2. Supplier Quality

Quality is crucial and serves as an indicator of the supplier's suitability in meeting the company's needs. The chosen supplier must adhere to predefined standard specifications.

3. Performance Accuracy

Reflects the supplier's capability to accurately fulfill the company's requisites in terms of type, quantity, and timeliness of goods ordered.

4. Communication Capability

This criterion emphasizes the supplier's ability to maintain effective communication and information exchange with the company, fostering a mutually beneficial relationship.

5. Product Availability

Ensures the supplier's capability to fulfill all requested needs in terms of quantity and specifications, a critical factor in meeting consumer demands.

Stevenson (2011) outlines six critical criteria for supplier selection: price, quality, service, location, supplier's stock policy, and flexibility. Price stands out as the foremost consideration, often leading to supplier preference when offering discounts for large order quantities. Following closely, quality prompts companies to invest more to meet specified standards.

Service represents the supplier's responsiveness to issues and their resolution strategies. Location impacts delivery times and associated costs for on-time deliveries. The supplier's stock policy ensures availability for prompt delivery during unexpected demand surges. Flexibility assesses the supplier's adaptability and willingness to accommodate changes/

TOPSIS

According to Olson (2004), the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method serves to identify a solution from various alternative sets that come with limitations. This involves minimizing the distance from the positive ideal point and maximizing the distance from the negative ideal point. Widely utilized, the TOPSIS method can effectively assess numerous alternatives across multiple criteria. Additionally, it offers rankings by assigning numerical values to preferences among alternatives, facilitating the determination of the most suitable option through analyzing their differences and similarities.

Basically, the TOPSIS method aims to select the best alternative using a simple concept. According to Hwang and Yoon (1981), there are 6 steps in using the TOPSIS method for supplier selection. Here is an explanation of each of the six steps in the application of the TOPSIS method.

1. Performing Alternative and Criterion Modeling

In the first step of the TOPSIS method, modeling is carried out in the form of a matrix. The matrix used will contain values D , which is an alternative matrix with a total of x criteria. Alternatives in the TOPSIS modeling matrix are denoted by i , while criteria are denoted by j . Here is the matrix used in the TOPSIS method.

$$D = \begin{pmatrix} x_{11} & x_{12} & \dots & x_{1j} \\ x_{21} & x_{22} & \dots & x_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ x_{i1} & x_{i2} & \dots & x_{ij} \end{pmatrix} \quad (1)$$

2. Creating Matrix R

Matrix R is a decision matrix that has undergone a normalization process. This matrix is used to transform the values x_{ij} from the previous equation. The equation for matrix R has the following form.

$$R_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad (2)$$

Description:

R_{ij} = The Normalized Decision Matrix

x_{ij} = Element of the Decision Matrix X

3. Weighting the Matrix

Matrix weighting is done on the previously normalized matrix. In matrix R , each column is multiplied by w_j which represents its weight. Here is the weighted normalized matrix.

$$D = \begin{pmatrix} w_1 r_{11} & w_2 r_{12} & \dots & w_j r_{1j} \\ w_2 r_{21} & w_2 r_{22} & \dots & w_2 r_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ w_i r_{i1} & w_i r_{i2} & \dots & w_i r_{ij} \end{pmatrix} \quad (3)$$

4. Positive and Negative Ideal Solutions

To determine the positive ideal solution, you select the largest values, while for the negative ideal solution, you choose the smallest values for each criterion. The positive ideal solution is denoted as A^+ , and the negative ideal solution is denoted as A^- .

$$A^+ = (\max V_{ij} | j \in j'), i = 1, 2, 3, \dots, m \quad (4)$$

$$A^- = (\min V_{ij} | j \in j'), i = 1, 2, 3, \dots, m \quad (5)$$

Description:

$j = 1, 2, 3, \dots, n$, Benefit Criteria

$j' = 1, 2, 3, \dots, n$, Cost Criteria

5. Calculating Separation Distances

The calculation of separation distances is performed from the available alternatives to the positive and negative ideal solutions. equation 6 is used to calculate the distance from the alternatives to the positive ideal solution, while equation 7 is used to calculate the distance from the alternatives to the negative ideal solution.

$$D_i^+ = \sqrt{\sum_{j=1}^n d(v_{ij} - v_j^+)^2, j = 1, 2, \dots, m} \quad (6)$$

$$D_i^- = \sqrt{\sum_{j=1}^n d(v_{ij} - v_j^-)^2, j = 1, 2, \dots, m} \quad (7)$$

Description:

D_i^+ = The Distance of Alternative to the Positive Ideal Solution

D_i^- = Distance of Alternative to the Negative Ideal Solution

v_j^+ = Positive Ideal Solution in Column j

v_j^- = Negative Ideal Solution in Column j

v_{ij} = Weighted Normalized Matrix in Row i and Column j

6. Calculating Closeness to the Most Ideal Solution

The final step in the TOPSIS method is to calculate the closeness to the most ideal solution. Subsequently, a ranking will be generated as a consideration for PT X in selecting the bamboo supplier. Equation 8 represents the equation for calculating the closeness to the most ideal solution.

$$CC_i = \frac{D_i^-}{D_i^- + D_i^+} \quad (8)$$

Description:

CC_i = Closeness Coefficient

S_i^- = Distance of Alternative to the Negative Ideal Solution

S_i^+ = Distance of Alternative to the Positive Ideal Solution

After completing the 6 steps of TOPSIS, conclusions will be drawn regarding the most ideal criteria and supplier for PT X. These results will be compared with other methods. The following sub-sections will discuss the PROMETHEE, AHP, ANP, and CPI methods, which are also used as comparisons in the selection of bamboo suppliers for PT X.

PROMETHEE

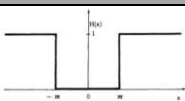
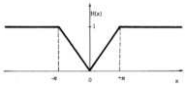
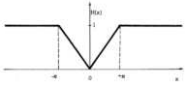
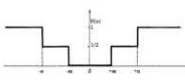
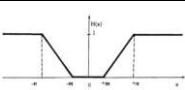
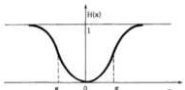
The easiest way to write your paper in accordance with the specified template is to use this file as a template and write your paper in this file. The paper should be written without page numbers and should preferably be organized in the following order of topics:

Another method related to Multi-Criteria Decision Making (MCDM) is the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) method. According to Suryadi and Ramdhani (1998), the PROMETHEE method is a technique that utilizes values within an outranking relationship. This method can address the core problem by comparing the probabilities of alternatives against the criteria with their basic criteria. There are four stages in using the PROMETHEE method as follows.

1. Determining Preferences

The preference determination stage of the PROMETHEE method requires input in the form of criteria data from each supplier used. This data contains the values of each predefined criterion. There are three main principles in determining preferences: minimization and maximization, preference types, and parameters. In the first principle, which concerns minimization and maximization, preference determination is tailored to the company's preferences regarding the criteria. There are six types of preference types in the PROMETHEE method as shown in Table 6.

