The application of AHP-PROMETHEE II for supplier selection

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Abstract. The evaluation and selection of the best supplier is a crucial decision-making process as it can reduce the supply chain cost and increase the quality of items supplied to a company. Choosing suppliers solely based on their previous experiences may contribute to higher purchase risk. The decision-making process is usually influenced by a variety of criteria that are often in conflict. Thus, this study employs the integration of Analytic Hierarchy Process (AHP) method and Preference Ranking Organization Method for Enrichment of Evaluation (PROMETHEE) II to handle supplier selection issues. AHP method was adopted to evaluate the weights of criterion. PROMETHEE II is a Multi-Attribute Decision Making method that is based on a mutual comparison of each alternative pair with respect to each of the selected criterion allowing the rankings of the alternatives from the best to the worst. A real-life data about supplier selection for railways project was used to demonstrate the operation of AHP-PROMETHEE II method. The data involved four decision makers, five alternatives (S1, S2, S3, S4, S5) and eight criteria specifically; aspect of the items (C1), arrangement of time (C2), shipment accomplishment (C3), total price of the item (C4), way of payment (C5), relation with supplier (C6), scope of product (C7), and supplier’s professional ability (C8). The findings showed that C4 was the most preferred criterion among the chosen criteria. Thus, the ranking order for criteria was C4 > C8 > C1 > C2 > C5 > C7 > C6 > C3 while the ranking order for the alternatives was S2 > S1 > S4 > S3 > S5, respectively. The findings were then compared with the result from the previous research. The sensitivity analysis was conducted by reducing criteria weights to zero. In conclusion, AHP-PROMETHEE II can be used to analyse the perfect order from best to worst.

1. Introduction

The selection of suppliers is the most significant decision-making problem, covering both quantitative and qualitative considerations, to determine the suppliers with the highest ability to consistently address the company’s requirement and at a reasonable cost [1]. A company should select an appropriate supplier as it will give many advantages to the company. For example, they will minimize the risk supply and increase product quality [2].

Various approaches may be used to analyse the relevant supplier of preference for a company, such as the Analytical Hierarchy Process (AHP) method and Preference ranking organization method for enrichment evaluations (PROMETHEE) II method. AHP is applied to rank the possibilities by
considering the importance of the different criteria [3]. PROMETHEE II is applied to compare a set of alternatives by classifying the weights from the AHP.

AHP is a common method used in Multiple Criteria Decision-Making (MCDM). Thomas L. Saaty established AHP in 1977. It is used to rank the possibilities regarding the importance of the different criteria [3]. AHP constructs the hierarchical structure in which the decision goal is placed on top, the list of chosen criteria on the center and the set of alternatives is at the lowest level [4]. PROMETHEE method established by Brans and Vincke [5] is one of the popular MCDM methods. PROMETHEE II is also a very straightforward ranking approach in design and implementation correlated to other approaches used for multi-attribute studies. PROMETHEE I is applied to determine the partial ranking while PROMETHEE II is applied to analyse the complete ranking of alternatives [4].

AHP cannot consider uncertain conditions in pair-wise processes. It is generally criticized for judgement inconsistency, accuracy and weak prioritisation method [6]. PROMETHEE II can be used only if the importance of the ratio scale has been stated by the decision makers which are called weightage [6]. Therefore, to overcome these drawbacks, AHP-PROMETHEE II method is formed. AHP is utilized to interpret the pattern of the problem and analyse the criteria weight [3], while PROMETHEE II is applied to produce a complete grade, starting from the top to the lowest [7].

One of the essential aspects in the manufacturing role is the choice of the best vendors and the procurement of the necessary materials [8]. The key issues arising in selecting the best supplier can be summed up as defeat to order in due time, incorrect arrival in due time, mistakes in cost trade, incorrect receipt of products, missing or defective products, stealing of components from shipment to manufacturing and dual storage [9]. Choosing suppliers simply based on previous experience can lead to the selection of inappropriate suppliers which can in turn trigger performance issues, budget cuts, shortages and pollution problems [10].

In this study, AHP-PROMETHEE II is used to choose the best supplier based on existing criteria. Thus, the goal of this study is to determine the best supplier for a company by using AHP-PROMETHEE II method. This paper contains five sections. The first section is the introduction of the research. The second section contains the literature review and the background theory of AHP, PROMETHEE II and AHP-PROMETHEE II. Next, section three is the methodology of AHP-PROMETHEE II method. Section four displays the result and discussion. Lastly, the last section includes the conclusion of the research.

2. Literature Review
This section includes the literature review and the background theory of AHP method, PROMETHEE II method and AHP PROMETHEE II method.