Table 6. PROMETHEE Preference Types

No.	Preference Types	
	Type of Criteria	Criteria Icon
1.	Basic Criteria	
2.	Quasi Criteria	
3.	Linear Criteria	
4.	Level Criteria	
5.	Linear Criteria and Non-Area Criteria	
6.	Gaussian Criteria	

In the PROMETHEE method, each criterion has specific characteristics delineated by q and p values, serving as the lower and upper bounds within predefined parameters. To ascertain these values, a calculation process involves determining the deviation value using the equation. The deviation is derived from the discrepancy between the compared criteria and their alternatives. The parameters (p , q , or s) are obtained through a quartile equation approach and subsequently adjusted by PT X. Sukarna (2005) discusses in their journal on the supplier selection proposal for the Braga City Walk Bandung project that q denotes the indifference threshold parameter, acquired from the first quartile value, while p signifies the preference threshold parameter derived from the third quartile value. Preferences Calculation

The preference calculation in the PROMETHEE method is based on the preference and indifference values, p and q . In the preference calculation, $H(d)$ is obtained, which represents the difference in criterion values among alternatives. This value has a direct relationship with p (preference) and q (indifference). To obtain the p and q values for each alternative, calculations are performed based on the paired preferences that have been defined. Here are the formulas used in the preference calculation for each criterion in the PROMETHEE method.

$$\text{Basic} = H(d) = \begin{cases} 0 & \text{jika } d \leq 0 \\ 1 & \text{jika } d > 0 \end{cases} \quad (9)$$

$$\text{Quasi} = H(d) = \begin{cases} 0 & \text{jika } -q \leq d \leq q \\ 1 & \text{jika } d < -q \text{ atau } d > q \end{cases} \quad (10)$$

$$\text{Linear} = H(d) = \begin{cases} \frac{d}{p} & \text{jika } -p \leq d \leq p \\ 1 & \text{jika } d < -p \text{ atau } d > p \end{cases} \quad (11)$$

$$\text{Level} = H(d) = \begin{cases} 0 & \text{jika } |d| \leq q \\ 0,5 & \text{jika } q < |d| \leq p \\ 1 & \text{jika } p < |d| \end{cases} \quad (12)$$

Linear and Non-Area =

$$H(d) = \begin{cases} 0 & \text{jika } |d| \leq q \\ \frac{|d| - q}{p - q} & \text{jika } q < |d| \leq p \\ 1 & \text{jika } p < |d| \end{cases} \quad (13)$$

$$\text{Gaussian} = H(d) = 1 - \exp\left\{-\frac{d^2}{2\sigma^2}\right\} \quad (14)$$

The value of "d" for each criterion is obtained by calculating the difference between each of the suppliers used. These values will provide insights into areas of inequality, helping to determine which is better. After determining the preference values, the next step is to calculate the preference index.

2. Calculating the Preference Index

In the process of calculating the preference index in the PROMETHEE method, decision-makers at PT X will be involved. This involvement is based on the level of preference intensity. Decision-makers will provide statements regarding alternative a being preferred over alternative b, considering all the criteria. There are rules within the preference index where, if there are criteria with the same importance values, the decision-maker's preference has an equal weight for all of them. Equation 15 below represents the formula used to calculate the preference index.

$$\phi(a, b) = \sum_i^n \pi P_i(a, b): \forall a, b \in A \quad (15)$$

Description:

P_i = Preference Function

π_i = Weight Value

3. Calculating Leaving Flow, Entering Flow, and Net Flow

The three aspects: leaving flow, entering flow, and net flow each have their own advantages and disadvantages. Leaving flow is the result of the sum based on those that have directions to move away from node a and become a unity.

$$\text{Leaving Flow} = \Phi^+ = \frac{1}{n-1} \sum_{x \in A} \phi(a, x) \quad (16)$$

$$\text{Entering Flow} = \Phi^- = \frac{1}{n-1} \sum_{x \in A} \phi(x, a) \quad (17)$$

$$\text{Net Flow} = \Phi(a) = \Phi^+(a) + \Phi^-(a) \quad (18)$$

AHP

Decision-making is a critical aspect that requires consideration of various factors to achieve optimal results for a company. The Analytical Hierarchy Process (AHP) is one of the methods that consider various aspects in its application, such as preferences, perceptions, experience, and intuition in a multicriteria problem. Fundamentally, the AHP method resolves the problem by creating a hierarchy that assesses the level of importance of variables influencing the available problem.

According to Saaty (1993), the Analytical Hierarchy Process (AHP) is a method for solving complex multicriteria problems by structuring them into a hierarchy that represents the problem's structure in a multilevel format, consisting of goals, factor levels, criteria, sub criteria, and, ultimately, the most detailed alternatives. In this hierarchy designed for the AHP method, there are elements within it that will be compared and have homogeneous properties. The AHP method requires creating a detailed and relevant hierarchy to represent the existing problem effectively (Saaty and Vargas, 2012). Figure 5 illustrates a three-level hierarchy of the Analytical Hierarchy Process (AHP).

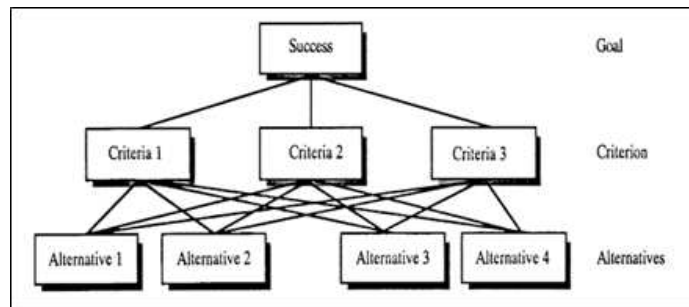


Figure 5. Three Levels of AHP Hierarchy

In the construction of pairwise comparison matrices within the AHP hierarchy, the reciprocal axiom is used to indicate a reciprocal relationship between two elements. According to Saaty (1993), there are eight steps in using the Analytical Hierarchy Process (AHP) method to solve a problem. Here is an explanation of each step.

1. Describing the Problem and Solutions

This step aims to understand the problems that arise in the company comprehensively. This is important because it will serve as a reference for the goals to be achieved and their solutions. Furthermore, by describing the problem, you will gather information about the criteria that impact the issue.

2. Creating the Hierarchy Structure

The hierarchy structure is created based on managerial perspectives, considering its ability to represent the problem comprehensively. This perspective begins with general objectives, influential criteria, and various alternative options.

3. Creating Pairwise Comparison Matrices

Pairwise comparison matrices illustrate the influence of the available elements on each criterion at a higher level. In the matrices created, each pair of elements is compared with two elements. Essentially, if one element does not contribute more than the other element, the other element will provide a greater contribution.

4. Normalizing Data

The normalization process is carried out by dividing the values of each element in the pairwise comparison matrix. These values are divided by the total value in each column. If there are specific conditions, such as multiple decision-makers, geometric means can be used for their pairwise comparisons.