2.1. AHP method
AHP is a well-known method of multiple criterion decision making to solve the complications that were evolved by Thomas L. Saaty in 1977. It is used to rank the possibilities regarding the importance of the different criteria [3]. Three essential components of the AHP are structuring the problems into a hierarchical structure that consists of objective and subordinate features (decomposition), making pairwise comparison of components at every level (assessment), and having distribution of level-specific, local priorities to universal priorities (synthesis) [11]. AHP structures the decision-making problem and monitors the decision-making process by determining goals, criteria, and alternatives, and then evaluates the criteria and alternatives in pairs, and determine alternative priorities. A scale of numbers that indicates how significant one element is over another is used when the element is compared pairwise [12]. The Saaty nine-point scale is applied to make the comparison. The outcome of the AHP method ranks the weight coefficients of the alternatives with respect to each criterion. AHP efficiently identifies and illustrates contradictions in decision-making by measuring inconsistencies for the entire process. As a result, the quantitative indicators can argue the decision.

The benefits of the AHP process are it is easy to handle multiple criteria, can be easily understood, and can completely handle both quantitative and qualitative input. Nonetheless, AHP is blamed for its
failure to competently handle the ambiguity in the decision maker’s judgment [13]. Table 1 shows the summary of past researches on supplier selection problem and criteria of the AHP method in the literature. The feasible and efficient representation of unknown data labelled D-Numbers, developed by X. Deng et al. [14] proposes a D-AHP approach in vendor selection problems, expanding the classical AHP approach. Dweiri et al. [15] applied AHP method with a decision model for supplier selection using a case study of automotive industry and conducted the sensitivity analysis to track the solidity of supplier selection decisions.

### Table 1. The summary of past researches on supplier selection problem and criteria of AHP method in the literature

| Author         | Title                                                                 | Method | Criteria                        |
|----------------|-----------------------------------------------------------------------|--------|---------------------------------|
| X. Deng et al. [14] | Supplier selection using AHP methodology extended by D numbers. | D-AHP  | ● Price.                        |
|                |                                                                       |        | ● Standard.                     |
|                |                                                                       |        | ● Quality of service.           |
|                |                                                                       |        | ● Profile of manufacturer.      |
|                |                                                                       |        | ● Uncertainty.                  |
| Dweiri et al. [15] | Designing an integrated AHP based decision support system for supplier selection in the automotive industry. | AHP    | ● Delivery.                     |
|                |                                                                       |        | ● Price.                        |
|                |                                                                       |        | ● Quality.                      |
|                |                                                                       |        | ● Service.                      |

#### 2.2. PROMETHEE II method

PROMETHEE is a MCDM method established by J.P. Brans for the first time in 1982 [5]. This method involves some different categories which are PROMETHEE I (partial ranking), PROMETHEE II (full ranking), and PROMETHEE III (interval ranking). PROMETHEE II needs very specific details for analysts and decision-makers, which ranks the alternatives entirely. Such details include a decision-making matrix containing the trade-off data of decision-makers between alternatives in all parameters, the weights (relative importance) of parameters, and functions for preferences. PROMETHEE II is the easiest and most efficient way of handling different quantitative and qualitative scales as well as classifying the alternatives based on net outranking flow values. In this process, the decision-maker considers information within each criterion (showing the decision-makers' favourites or preferences) and information between criteria (about the relative value of the criteria as compared to each other) [6]. The downsides are it does not show the exact way on how to obtain the weights and it requires the assignment of values with no clear method by which to assign those values [16].

Table 2 shows the summary of past research on supplier selection problem and criteria of the PROMETHEE method in the literature. Strantzali et al. [17] applied PROMETHEE II to calculate all the capability of export terminals and study the history of natural gas supply in Greece. The researchers have also calculated the complete preorder by using PROMETHEE II where the outright theory was used to identify the alternatives, together with a simple usage and reduced complexity. Segura and Maroto [18] have been using PROMETHEE method that has demonstrated greater capacity and robustness in establishing portfolios of suppliers that are partners in the enterprise and in recognizing certain forms of relationships, such as industry actions, long-term commitment, or those which are excluded from its portfolio in selected suppliers. PROMETHEE enables suppliers to choose the best or mark them based on their vital and strategic scores by pointing to a more humorous connection to procurement management and shows the reverse problem the ranking will change when new suppliers are introduced.
Table 2. The summary of past research on supplier selection problem and criteria of PROMETHEE method in the literature

| Author                  | Title                                                                 | Method        | Criteria                                      |
|-------------------------|----------------------------------------------------------------------|---------------|-----------------------------------------------|
| Strantzali et al. [17]  | A decision support access for appraising liquefied natural gas supply options: Implementation on Greek case study. | PROMETHEE II  | ● Distance.                                   |
|                         |                                                                       |               | ● Delivery charges.                           |
|                         |                                                                       |               | ● Consumption of gasoline.                    |
|                         |                                                                       |               | ● Opportunity.                                |
|                         |                                                                       |               | ● Spot rate.                                  |
|                         |                                                                       |               | ● R/P correlation.                            |
|                         |                                                                       |               | ● Methane number.                             |
|                         |                                                                       |               | ● EEOI.                                       |
| Segura and Maroto [18]  | A multiple criteria supplier segmentation using outranking and PROMETHEE value function techniques. |               | ● Safety.                                     |
|                         |                                                                       |               | ● Delivery time.                              |
|                         |                                                                       |               | ● Provisioning factor.                        |
|                         |                                                                       |               | ● Company image.                              |
|                         |                                                                       |               | ● Risk.                                       |

2.3. AHP-PROMETHEE II method

An effective and detailed evaluation model that incorporates AHP with PROMETHEE II is the AHP-PROMETHEE II method. All parameters are allocated using AHP by comparing an alternative with another in the rating scale and weight matrix standardization while outranking flow calculation using PROMETHEE II [19]. AHP appears very promising as it uses a comparison matrix to make decision making more efficient and exact. PROMETHEE II is incorporated with AHP to remove the uncertainty of the comparison matrix. PROMETHEE II, however, is an outright process using flow decision measures to identify optimal alternatives by increasing speed and reducing time. Thus, the hybrid AHP-PROMETHEE II is an efficient MCDM solution in choosing the best alternative [20].

Table 3 shows the summary of past research on supplier selection problem and criteria of the AHP-PROMETHEE method in the literature.

Table 3. The summary of past research on supplier selection problem and criteria of AHP-PROMETHEE method in the literature

| Author      | Title                                                                 | Method        | Criteria                                      |
|-------------|-----------------------------------------------------------------------|---------------|-----------------------------------------------|
| Polat [21]  | Subcontractor selection using the integration of the AHP and PROMETHEE Method. | AHP-PROMETHEE | ● The price of sale.                           |
|             |                                                                       |               | ● Monetary situations.                        |
|             |                                                                       |               | ● Capital adequacy.                          |
|             |                                                                       |               | ● Quality performance.                       |
|             |                                                                       |               | ● Safety performance.                        |
|             |                                                                       |               | ● Experience.                                |
|             |                                                                       |               | ● Technical competence.                      |
| Roy et al. [19] | A capable Hybrid MCDM based on the access for car election in automobile commerce. | Fuzzy AHP-PROMETHEE II | ● Cost.                                      |
|             |                                                                       |               | ● Safety.                                    |
|             |                                                                       |               | ● Look.                                      |

Polat [21] applied AHP and PROMETHEE to select the subcontractors. Roy et al. [19] applied Fuzzy AHP and PROMETHEE II to solve the best car models selection problem for customers. The structure of the subcontracting selection issue was formulated by Polat [21] where the weight of the parameters were determined by AHP, while Roy et al. [19] applied the consolidation of fuzzy and the AHP
prototype to eliminate ambiguities of the comparison matrix and increase the power of the AHP approach by integrating the fusing membership role. These two studies included the PROMETHEE method for determining the goals for alternative solutions, based on AHP weights and decision-maker choice features.

3. Methodology
This study used the integrated AHP-PROMETHEE II method where the conceptual model for decision-making process was described by:

- Identifying the criteria and alternatives for formation of decision hierarchical structure.
- Using AHP method to develop the criteria weights matrix.
- Using PROMETHEE II method to evaluate and to rank the alternatives from the best to the worst.

3.1. AHP framework
The procedure of AHP method starts with decomposing the complex decision-making problem hierarchically where the structure consists of objectives, criteria, sub criteria (if any) and alternatives. AHP can deal with both qualitative and quantitative data. In this hybrid method, AHP method was used to determine the relative weights of criteria. Then these weights were further used in PROMETHEE II method to rate a set of alternatives with conflicting criteria. The steps listed below shows the procedures of AHP method in evaluating the importance of criteria weights [12].

Step 1: Develop the hierarchical structure.
Step 2: Perform data scaling by using the linguistic variables for the importance weights of the criteria [10] as shown in table 4.

**Table 4. Linguistic variables for the importance weights of the criteria**

| Linguistic Variables                             | Crisp AHP Scale |
|-------------------------------------------------|-----------------|
| Equally Preferred (EqP)                         | 1               |
| Equally to Moderately Preferred (Eq-MP)         | 2               |
| Moderately Preferred (MP)                       | 3               |
| Moderately to Strongly Preferred (M-SP)         | 4               |
| Strongly Preferred (SP)                         | 5               |
| Strongly to Very Strongly Preferred (S-VSP)     | 6               |
| Very Strongly Preferred (VSP)                   | 7               |
| Very Strongly to Extremely Preferred (VS-ExP)   | 8               |
| Extremely Preferred (ExP)                       | 9               |

Step 3: Establish the pairwise comparison matrix, \( P_{ax} \) for criteria in which each component, \( p_{ij} (i, j = 1, 2, ..., n) \), represents the weight of the criterion given by the decision maker where \( p_{ij} > 0 \) and \( p_{ij} = \frac{1}{p_{ji}} \).

Step 4: Establish the normalized pairwise comparison matrix. The component of the matrix \( P_{nx} \) is divided with the sum of its column and the sum of each column for normalized pairwise comparison matrix must be 1.

Step 5: Calculate the criteria weights by averaging the entire elements in the row of matrix \( P_{nx} \).