5. Calculating Eigenvector Values and Consistency Testing

The Eigenvector value is a vector obtained by multiplying the vector itself by the Eigenvalue. The expected Eigenvector value is the maximum value. Once the Eigenvector values are obtained, the consistency test is conducted to ensure that the data is consistent.

6. Performing Iterations of Steps 3, 4, and 5 Across All Levels of Hierarchy.

After steps 3, 4, and 5 have been completed at one level of hierarchy, the other levels need to follow the same steps. This is done to ensure the validity of the data used. Additionally, the repetition of these steps aims to test the data comprehensively across all hierarchy levels.

7. Performing Eigenvector Weighting Calculation on Pairwise Comparison Matrix.

Based on the obtained Eigenvector values, weighting is applied to each element. This weighting is done to determine the priority level of the elements. The prioritization of the priority vector with criteria weights will utilize a hierarchy composition. The result of this weighting will yield the priority vector values, and if multiple results are obtained, an arithmetic mean will be calculated.

8. Performing Consistency Evaluation.

Consistency evaluation is carried out by the process of multiplying the consistency index by each of the continuous criteria priorities. The resulting products will be summed, and then divided by the appropriate random consistency index. The hierarchy consistency ratio should be 10% or less of that value. If a ratio greater than this value is obtained, corrective measures are necessary.

ANP

Analytical Network Process (ANP) is a method developed from the Analytical Hierarchy Process (AHP). In the ANP method, it is more suitable for addressing issues related to supplier selection due to the interdependencies among criteria within the hierarchy (Saaty, 2008). The Analytical Network Process (ANP) method serves several functions, as follows:

1. Complexity Structuring

The first function aims to organize the problem hierarchically into homogeneous clusters. Homogeneous clusters mean that the criteria within them exhibit similar characteristics. This hierarchical structuring allows for modeling supplier-related issues within the framework of the Analytical Network Process (ANP).

2. Ratio Scale Measurement

Ratio scale measurement serves the purpose of determining proportions. Moreover, the level of accuracy in ratio scale measurement is the most precise when compared to measurements of other hierarchy elements. In ratio scale measurement, each scale has an equal distance.

3. Synthesis

Synthesis aims to integrate various parts of the problem under examination. The decomposed parts come together using the ANP method. This helps in the measurement process.

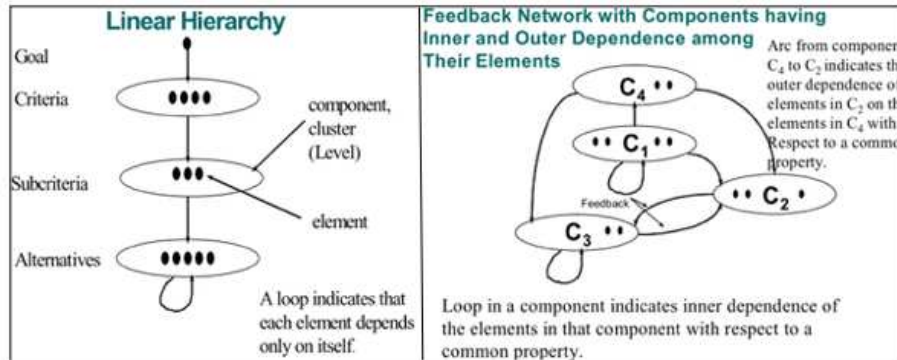


Figure 6. Comparison of AHP and ANP Methods

In Figure 6, a comparison is made between the AHP and ANP methods. In the AHP method, there is a linear hierarchy consisting of objectives, criteria, sub-criteria, and alternatives. In the ANP method, there are feedback loops among the criteria. The linear hierarchy in the AHP method represents the levels among criteria and tends to be independent. The feedback loops in the ANP method create a network-like structure that connects every criterion, not following a direct downward structure like the AHP method.

In the ANP method, there are two types of relationships, as defined by Saaty and Vargas (2006): inner dependence and outer dependence. Inner dependence refers to the relationships among criteria within the same component, while outer dependence refers to the relationships between criteria from different components. In the implementation process, AHP tends to be more structured compared to the ANP method. However, AHP is not suitable for complex problems and may result in less accurate conclusions when used for solving such problems. The use of the ANP method leads to more accurate and detailed decisions regarding the relationships among criteria, which will be classified later.

The Analytical Network Process (ANP) method has a more complex set of steps compared to the Analytical Hierarchy Process (AHP). According to Saaty and Vargas (2006), there are six main steps in solving a problem using the ANP method. Here are the six steps in using the ANP method:

1. Model Construction

The first step, after identifying the problem, decision-makers in the company, and the criteria and sub-criteria, is to create a conceptual model in the form of a network. This aims to form a model consisting of nodes (attributes) and clusters. Then, inner dependence relationships among nodes within the same cluster and outer dependence relationships among nodes from different clusters are established.

2. Creating Pairwise Comparison Matrices and Priority Weights

The results of the pairwise comparison matrices are determined by the decision-makers within the company. In the weighting process, a quantitative scale ranging from 1 to 9, as proposed by Saaty and Vargas (2006), is used. Below is an explanation of the criteria for the scale based on their level of importance:

Table 7. Scale of Importance Level

Level of Importance	Definition	Description
1	Equal Importance	Both criteria have equal influence
3	Moderate Importance	Slight preference for one criterion
5	Strong Importance	Significant preference for one criterion
7	Very Strong Importance	One criterion is significantly more influential and dominant
9	Extreme Importance	One criterion is absolutely preferred
2, 4, 6, 8	Intermediate	Value between two adjacent values

The value obtained from pairwise comparison weighting is used to create a matrix for comparing their levels of importance. The matrix used for this purpose is the pairwise comparison matrix. After performing the weighting in the previous step and creating the table of pairwise comparison matrices, the next step involves obtaining the result from the pairwise comparison matrix in the form of an equation. The result of the pairwise comparison matrix will yield a value denoted as 'A,' which will be used to determine the element weights.

3. Calculating Eigenvector Values

Eigenvector values represent the priority weights obtained from the pairwise comparison matrix. These values serve as the basis for calculations used in forming the supermatrix. Here is the formula used to calculate the Eigenvector values from the pairwise comparison matrix:

$$A.W = \lambda_{maks} . W \quad (19)$$

Description:

A = Comparison Matrix

W = Eigenvector Value

λ_{maks} = Largest Eigenvalue

After obtaining the Eigenvector values, the next step is to calculate the consistency ratio. The consistency ratio obtained is referred to as the Consistency Index (CI). Here is the formula used to calculate the CI:

$$CI = \frac{\lambda_{maks} - n}{n - 1} \quad (20)$$

The next step after calculating the Consistency Index (CI) is to compute the Consistency Ratio (CR). The CR is obtained by dividing the Consistency Index (CI) by the Random Index (RI). Here is the formula used to calculate the Consistency Ratio (CR):

$$CR = \frac{CI}{RI} \quad (21)$$

Description:

CI = Consistency Index

RI = Random Index

The Random Index (RI) value to be used has predefined reference values for the results obtained. The magnitude of the RI value is determined by the number of criteria used. The Random Index (RI) value is obtained from 500 random sample matrices. Subsequently, the Consistency Ratio (CR) is calculated, and its value must be less than 0.1 to be considered consistent, while a CI value greater than 0.1 is considered inconsistent.