Step 6: Calculate the Consistency Ratio, CR using below equation and Random Index (RI) shown in table 5 whereas
\[ CR = \frac{CI}{RI} \]  

(3.1)

and let \( \lambda_{\text{max}} \) be the maximum eigenvector, \( n \) is the size of the matrix and the Consistency Index, \( CI \) can be expressed as:

\[ CI = \frac{\lambda_{\text{max}} - n}{n-1} \]  

(3.2)

The judgment is consistent if \( CR < 0.1 \).

| n  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|----|----|----|----|----|----|----|----|----|----|----|
| RI | 0  | 0  | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

**Table 5. Random Index (RI)**

3.2. **PROMETHEE II framework**

The PROMETHEE II outranking method was used to generate a complete ranking of alternatives in the study. The steps listed below shows the procedures of PROMETHEE II method in evaluating and providing the complete ranking of the alternatives [21, 22, 23].

Step 1: Construct the decision matrix. The data will be evaluated using the scales in table 6.

**Table 6. Linguistic variables for alternatives**

| Linguistic Variables                  | Crisp AHP Scale |
|---------------------------------------|-----------------|
| Very Bad (VB)                         | 1               |
| Very Bad to Bad (VB-B)                | 2               |
| Bad (B)                               | 3               |
| Bad to Average (B-A)                  | 4               |
| Average (A)                           | 5               |
| Average to Good (A-G)                 | 6               |
| Good (G)                              | 7               |
| Good to Very Good (G-VG)              | 8               |
| Very Good (VG)                        | 9               |

Step 2: Normalize the decision matrix by using equation (3.3) and (3.4) for beneficial criteria and non-beneficial criteria, respectively.

\[ R_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \quad \text{for } i = 1, 2, 3, \ldots, m; j = 1, 2, 3, \ldots, n \quad \text{(Beneficial criteria)} \]  

(3.3)

\[ R_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \quad \text{for } i = 1, 2, 3, \ldots, m; j = 1, 2, 3, \ldots, n \quad \text{(Non - Beneficial criteria)} \]  

(3.4)

Step 3: Compute the evaluative differences of \( i \)th alternative with respect to another alternative, \( d_{ij}(a,b) \) by using:

\[ d_{ij}(a,b) = g_j(a) - g_j(b) \]  

(3.5)

Step 4: Compute the preference function, \( P_j(a,b) \) using:

\[ P_j(a,b) = 0 \quad \text{if } R_{aj} \leq R_{bj} \text{ such that } D(M_a - M_b) \leq 0 \]

\[ P_j(a,b) = R_{aj} - R_{bj} \quad \text{if } R_{aj} > R_{bj} \text{ such that } D(M_a - M_b) > 0 \]  

(3.6)
Step 5: Compute the aggregated preference, \( \pi(a,b) \) by using:

\[
\pi(a,b) = \frac{\sum_{j=1}^{n} w_j P_j(a,b)}{\sum_{j=1}^{n} w_j} \quad \text{where} \quad \sum_{j=1}^{n} w_j = 1
\]  

(3.7)

Given that \( \sum_{j=1}^{n} w_j \) is the sum of the weight for criteria.

Step 6: Determine the leaving and the entering outranking flow using equation (3.8) and (3.9) respectively.

Leaving (positive) flow for \( a^{th} \) alternative, \( \varphi^+(a) = \frac{1}{m-1} \sum_{b=1}^{m} \pi(a,b) \) where \( a \neq b \)  

(3.8)

Entering (negative) flow for \( a^{th} \) alternative, \( \varphi^-(a) = \frac{1}{m-1} \sum_{b=1}^{m} \pi(b,a) \) where \( a \neq b \)  

(3.9)

Step 7: Compute the net outranking flow for each alternative using:

\[ \varphi(a) = \varphi^+(a) - \varphi^-(a) \]

(3.10)

3.3. The implementation of integrated AHP-PROMETHEE II method

In this study, a real-life empirical data on the selection of rail suppliers in an intercity railway project in Saudi Arabia [11] was applied to demonstrate the application of AHP-PROMETHEE II method. There were eight (8) criteria, five (5) suppliers (S1, S2, S3, S4, S5) and four (4) decision makers from civil engineering that were highly experienced in the project involved in the decision-making process. The selected criteria were; aspect of the items (C1), arrangement of time (C2), shipment accomplishment (C3), item price (C4), way of payment (C5), relation with supplier (C6), scope of product (C7), and supplier’s professional ability (C8). Figure 1 below shows the hierarchical structure of the problem.
Meanwhile table 7 depicts the judgments of the decision makers and the linguistic variables was then converted to a crisp value using the scales in table 4.

| DM# | C# | Criteria of Supplier Selection (C#) |
|-----|----|------------------------------------|
|     |    | C1       | C2       | C3       | C4       | C5       | C6       | C7       | C8       |
| DM1 | C1 | EqP      | Eq-MP    | M-SP     | 1/M-SP   | Eq-MP    | MP       | Eq-MP    | Eq-MP    |
|     | C2 | 1/Ep-MP  | EqP      | SP       | 1/Ep-MP  | EqP      | M-SP     | Eq-MP    | Eq-MP    |
|     | C3 | 1/M-SP   | 1/SP     | EqP      | 1/VS-ExP | 1/M-SP   | 1/Ep-MP  | Eq-MP    | 1/Ep-MP  |
|     | C4 | M-SP     | Eq-MP    | VS-ExP   | EqP      | Eq-MP    | VSP      | S-VSP    | EqP      |
|     | C5 | 1/Ep-MP  | EqP      | M-SP     | 1/Ep-MP  | EqP      | M-SP     | Eq-MP    | 1/M-SP   |
|     | C6 | 1/MP     | 1/M-SP   | Eq-MP    | 1/VSP    | 1/M-SP   | EqP      | EqP      | 1/M-SP   |
|     | C7 | 1/Ep-MP  | 1/Ep-MP  | 1/VSP    | 1/M-SP   | 1/Ep-MP  | EqP      | EqP      | 1/M-SP   |
|     | C8 | 1/Ep-MP  | 1/Ep-MP  | 1/VSP    | 1/M-SP   | 1/Ep-MP  | EqP      | M-SP     | M-SP     |

| DM2 | C1 | EqP      | MP       | Eq-MP    | EqP      | Eq-MP    | M-SP     | MP       | Eq-MP    |
|     | C2 | 1/Ep-MP  | EqP      | M-SP     | 1/Ep-MP  | MP       | M-SP     | SP       | Eq-MP    |
|     | C3 | 1/Ep-MP  | 1/M-SP   | EqP      | 1/VS-ExP | 1/M-SP   | 1/Ep-MP  | Eq-MP    | 1/M-SP   |
|     | C4 | 1/M-SP   | 1/Ep-MP  | 1/M-SP   | EqP      | 1/Ep-MP  | M-SP     | S-VSP    | S-VSP    | Eq-MP    |
|     | C5 | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | 1/S-SP   | 1/Ep-MP  | EqP      | EqP      | 1/M-SP   |
|     | C6 | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | 1/S-VSP  | 1/Ep-MP  | EqP      | EqP      | 1/M-SP   |
|     | C7 | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | 1/S-VSP  | 1/Ep-MP  | EqP      | EqP      | 1/M-SP   |
|     | C8 | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | 1/S-VSP  | 1/Ep-MP  | EqP      | M-SP     | M-SP     |

| DM3 | C1 | EqP      | M-SP     | S-VSP    | Eq-MP    | 1/VSP    | MP       | Eq-MP    | EqP      |
|     | C2 | 1/Ep-MP  | EqP      | M-SP     | 1/Ep-MP  | 1/Eq-MP  | MP       | 1/Ep-MP  | 1/M-SP   |
|     | C3 | 1/S-VSP  | 1/Ep-MP  | 1/M-SP   | 1/Ep-MP  | 1/Eq-MP  | EqP      | 1/Ep-MP  | 1/S-VSP  |
|     | C4 | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | EqP      | 1/Eq-MP  | Eq-MP    |
|     | C5 | 1/VS-ExP | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | EqP      | Eq-MP    | 1/M-SP   |
|     | C6 | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | EqP      | Eq-MP    | 1/S-VSP  |
|     | C7 | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | EqP      | Eq-MP    | 1/S-VSP  |
|     | C8 | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | EqP      | S-VSP    | S-VSP    | EqP      |

| DM4 | C1 | EqP      | 1/SP     | EqP      | 1/VS-ExP | 1/Ep-MP  | EqP      | EqP      | EqP      |
|     | C2 | 1/Ep-MP  | EqP      | ExP      | 1/Ep-MP  | EqP      | ExP      | Eq-MP    | Eq-MP    |
|     | C3 | 1/Ep-MP  | EqP      | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | EqP      | 1/Ep-MP  | 1/M-SP   |
|     | C4 | 1/Ep-MP  | EqP      | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | EqP      | 1/Ep-MP  | 1/M-SP   |
|     | C5 | 1/Ep-MP  | EqP      | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | EqP      | 1/Ep-MP  | 1/M-SP   |
|     | C6 | 1/Ep-MP  | EqP      | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | EqP      | 1/Ep-MP  | 1/M-SP   |
|     | C7 | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | 1/Ep-MP  | EqP      | EqP      | EqP      |
|     | C8 | 1/Ep-MP  | 1/Ep-MP  | M-SP     | EqP      | Eq-MP    | Eq-MP    | EqP      | EqP      |
Table 8 shows pairwise comparison matrix for the chosen criteria.