4. Creating the Supermatrix

In the Analytical Network Process (ANP) method, a large matrix known as the supermatrix is required. The network within the supermatrix has interconnected relationships among its elements. There are three steps in creating the supermatrix: The first step involves creating an unweighted supermatrix that contains Eigen vector values from the pairwise comparison matrix within a network. Next, a weighted supermatrix is constructed to determine the overall weights of the elements. After that, the limiting supermatrix is formed, which is the final step achieved by multiplying the weighted supermatrix by itself. If the obtained values have stabilized, the multiplication process is halted to proceed to the next step.

5. Selecting the Best Alternative

The final stage of the Analytical Network Process (ANP) method, after the supermatrix creation process is completed, involves selecting the best alternative from the available suppliers. Before this selection process, a normalization process is required for each element. This is done using a method known as normalization by cluster. If a weight has the highest value, it indicates the highest priority. The ANP method encompasses crucial inter-criterion feedback, a pivotal aspect in the selection process of bamboo suppliers at PT X. This method finds support in literature, as indicated by Bakhtiar, Rahmadani, Deliana, and Bagus (2021), who explored the ANP's role in supplier selection for rail pad component 158-7 procurement. Their study highlights how ANP's interconnected feedback influences criteria, aiding decision-making based on diverse assessments during data processing. Another supporting study, conducted by Puspitasari and Yancadianti (2016), emphasizes the ANP method's utility in selecting environmentally friendly suppliers. This research showcases how ANP unveils the significance levels among stakeholders, revealing the interrelationships between criteria and sub-criteria. Furthermore, Sumiyatun and Retantyo (2016) integrated ANP with TOPSIS in their study, determining the priority of university promotional media. This integration demonstrates the effectiveness of combining ANP and TOPSIS methods in decision-making processes.

CPI

The subsequent method utilized in selecting bamboo suppliers is the Composite Performance Index (CPI) method. As described by Marimin (2004), the CPI method is instrumental in establishing rankings among available supplier alternatives by evaluating their performance. Performance acts as the key index for each supplier, facilitating their selection as viable alternatives. Gasperz (1990) delineates eight primary steps involved in computing the Composite Performance Index.

1. Determining Variables: The first step is to determine the variables to be used in selecting suppliers. In the research on the selection of bamboo suppliers, there are 12 relevant variables to determine the primary supplier among the three available.
2. Calculating Averages and Standard Deviations: This step aims to calculate the average and standard deviation of each variable. It is done to determine the average weight of each variable. Additionally, the standard deviation is used to understand the data dispersion for variables whose weights have been averaged.
3. Calculating Correlation Coefficients: The third step involves calculating the correlation coefficient between two bamboo supplier selection variables. This is done to determine whether the variables in the model play a significant role. Below is the formula used to find the coefficient between two variables.

$$\text{Correl}_{(x,y)} = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}} \quad (22)$$

Description:

$\text{Correl}_{(x,y)}$ = Correlation coefficient between 2 variables

x = First correlated variable

y = Second correlated variable

\bar{x} = Mean value of each first correlated variable

\bar{y} = Mean value of each second correlated variable

4. Creating a coefficient matrix between two variables serves the purpose of clarifying the correlations that exist within each variable. Additionally, the creation of a correlation coefficient matrix aims to facilitate the iteration process to be conducted.
5. Finding the value of "c" through an iterative process is the next step. The iteration process continues until the obtained value of "c" has differences that are not too far from the results of the previous iterations. In the first iteration process, the value of "c" is initially set to 1. Then, the latest value of " c_j " is calculated by dividing each "c" value of the twelve variables by the result of λc_1 . The "c" values obtained from each variable are then applied to the original correlation coefficient matrix, resulting in a new matrix based on the improved "c" values.
6. Once the results of "c" from the final iteration process do not significantly differ from the previous iterations, the iteration process is stopped. Subsequently, the root value is calculated based on the average of the last obtained "c" values. Below is the formula used for this process.

$$vn = \sqrt{c_1^2 + c_2^2 + c_3^2 + \dots + c_j^2} \quad (23)$$

Description:

c_j = The Value of c to j from the last iteration

7. The result of the calculation of the normal vector will divide the " c_j " values from the last iteration to obtain the value of " c_j^* ". Afterward, a composite index model will be obtained in the form of standardized variables. The following equation represents the composite index model equation used in the selection of bamboo suppliers:

$$I = \frac{kc_1}{s_1} X_1 + \dots + \frac{kc_j}{s_j} X_j \quad (24)$$

Description:

I = Composite Index Model

k = Constant

c_j = Value from c_j from the last iteration

s_j = Standard Deviation of the variable X_j

To obtain the results of the composite index model calculation, it is necessary to determine constant value "k" beforehand. The data required for calculating the constant "k" has similarities to the composite index model equation, but some modifications are made where "x" values used are the averages. Equation 25 is used to find the constant "k":

$$k \left(c_1 \frac{\bar{x}_1}{s_1} + \dots + c_j \frac{\bar{x}_j}{s_j} \right) = 100 \quad (25)$$

Description:

k = Constant

c_j = Value from c_j from the last iteration

s_j = Standard Deviation of Variable X_j

\bar{x} = Mean value of each variable

8. The last phase in the CPI method involves computing the final scores for each available alternative. This calculation multiplying the composite index model value for each variable by the outcomes from the judgment questionnaire. Subsequently, the total score for each supplier is calculated. An analysis of the obtained results will ascertain the chosen alternative based on the highest score.

1.3 Results and Discussion

In this section, the results of the research will be explained. Each method used will create a model for selecting bamboo suppliers, making the data processing process more straightforward. The following is a discussion of the results of the selection of bamboo suppliers from each method used.

Criteria dan Subcriteria

The identification of criteria and sub-criteria is conducted through two distinct processes: a literature review to gather considerations for these aspects and interviews with decision-makers, specifically Mr. Budi Tjahjono. The literature referred to for selecting criteria and sub-criteria for supplier evaluation was derived from sources such as Dickson (1996), Fauzi (2004), and Stevenson (2011), as previously mentioned in the preceding chapter.