### Table 8. The pairwise comparison matrix for criteria

| DM# | C# | Criteria of Supplier Selection (C#) | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 |
|-----|----|------------------------------------|----|----|----|----|----|----|----|----|
|     |    |                                    | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 |
| DM1 | C1 |                                    | 1  | 2  | 4  | 1/4| 2  | 3  | 2  | 2  |
|     | C2 |                                    | 1/2| 1  | 5  | 1/2| 1  | 4  | 2  | 2  |
|     | C3 |                                    | 1/4| 1/5| 1  | 1/8| 1/4| 1/2| 2  | 1/2|
|     | C4 |                                    | 4  | 2  | 8  | 1  | 2  | 7  | 6  | 1  |
|     | C5 |                                    | 1/2| 1  | 4  | 1/2| 1  | 4  | 2  | 1/4|
|     | C6 |                                    | 1/3| 1/4| 2  | 1/7| 1/4| 1  | 1  | 1/4|
|     | C7 |                                    | 1/2| 1/2| 1/2| 1/6| 1/2| 1  | 1  | 1/4|
|     | C8 |                                    | 1/2| 1/2| 2  | 1  | 4  | 4  | 4  | 1  |
| DM2 | C1 |                                    | 1  | 3  | 2  | 1  | 2  | 4  | 3  | 2  |
|     | C2 |                                    | 1/3| 1  | 4  | 1/2| 3  | 4  | 5  | 2  |
|     | C3 |                                    | 1/2| 1/4| 1  | 1/8| 1/8| 2  | 2  | 1/4|
|     | C4 |                                    | 1  | 2  | 8  | 1  | 4  | 6  | 6  | 2  |
|     | C5 |                                    | 1/2| 1/3| 8  | 1/4| 1  | 5  | 3  | 1/4|
|     | C6 |                                    | 1/4| 1/4| 1/2| 1/6| 1/5| 1  | 1  | 1/4|
|     | C7 |                                    | 1/3| 1/5| 1/2| 1/6| 1/3| 1  | 1  | 1/4|
|     | C8 |                                    | 1/2| 1/2| 2  | 1/2| 4  | 4  | 4  | 1  |
| DM3 | C1 |                                    | 1  | 4  | 6  | 2  | 8  | 3  | 2  | 1  |
|     | C2 |                                    | 1/4| 1  | 4  | 1/2| 3  | 5  | 1  | 1/4|
|     | C3 |                                    | 1/6| 1/4| 1  | 1/4| 1/2| 1  | 1/2| 1/6|
|     | C4 |                                    | 1/2| 2  | 4  | 1  | 3  | 5  | 1/2| 2  |
|     | C5 |                                    | 1/8| 1/3| 2  | 1/3| 1  | 2  | 1/4| 1/6|
|     | C6 |                                    | 1/3| 1/5| 1  | 1/5| 1/2| 1  | 1/4| 1/6|
|     | C7 |                                    | 1/2| 1  | 2  | 2  | 4  | 4  | 1  | 1/5|
|     | C8 |                                    | 1  | 4  | 6  | 1/2| 6  | 6  | 5  | 1  |
| DM4 | C1 |                                    | 1  | 1/5| 1  | 1/8| 1/8| 1/2| 1  | 1  |
|     | C2 |                                    | 5  | 1  | 1  | 1/2| 1  | 9  | 2  | 2  |
|     | C3 |                                    | 1  | 1/9| 1  | 1/8| 1/2| 1  | 1  | 1/4|
|     | C4 |                                    | 8  | 2  | 8  | 1  | 2  | 7  | 7  | 1  |
|     | C5 |                                    | 8  | 1  | 2  | 1/2| 1  | 3  | 4  | 1/2|
|     | C6 |                                    | 2  | 1/9| 1  | 1/7| 1/3| 1  | 1  | 1/2|
|     | C7 |                                    | 1  | 1/2| 1  | 1/7| 1/4| 1  | 1  | 1  |
|     | C8 |                                    | 1  | 1/2| 4  | 1  | 2  | 2  | 1  | 1  |

The criteria weights will be computed using the AHP method first. When the CR was calculated, it was found that the judgment of the second decision maker (DM2) was inconsistent since the value of CR for DM2 is 0.1190 > 0.1. Thus, the judgment of DM2 must be rejected from the decision-making process. Table 9 shows the judgments of the decision makers towards the alternatives. Meanwhile, table 10 shows the decision matrix for the problem. The scales in table 6 is used to form the matrix. Then the criteria weights evaluated previously using AHP method were further used in PROMETHEE II method to rank a set of alternatives with respect to the conflicting criteria. Microsoft Excel was used to analyse the data.
Table 9. The performance evaluations of alternatives

| DM  | Alternatives | C1  | C2  | C3  | C4  | C5  | C6  | C7  | C8  |
|-----|--------------|-----|-----|-----|-----|-----|-----|-----|-----|
| DM-1| S1           | A-G | A   | G   | A   | G   | VG  | B-A | G-VG|
|     | S2           | VG  | G   | B-A | B   | B-A | B-A | G   | VG  |
|     | S3           | G-VG| A-G | B   | A   | B-A | B-A | B-A | G-VG|
|     | S4           | G-VG| A   | G   | G   | B-A | A-G | A   | A-G |
|     | S5           | G   | G-VG| A   | B-A | B   | A   | G   | A-G |
| DM-3| S1           | A-G | B   | G-VG| A-G | G   | VG  | B   | G   |
|     | S2           | VG  | A   | A   | B-A | B-A | B-A | G   | G-VG|
|     | S3           | G-VG| A-G | B   | A-G | A   | B-A | A   | G   |
|     | S4           | G   | B   | G   | G   | A-G | G-VG| B-A | A-G |
|     | S5           | A-G | G-VG| B-A | A   | A   | B   | G   | A-G |

Table 10. The decision matrix

| Alternatives | C1  | C2  | C3  | C4  | C5  | C6  | C7  | C8  |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|
| S1           | 6.3333 | 4.0000 | 7.3333 | 6.3333 | 7.3333 | 8.6667 | 3.6667 | 7.3333 |
| S2           | 9.0000 | 6.3333 | 4.3333 | 3.6667 | 4.6667 | 4.0000 | 6.6667 | 8.3333 |
| S3           | 7.3333 | 6.0000 | 3.0000 | 6.0000 | 4.6667 | 4.0000 | 4.0000 | 7.3333 |
| S4           | 7.3333 | 4.0000 | 6.6667 | 7.3333 | 6.0000 | 7.0000 | 4.6667 | 6.0000 |
| S5           | 6.3333 | 8.0000 | 4.3333 | 5.0000 | 4.6667 | 3.6667 | 7.3333 | 5.3333 |

4. Result and Discussion

4.1. Weightage and rank of criteria

![Weightage of Criteria](image_url)
Table 11. Weight of the supplier selection criteria

| Criteria                  | AHP method | Result from Polat et al. [10] |
|---------------------------|------------|-------------------------------|
|                           | Weight     | Rank             | Weight | Rank |
| C1 Product’s quality      | 0.15       | 3                | 0.14   | 4    |
| C2 Arrangement of time    | 0.1428     | 4                | 0.16   | 3    |
| C3 Shipment accomplishment| 0.0402     | 8                | 0.04   | 7    |
| C4 Item price             | 0.253      | 1                | 0.26   | 1    |
| C5 Payment conditions     | 0.1046     | 5                | 0.1    | 5    |
| C6 Relation with supplier| 0.0426     | 7                | 0.04   | 8    |
| C7 Production quantity    | 0.0782     | 6                | 0.06   | 6    |
| C8 Supplier’s professional ability | 0.1886 | 2 | 0.18 | 2 |

In this study, real life data about the selection of rail suppliers in an intercity railway project in Saudi Arabia [10] is applied to demonstrate the application of AHP-PROMETHEE II. AHP-PROMETHEE II is used to analyse the perfect order from the best to the worst. Furthermore, there were eight criteria that were known as C1, C2, C3, C4, C5, C6, C7, and C8.

Polat et al. [10] used Fuzzy AHP to compute the weightage of the supplier selection criteria. Table 11 and Figure 2 show the weightage of the criteria. Figure 2 shows that C4 has the highest score of 0.26 and hence C4 has been selected as the best criteria. Table 11 shows that the ranking order for criteria using Fuzzy AHP was C4 > C8 > C2 > C1 > C5 > C7 > C3 > C6. However, in this study, AHP was applied to determine the weightage of criteria. The ranking order for criteria was C4 > C8 > C1 > C2 > C5 > C7 > C6 > C3 and C4 also has been selected as the best criteria. Figure 2 shows that the score for C4 using AHP method is 0.253. C4 has the capability to achieve high profit margins and it is a major determinant of a company’s ability to be competitive [25]. The ranking of C1, C2, C3 and C6 were switched compared to Polat et al. [10]. Furthermore, Polat et al. [10] used four decision makers, but when using the AHP method, the judgement of the second decision maker (DM 2) had to be rejected since it was inconsistent.

4.2. Weightage and rank of alternatives

Table 12. Alternatives ranking

| Alternatives | AHP-PROMETHEE II Net Outranking | Rank | Alternatives | Result from Polat et al. [10] | $d_i^+$ | $d_i^-$ | $CC_i^j$ | Rank |
|--------------|---------------------------------|------|--------------|--------------------------------|--------|--------|---------|------|
| S1           | 0.0964                          | 2    | S1           | 7.2                            | 0.93   | 0.114  | 1       |
| S2           | 0.3531                          | 1    | S2           | 7.22                           | 0.9    | 0.111  | 3       |
| S3           | -0.1156                         | 4    | S3           | 7.23                           | 0.9    | 0.11   | 4       |
| S4           | -0.0885                         | 3    | S4           | 7.21                           | 0.92   | 0.113  | 2       |
| S5           | -0.2453                         | 5    | S5           | 7.25                           | 0.88   | 0.108  | 5       |