After identifying criteria and sub-criteria from the literature review, the subsequent step involves conducting interviews with key decision-makers responsible for supplier selection at PT X. These interviews aim to explore various aspects related to PT X's considerations when choosing bamboo suppliers. To derive comprehensive criteria and sub-criteria for decision-makers, questions based on criteria found in the literature by Dickson (1996), Fauzi (2004), and Stevenson (2011) serve as reference points during the interview process. Combining insights from the literature and additional criteria gleaned from these discussions, the criteria and sub-criteria for selecting bamboo suppliers at PT X are established. The table below summarizes the amalgamated criteria and sub-criteria, which will guide PT X in the supplier selection process, integrating findings from both the literature study and interviews with the company's decision-makers

Table 8. Criteria dan Subcriteria

No.	Criteria	Subcriteria
1.	Price	Bamboo Offer Price
		Discount Price
2.	Quality	Bamboo Specification
		Return Quantity
3.	Delivery	Accuracy of Bamboo Quantity
		On-time Delivery
4.	Service	Bamboo Stock Information
		Order Response
		Complaint Response
5.	Flexibility	Payment Terms
		Bamboo Order Quantity
		Faulty Bamboo Return Process

Results and Discussion of AHP

The initial method employed to determine priority weights is the Analytical Hierarchy Process (AHP). This method involves creating a hierarchical model structured around objectives, criteria, sub-criteria, and alternative suppliers. However, it's important to note that the AHP model for selecting bamboo suppliers differs from the Analytical Network Process method. Unlike the ANP method, the AHP model doesn't delve into the inner or outer dependence relationships between objectives, criteria, or sub-criteria. Figure 7 illustrates the model formulated for selecting bamboo suppliers using the AHP method.

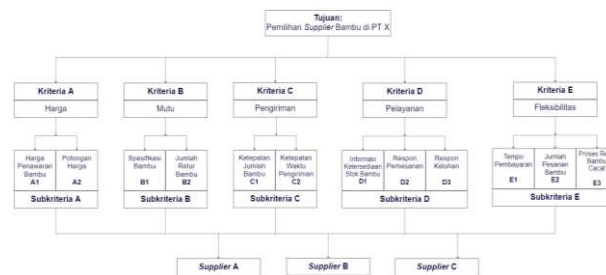


Figure 7. AHP Bamboo Supplier Selection Model

In the AHP method, an overall weight calculation will be performed to determine the level of inconsistency of criteria that influence the decision-making process for selecting bamboo suppliers. The calculation is carried out for 5 criteria and 12 sub-criteria that are considered for the selection of bamboo suppliers at PT X. The calculation of the overall weights is done by multiplying the weights of criteria with their respective sub-criteria. Below are the results of the overall weight calculation for the AHP method.

Table 9. AHP Overall Weights

Criteria	Weights of Criteria	Subcriteria	Weights of Subcriteria	Overall Weights
Price	0,367	Bamboo Offer Price	0,833	0,306
		Discount Price	0,167	0,061
Quality	0,377	Bamboo Specifications	0,143	0,054
		Bamboo Return Quantity	0,857	0,323
Delivery	0,128	Accuracy of Bamboo Quantity	0,800	0,102
		On-time Delivery	0,200	0,026
Service	0,058	Bamboo Stock Information	0,705	0,041
		Order Response	0,211	0,012
		Complaint Response	0,084	0,005
Flexibility	0,07	Payment Terms	0,625	0,044
		Faulty Bamboo Return Process	0,137	0,010
		Bamboo Order Quantity	0,239	0,017

Based on the results of the overall weight calculations obtained from Table 9, you can determine the priority levels of each criterion and sub-criterion in the selection of bamboo suppliers. In that table, it's evident that the "Quality" criterion has the highest weight at 0.377, and the highest overall weight is found in the "Price" criterion with its sub-criterion "Quantity of bamboo returns" having a weight of 0.323. The overall weights will undergo a synthesis model process in the SuperDecisions software to determine the weights of each supplier alternative.

Table 10. Priority Weights of Alternative Suppliers in AHP

Priority Weights of Alternative Suppliers in AHP		
Alternative	Priority Weights	Ranking
Supplier A	0,180	3
Supplier B	0,471	1
Supplier C	0,349	2

The table 10 illustrates the priority weights assigned to each supplier alternative. Supplier A holds a priority weight of 0.180, supplier B is weighted at 0.471, while supplier C stands at 0.348. Consequently, supplier B emerges with the highest priority weight among the compared suppliers.

Results and Discussion of ANP

The selection model for bamboo suppliers using the Analytical Network Process (ANP) method involves the creation of a comprehensive model based on the company's criteria, sub-criteria, and their interrelationships. This model integrates each criterion and sub-criterion within a diagram that illustrates their respective connections. Figure 8 depicts the bamboo supplier selection model utilizing the ANP method.

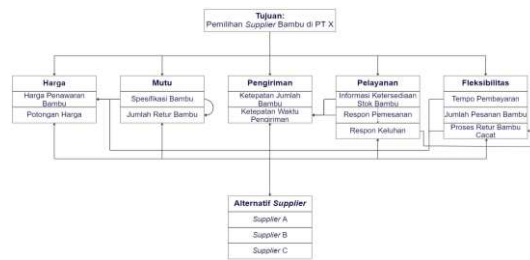


Figure 8. The Bamboo Supplier Selection Model using ANP

The process of calculating the 'normalized by cluster' values encompasses the entire cluster, enabling the determination of priority levels in the selection of bamboo suppliers at PT X. This computation involves dividing the values within the limiting supermatrix by the total value of each cluster in the same supermatrix. Below, you'll find a summary of the outcomes derived from the 'normalized by cluster' calculation for the Analytical Network Process (ANP) method.

Table 11. ANP Overall Weights

Criteria	Cluster	Normalized by Cluster	Overall Weights
Alternative	Supplier A	0,188	-
	Supplier B	0,445	
	Supplier C	0,367	
Flexibility	Bamboo Order Quantity	0,275	0,031
	Faulty Bamboo Return Process	0,565	0,063
	Payment Terms	0,160	0,160
Goals	Supplier Selection for Bamboo at PT X	0,000	-
Price	Bamboo Offer Price	0,629	0,235
	Discount Price	0,371	0,138
Quality	Return Quantity	0,547	0,207
	Bamboo Specification	0,453	0,171
Service	Bamboo Stock Information	0,221	0,012
	Complaint Response	0,508	0,027
	Order Response	0,272	0,015
Delivery	Accuracy of Bamboo Quantity	0,395	0,033
	On-time Delivery	0,605	0,051

Table 11 displays the normalized values by cluster for each node. The outcomes derived from the 'normalized by cluster' obtained through the SuperDecisions software have been meticulously cross-verified through a manual validation process, ensuring consistent results. These validated 'normalized by cluster' outcomes form the basis for establishing the priority ranking of each supplier alternative. The subsequent section outlines the priority ranking assigned to each supplier alternative based on these results.

Table 12. Priority Weights of Alternative Suppliers in ANP

Priority Weights of Alternative Suppliers in ANP		
Alternative	Priority Weights	Ranking
Supplier A	0,188	3
Supplier B	0,445	1
Supplier C	0,367	2

The results of the 'normalized by cluster' calculations yield the priority ranking of bamboo supplier alternatives. Table 12 displays the priority weights of supplier alternatives obtained through the ANP method. Supplier B emerges as the top priority with a normalized weight of 0.445, followed by Supplier C as the second priority with a weight of 0.367. Finally, Supplier A secures the third priority position with a weight of 0.188.

Results and Discussion of PROMETHEE and TOPSIS

The PROMETHEE and TOPSIS methods play crucial roles in the ranking process, utilizing the outcomes derived from the AHP and ANP data processing. This ranking process aims to enhance the objectivity of the decision-making procedure for selecting bamboo suppliers. The results obtained from the AHP and ANP methods, comprising priority weights, are integrated into the PROMETHEE and TOPSIS methodologies for the bamboo supplier selection model, illustrated in Figures 7 and 8. Both PROMETHEE and TOPSIS methods receive input data from the AHP and ANP, in addition to questionnaires assessing the performance framework of each supplier. For the PROMETHEE method, the questionnaire outcomes (as detailed in Appendix C) will specify 'Max' or 'Min' for each sub-criterion. Below is a summary table of the questionnaire results from the PROMETHEE method.

Table 13. PROMETHEE Questionnaire Results

Criteria	Subcriteria	Supplier A	Supplier B	Supplier C	Max/ Min
Price	Bamboo Offer Price	4	3	5	Min
	Discount Price	3	4	2	Max
Quality	Bamboo Specification	3	5	4	Max
	Return Quantity	2	4	4	Min
Delivery	Accuracy of Bamboo Quantity	2	4	3	Max
	On-time Delivery	2	3	3	Max
Service	Bamboo Stock Information	3	4	4	Max
	Order Response	4	4	3	Max
	Complaint Response	2	3	4	Max
Flexibility	Payment Terms	3	4	2	Max
	Faulty Bamboo Return Process	2	4	3	Max
	Bamboo Order Quantity	4	3	2	Max

In Table 13, the "Max" notation is used when a higher value for the sub-criterion is considered better. For example, in the case of the discount sub-criterion, a higher relationship between the discount and the supplier is considered better. On the other hand, the "Min" notation is used when a lower value for the sub-criterion is considered better. An example of the "Min" notation is in the price of bamboo offering sub-criterion, where it is considered better if the price of the bamboo offering is lower with the alternative.

The AHP-PROMETHEE I method involves the calculation of leaving flow, entering flow, and net flow. The purpose of calculating each flow is to determine the ranking of each supplier. The ranking process is based on the highest net flow value, which is given the highest priority. The calculations are performed using the formulas found in Equation 16, Equation 17, and Equation 18. Below are the results of the calculations for leaving flow, entering flow, net flow, and the ranking of each supplier.

Table 14. Supplier Ranking of AHP-PROMETHEE I

AHP	Leaving Flow	Entering Flow	Net Flow	Ranking
a	0,003	-0,650	0,654	1
b	0,049	-0,049	0,098	2
c	0,015	0,053	-0,037	3

In the table above, Supplier A occupies the first ranking because it has the highest net flow value of 0.654. Following Supplier A, the second and third rankings are held by Supplier B and Supplier C, respectively. In the ANP-PROMETHEE I method, the process of calculating leaving flow, entering flow, and net flow will also be carried out to determine the ranking afterward. The calculations for leaving flow, entering flow, and net flow are performed to determine the ranking of Supplier A. Below are the results of the calculations for the ANP-PROMETHEE I method.

Table 15. Supplier Ranking of ANP-PROMETHEE I

ANP	Leaving Flow	Entering Flow	Net Flow	Ranking
a	-0,070	-0,709	0,638	1
b	0,051	-0,051	0,101	2
c	0,020	-0,020	0,039	3

The rankings for each supplier can be derived from Table IV.41. Supplier A secured the top position with a value of 0.638, the highest among all suppliers, earning it the first rank. Following that, Supplier B claimed the second rank with a net flow value of 0.101. Lastly, in the ANP PROMETHEE I method, Supplier C secured the third rank, attaining a net flow value of 0.039.

The data for selecting bamboo suppliers at PT X is also processed using the TOPSIS method. The TOPSIS method is used to compare with the AHP and ANP methods to determine the priority of bamboo suppliers at PT X. The input data used in the TOPSIS method consists of the importance weights of each sub-criterion that has been processed in the AHP and ANP comparison matrix. The use of the TOPSIS method aims to select the alternative with the closest distance to the ideal solution and the farthest distance to the negative ideal solution. There are several stages in data processing using the TOPSIS method, including creating judgment questionnaires, arranging decision matrices that have been normalized and weighted, calculating positive and negative ideal solutions, and finally determining the priority of bamboo suppliers.

Table 16. TOPSIS Questionnaire Results

Criteria	Subcriteria	Supplier A	Supplier B	Supplier C	Description
Price	Bamboo Offer Price	4	3	5	Cost
	Discount Price	3	4	2	Benefit
Quality	Bamboo Specification	3	5	4	Benefit
	Return Quantity	2	4	4	Cost
Delivery	Accuracy of Bamboo Quantity	2	4	3	Benefit
	On-time Delivery	2	3	3	Benefit
Service	Bamboo Stock Information	3	4	4	Benefit
	Order Response	4	4	3	Benefit
	Complaint Response	2	3	4	Benefit
Flexibility	Payment Terms	3	4	2	Benefit
	Faulty Bamboo Return Process	2	4	3	Benefit
	Bamboo Order Quantity	4	3	2	Benefit

The table above provides a summary of the TOPSIS method questionnaire for supplier evaluation based on each sub-criterion. There are "cost" and "benefit" labels for each sub-criterion. "Benefit" implies that the larger the value of the sub-criterion, the better it is. For example, the larger the discount offered by the supplier, the better. On the other hand, "cost" implies that the smaller the value of the sub-criterion, the better. For instance, in the case of the bamboo offering price, "cost" indicates that the lower the price of bamboo offered, the better it is for PT X to obtain a lower-priced bamboo. The values of the closeness coefficients or preferences will undergo a ranking process from the largest to the smallest to determine the supplier with the highest priority. The following table provides the preference values and ranking of alternatives for each supplier.

Table 17. Supplier Ranking of AHP-TOPSIS

Alternative	Preferennce	Ranking
Supplier A	0,483	2
Supplier B	0,620	1
Supplier C	0,290	3

The table above provides the ranking results of suppliers using the AHP-TOPSIS method. In this method, the supplier in the first position is supplier B with a weight of 0.620. Then, in the second position, we have supplier A with a weight of 0.483. Finally, in the third position, we have supplier C with a weight of 0.290. In the ANP-TOPSIS method, closeness coefficients are also calculated to determine the preference values and ranking of each supplier. For the preference of alternative suppliers A, B, and C, it can be observed that alternative suppliers have the first priority. This priority is determined by the ranking process based on the closeness coefficient or preference value.

Table 18. Supplier Ranking of ANP-TOPSIS

Alternative	Preferennce	Ranking
Supplier A	0,413	3
Supplier B	0,685	1
Supplier C	0,499	2

Table 18 shows that supplier B has the highest preference value, which is 0.685, making it the top-ranked supplier compared to the others. In the second position, we have supplier C, and A with a weight of 0.413.