Polat et al. [10] used Fuzzy TOPSIS to compute the weightage of alternatives. Table 12 shows the average ranking of the alternatives based on decision maker’s preference. The ranking order is S1 > S4 > S2 > S3 > S5. S1 was selected as the best supplier in the railway project and they did not experience any severe problems during the construction phase [10]. In this study, AHP-PROMETHEE II was applied to implement ranking of the alternatives in rail suppliers. The findings show that the ranking order was S2 > S1 > S4 > S3 > S5. S2 was the highest net outranking when AHP-PROMETHEE II was applied. The worst supplier for AHP-PROMETHEE II was S5. Therefore, by using AHP-PROMETHEE II, S2 was selected as the best supplier in the railway project.
4.3.  Sensitivity Analysis

In this subsection, a sensitivity analysis was conducted to analyse the impact of adjusting weights of the main criteria and conditions on supplier’s ranking. The analysis performed eight scenarios regarding different criteria weights in which the weights of criteria is reduced to zero one by one [26]. Table 13 and figure 3 shows the simulation of sensitivity analysis being implemented by making certain changes to the values of each criterion, whether for the aspect of the items (C1), arrangement of time (C2), shipment accomplishment (C3), item price (C4), way of payment (C5), relation with supplier (C6), scope of product (C7), and supplier’s professional ability (C8). Then, the rank order due to such changes was observed. For example, Scenario 1 shows that the ranking of suppliers was retained, thus the order was still S2 > S1 > S4 > S3 > S5 when the weight of criteria 1 is shifted to zero. This situation was applied in other scenarios to investigate if the ranking of suppliers will be affected or not. Figure 3 shows supplier S2 recorded the maximum score in seven out of eight scenarios (scenarios 1, 2, 3, 5, 6, 7 and 8). Meanwhile, supplier S5 recorded the least score in six out of eight scenarios (scenarios 1, 3, 4, 5, 6 and 7). Overall, the final rank of the supplier for selecting the rail suppliers in an intercity railway project tends to be reasonably sensitive to criterion weighting values.

| Scenario | Criteria | Weightage | AHP-PROMETHEE II |
|----------|----------|-----------|------------------|
| Scenario 1 | (C2, C3, C4, C5, C6, C7, C8) | (0.1744,0.0477,0.2823,0.1148,0.0455,0.0974,0.2379) | S2 > S1 > S4 > S3 > S5 |
| Scenario 2 | (C1, C3, C4, C5, C6, C7, C8) | (0.1650,0.0505,0.2938,0.1229,0.0538,0.0907,0.2232) | S2 > S1 > S3 > S5 > S4 |
| Scenario 3 | (C1, C2, C4, C5, C6, C7, C8) | (0.1566,0.1506,0.2579,0.1080,0.0426,0.0854,0.1990) | S2 > S1 > S3 > S4 > S5 |
| Scenario 4 | (C1, C2, C3, C5, C6, C7, C8) | (0.1994,0.1972,0.0567,0.1495,0.0607,0.0944,0.2420) | S1 > S2 > S4 > S3 > S5 |
| Scenario 5 | (C1, C2, C3, C4, C6, C7, C8) | (0.1602,0.1671,0.0456,0.2996,0.0507,0.0860,0.1908) | S2 > S1 > S3 > S4 > S5 |
| Scenario 6 | (C1, C2, C3, C4, C5, C7, C8) | (0.1659,0.1353,0.0432,0.2651,0.1076,0.0818,0.2012) | S2 > S1 > S3 > S4 > S5 |
| Scenario 7 | (C1, C2, C3, C4, C5, C6, C8) | (0.1717,0.1607,0.0392,0.2705,0.1101,0.0531,0.1948) | S2 > S1 > S4 > S3 > S5 |
| Scenario 8 | (C1, C2, C3, C4, C5, C6, C7) | (0.1843,0.1660,0.0501,0.3115,0.1359,0.0521,0.100) | S2 > S1 > S4 > S5 > S3 |
5. Conclusion

This paper presented the combinations of MCDM approaches which was AHP-PROMETHEE II method that focuses on assisting the contractors in selecting the most significant rail supplier among the accessible set of alternatives. The presented method allows the decision makers to convey their criteria desired by crisp AHP scale [10]. In this study, the AHP-PROMETHEE II was utilised to get the most systematic supplier. PROMETHEE II was applied to provide a perfect order from the best to the worst [27] and to assess the first concern of alternatives based on the weightage of criteria determined from AHP [3]. This proposed method helps the company to assess and choose the finest rail supplier in order to demonstrate how this method can be implemented in the sense of actual-life problem depending on selected criteria. Overall, it can be validated that S2 is the most preferred supplier and the least preferred supplier is S5. In the future, the adoption of other methods to the present method needs to be added to increase the precision and efficacy of the result. For instance, in the evaluation procedure traditionally the crisp scale was used in MCDM methods. However, the crisp scale cannot deal with the uncertainty and fuzziness in decision making [28]. Therefore, fuzzy set theory was recommended to handle with the uncertainty and fuzziness of individual opinion by coming out with mathematical structure, as fuzzy method is generally integrated with MCDM method such as AHP, PROMETHEE, TOPSIS and VIKOR [27].

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