Results and Discussion of CPI

The model for selecting bamboo suppliers using the Composite Performance Index (CPI) method involves direct calculations based on the twelve subcriteria used. These twelve subcriteria will be converted into variables to determine the most suitable alternative based on the composite index value. Below is the model for selecting bamboo suppliers using the CPI method.

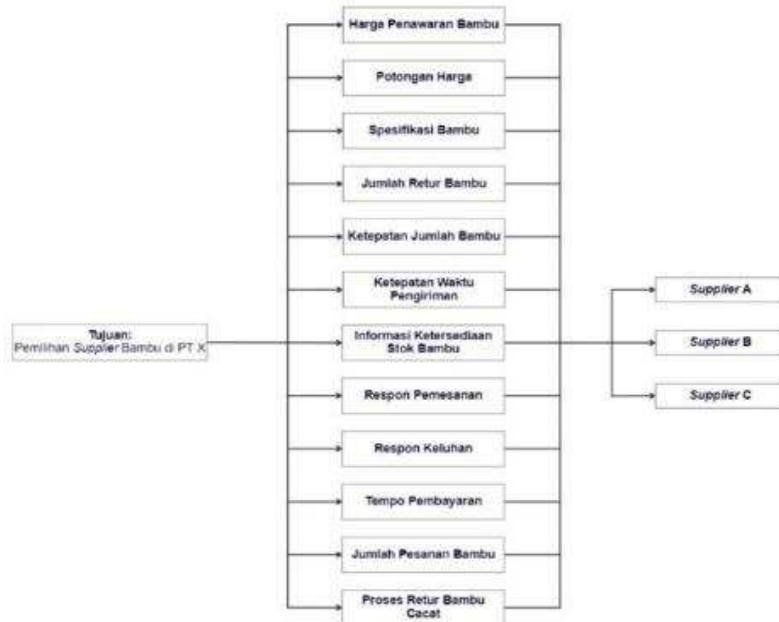


Figure 9. Model for Selecting Bamboo Suppliers using CPI

In Figure 9, we can observe the bamboo supplier selection model using the CPI method, where there are no overarching criteria for each of the subcriteria utilized. Consequently, all twelve criteria in use will individually influence the selection of bamboo suppliers at PT X. This is because the values of each subcriterion are not aggregated into a single value within a criterion, allowing us to assess their individual impacts.

The final step in data processing for the bamboo supplier selection model at PT X using the Composite Performance Index (CPI) method is to calculate the total value for each supplier. The calculation of the total value aims to determine the priority order of bamboo suppliers to be used by PT X. The total value is obtained by multiplying the results of the composite index model for each variable with the results of the judgment questionnaire. The table below presents the total values and priority orders for each supplier

Table 19. Supplier Ranking of CPI

Supplier	Total Value	Ranking
A	54,255	3
B	121,019	2
C	124,726	1

The table above represents the final results of data processing using the CPI method. In this table, it can be observed that Supplier C has the highest total value, amounting to 124.726. This places Supplier C in the first position in the bamboo supplier selection at PT X. The second and third positions are occupied by Supplier B and Supplier A, with respective total values of 121.019 and 54.255.

Selected Suppliers

Based on all the data processing conducted in the subsequent sub-sections, a summary of the supplier priorities from each method will be carried out for comparison. This recapitulation process aims to compare the results obtained based on the AHP, ANP, CPI, PROMETHEE, and TOPSIS methods.

Table 20. Priority Order of Bamboo Suppliers

Priority Order of Bamboo Suppliers			
Methods	Alternative		
	Supplier A	Supplier B	Supplier C
AHP	1	3	2
ANP	1	3	2
AHP-TOPSIS	2	3	1
ANP-TOPSIS	1	3	2
AHP-PROMETHEE I	3	2	1
ANP-PROMETHEE I	3	2	1
CPI	1	2	3
Total Points	12	18	12
Priority Order	2	1	2

The point calculation process involves converting the ranking levels into a point scale. The first rank will receive 3 points, the second rank will receive 2 points, and the third rank will receive 1 point. Based on this conversion, the result shows that supplier B is selected as the main supplier with a total of 18 points. Supplier A and supplier C will still be considered as proposed suppliers for PT X if supplier B cannot meet the company's needs, as both suppliers received an equal score of 12 points.

1.4 Conclusion

Based on the results of the research on the selection of bamboo suppliers at PT X using the AHP, ANP, CPI, PROMETHEE, and TOPSIS methods, several conclusions can be drawn. These conclusions provide answers to the research questions formulated earlier. The following are the conclusions drawn from the research:

1. The selection process for bamboo suppliers at PT X involves considering 5 criterias and 12 subcriterias when making decisions. These criteria encompass price, quality, delivery, service, and flexibility. Under the price criterion, there are subcriteria such as bamboo offering price and discount rates. For quality assessment, subcriteria include bamboo specifications and the quantity of bamboo returns. The delivery criterion comprises subcriteria like accuracy in bamboo quantity and on-time delivery. Information regarding bamboo stock availability, order responsiveness, and complaint responsiveness falls under the service criterion. Lastly, subcriteria under the flexibility criterion encompass payment terms, bamboo order quantity, and process for returning defective bamboo.
2. The AHP method employs a hierarchical model with four levels: goals, criteria, subcriteria, and alternatives. Conversely, the ANP method utilizes a network model to accommodate relationships between criteria and subcriteria, comprising one inner dependence relationship and eight outer dependence relationships. In the PROMETHEE method for selecting bamboo suppliers, an integrated approach combining AHP and ANP methods is used. This process involves additional data derived from judgment questionnaires. Similarly, the TOPSIS method employs a model akin to PROMETHEE, utilizing weights from AHP and ANP methodologies alongside data from judgment questionnaires. On the other hand, the CPI method directly connects the 12 subcriteria used for alternative selection considerations, focusing solely on data obtained from judgment questionnaires to achieve its primary objective in selecting bamboo suppliers.
3. The priority for selecting bamboo suppliers at PT X, based on the comparisons of the AHP, ANP, CPI, PROMETHEE, and TOPSIS methods, suggests that supplier B is proposed as the primary supplier. This conclusion is reached because the conversion of priority rankings from each method into points results in supplier B receiving the highest point total, amounting to 18 points. Considering this outcome, supplier B is recommended as the primary priority in the selection of bamboo suppliers at PT X.

References

- Abidi, H., Dullaert, W., De Leeuw, S., Lysko, D., & Klumpp, M. (2019). Study of Road Maintenance Program Priority, Using the Analytical Network Process. 30(2). <https://doi.org/10.1108/IJLM-07-2017-0178>
- Bakhtiar, A., Rahmadani, D., L. Deliana, W., M. Bagus. (2021). ANALISIS PEMILIHAN SUPPLIER MENGGUNAKAN METODE ANALYTICAL NETWORK PROCESS (ANP) PADA PENGADAAN KOMPONEN RAIL PAD 158-7 (STUDI KASUS: PT. PINDAD (PERSERO)). Jurnal Teknik Industri, 16 (1). Downloaded from <https://ejournal.undip.ac.id/index.php/jgti/article/view/34972/18826>.
- Betanewsid. Beginilah Proses Penerapan Teknologi Bambu di Tol Semarang-Demak. Diakses pada 1 September 2022. <https://betanews.id/2022/04/beginilah-proses-penerapan-teknologi-bambu-di-tol-semarang-demak-2-5.html/2>.
- Cheng, L., Wang, Y., & Peng, Y. (2020). Research on risk assessment of high-speed railway operation based on network ANP. [Judul Jurnal], 3(1), 37-51. <https://doi.org/10.1108/SRT-10-2020-0024>.
- Dickson, G.W. (1996). An Analysis of Vendor Selection Systems and Decisions. Journal of Purchasing, 2, 5-17.
- Fauzi, A. (2004). Ekonomi Sumber Daya Alam dan Lingkungan. Jakarta: Gramedia Pustaka Utama.
- Puspitasari, N. B. & Yancadianti, K. H. (2016). ANALISA PEMILIHAN SUPPLIER RAMAH LINGKUNGAN DENGAN METODE ANALYTICAL NETWORK PROCESS (ANP) PADA PT KIMIA FARMA PLANT SEMARANG. Jurnal Teknik Industri, 11 (1). Downloaded from <https://ejournal.undip.ac.id/index.php/jgti/article/view/10147>.
- Gasperz, V. (1990). Analisis Kuantitatif untuk Perencanaan. Bandung: TARSITO.
- Grigg, N. (1988). Infrastructure Engineering and Management. New York: John Wiley & Sons.
- Hwang, C. L. & Yoon, K. (1981). Multiple Attribute Decision Making: Methods and Applications. New York: Springer-Verlag.
- JDIH BPK RI. UNDANG-UNDANG REPUBLIK INDONESIA NOMOR 38 TAHUN 2004 TENTANG JALAN. Diakses pada 24 Agustus 2022. <https://peraturan.bpk.go.id/Home/Details/40785/uu-no-38-tahun-2004>.
- Kementerian Pekerjaan Umum dan Perumahan Masyarakat. Kemeterian PUPR Lakukan Pengujian Kekuatan Bambu Untuk Peningkatan Daya Dukung Tanah Dasar Konstruksi Tol Semarang-Demak. Diakses pada 19 Agustus 2022. <https://pu.go.id/berita/kementerian-pupr-lakukan-pengujian-kekuatan-bambu-untuk-peningkatan-daya-dukung-tanah-dasar-konstruksi-tol-semarang-demak>.
- Kementerian Pekerjaan Umum dan Perumahan Masyarakat. Konstruksi Tol Semarang-Demak Ditargetkan Mulai Tahun 2022. Diakses pada 19 Agustus 2022. <https://binamarga.pu.go.id/index.php/berita/konstruksi-tol-semarang-demak-ditargetkan-mulai-tahun-ini>.
- Kementerian Sekretariat Negara Republik Indonesia. Enam Fokus Utama untuk RAPBN Tahun 2022. Diakses pada 19 Agustus 2022. https://www.setneg.go.id/baca/index/enam_fokus_utama_untuk_rapbn_tahun_2022.
- Keswara, B. D. (2012). Studi Penimbunan Bertahap dan Perkuatan Matras-Cerucuk Bambu Sebagai Metode Perbaikan Untuk Kasus Timbunan di Atas Tanah Lunak, Jurnal Teknik Sipil, 1, 2-4.
- Marimin. (2004). Teknik dan Aplikasi Pengambil Keputusan Kriteria Majemuk. Jakarta: PT Gramedia Widiasarana Indonesia.
- Mukherjee, K. (2017). Studies in Systems, Decision and Control 88 Supplier Selection An MCDA-Based Approach. India: Springer.
- Muryani, M., Nisa, K., Esquivias, M. A., & Zulkarnain, S. H. (2023). Strategies to Control Industrial Emissions: An Analytical Network Process Approach in East Java, Indonesia. 15, 7761. <https://doi.org/10.3390/su15107761>
- Olson, D. L. (2004). Comparison of Weights in TOPSIS Models. Mathematical and Computer Modelling, 40, 721-727. DOI: 10.1016/j.mcm.2004.10.003.
- Suryadi, K. & Ramdhani, M. A. (1998). Sistem Pendukung Keputusan Suatu Wacana Struktural Idealisasi Dan Implementasi konsep Pengambilan Keputusan. Bandung: Remaja Rosdakarya Offset.
- Tabucanon, M. T. (1988). Multiple Criteria Decision Making in Industry. Bangkok: Elseveir Science Publisher.
- Railway Enthusiast Digest. Teknologi Matras Bambu dalam Pembangunan Jalur Ganda Lintas Utara. Diakses pada 27 Agustus 2022. <https://redigest.web.id/2021/12/teknologi-matras-bambu-dalam-pembangunan-jalur-ganda-lintas-utara/#.YwyzYHQBxY>.
- Saaty, T. L. (1993). Pengambilan Keputusan Bagi Para Pemimpin. Jakarta: PT Pustaka Binaman Pressindo.
- Saaty, T. L., & Vargas, L. G. (2006). Decision making with the analytic network process. United States of America: Springer.
- Saaty, T. L. (2008). Decision Making With Analytical Hierarchy Process. International. Journal Service Science, 1 (1), 83-98. DOI: 10.9744/jti.15.1.25-32.
- Saaty, T. L. & Vargas, L. G. (2012). International Series in Operations Research and Management Science, 2nd ed. New York: Springer.
- Solihin, I. (2012). Manajemen Strategi. Jakarta: Erlangga.
- Stevenson, W. J. (2011). Operations Management, 11th Edition. New York: McGraw-Hill.

- Sukarna, E. Y. (2005). Usulan Pemilihan Supplier Jasa (Kontraktor) Dengan Menggunakan Metoda Promethee Pada Proyek Braga City Walk Bandung, Tugas Akhir Sarjana. Bandung: Institut Teknologi Nasional.
- Sumiyatun & Retantyo, W. (2016). KOMBINASI METODE ANP DAN TOPSIS DALAM MENENTUKAN PRIORITAS MEDIA PROMOSI PERGURUAN TINGGI (STUDI KASUS: STMIK AKAKOM YOGYAKARTA). Jurnal Informatika dan Komputer, 1 (2).
- Surbakti, M., & Harefa, K. C. (2017). Study of Road Maintenance Program Priority, Using the Analytical Network Process. 180(1). <https://doi.org/10.1088/1757-899X/180/1/012144>
- Velasquez, M., & Hester, P. T. (2013). An Analysis of Multi Criteria Decision Making Methods. International Journal of Operation Research, 10 (2), 56-66. Downloaded from: https://www.researchgate.net/publication/275960103_An_analysis_of_multi-criteria_decision_making_methods.
- Yitmen, I., Al-Musaed, A., & Yucelgazi, F. (2022). ANP model for evaluating the performance of adaptive façade systems in complex commercial buildings based on network ANP. 29(1), 431-455. Emerald Publishing Limited.