

# **Framework for Supplier Selection Using MCDM Methods: A Case Study at a Cement Manufacturing Company**

**Mustafizur Rahman**

Computational Science

The University of Texas at El Paso

Texas, USA

[mrahman28@miners.utep.edu](mailto:mrahman28@miners.utep.edu)

**Sarojit Kumar Biswas and Md. Mahafuj Anam Murad**

Department of Industrial and Production Engineering

Jashore University of Science and Technology

Jashore, Bangladesh

[sarojitipe@just.edu.bd](mailto:sarojitipe@just.edu.bd), [mahafujmurad.info@gmail.com](mailto:mahafujmurad.info@gmail.com)

## **Abstract**

The main objective of this research is to develop several multi-criteria decision-making (MCDM) models to assist in the supplier selection for the cement manufacturing industry. Supplier selection is a very complex task involving qualitative and quantitative data to determine the best suppliers. It is very important for a company's ability to maintain efficient operations and competitive prices. Four different models of MCDM have been combined into an MCDM hybrid model using Grey Relation Analysis (GRA), TOPSIS, VIKOR, and PROMETHEE II techniques. A case study was performed on a cement manufacturing company in Bangladesh, and the above-mentioned hybrid MCDM model was applied to determine the top five indicators for performance evaluation of suppliers, which include price, quality system, organizational structure, service facility, and manufacturing capabilities. The result of this study was that all of the MCDM models selected supplier S1 as the number one supplier, but due to the sensitivity analysis, the results are stable and consistent. The results of this study indicate that the application of a multi-directed MCDM technique will give a greater degree of accuracy and reliability regarding supplier selection than applying single-directed method techniques. The research provides a framework that will be transparent in selecting suppliers according to their performance and will also identify the applicability of data-driven decision-making techniques in the course of improving the overall functioning of the supply chain. The research also provides a template that can be used across other manufacturing industries to assist companies in determining the best suppliers for their operations.

## **Keywords**

Cement Manufacturing, GRA, MCDM, PROMETHEE-II, TOPSIS, Supplier Selection, VIKOR.

## **1. Introduction**

Supplier selection is one of the biggest problems in the manufacturing field. Manufacturing is material and machine-intensive in its nature. The cost of capital, machinery, raw materials, and parts of a product forms an enormous percentage of the overall costs in manufacturing. It is common in manufacturing companies to take away a substantial part of the budget to be used in raw material and component purchases. This amount of money may constitute between 40 and 60 per cent of the whole budget on average (Heberling, 1993; Kaviani et al., 2020). Thus, the potential costs saved by the Manufacturing companies by finding the appropriate suppliers are great. In the current competitive marketplace, cost savings become very important to the marketing expenses of a product. Manufacturing businesses are also shifting more to core competitiveness and thus use suppliers to carry out the non-core operations like tax

reporting, accounting, payroll, invoicing, market research, and staff augmentation (Tahiduzzaman et al., 2017). The manufacturing companies are able to streamline their operations and cut costs by making the right selection of suppliers, which gives them a competitive advantage. (Taherdoost et al., 2019). Manufacturing firms have many competitive advantages associated with supplier selection. A well-selected supplier will allow these companies to enjoy better purchasing, logistics, transportation, operations management, marketing, and a decrease in inventory. These areas are crucial to the success of a manufacturing business, and supplier selection can be regarded as an important part of the whole strategy.

Effective Supplier selection can be used to streamline it, enhance efficiency, and finally, cost reduction and enhanced profitability. Lou et al. (2022), Isnaini et al. (2020), and Sobaih et al. (2020) indicated that supplier selection is not only necessary in improving the performance of a business but also the success of the entire organization. The manufacturing firms can achieve a major competitive edge with the help of the appropriate choice of suppliers. This will involve better product innovation, quality, and competitive pricing. (Reklitis et al., 2021). Thus, the risk of losing competitive advantages can be significantly reduced by suppliers who are interested in engaging in the activities of a company (Abeysekara et al., 2019).

Due to rising competition in the business world, firms are failing to address the needs of their clients in a diverse way. The fact that suppliers and companies have different criteria has further complicated the selection of the right supplier. Luckily, various processes, standards, and modalities are currently present in terms of supplier selection. There are other general rules that would be of greater importance during the importation of the right supplier. (Leblebicioğlu et al., 2021). The question is now establishing the right parameters that render the evaluation of the suppliers simple. The selection of suppliers is also vital in controlling the cost of manufacture and competitiveness. Their task is now more difficult because of the complexity of global supply chains and the changes in market requirements. Effective supplier selection is further complicated by the absence of a systematic methodology that encompasses the multi-dimensional requirements of the supplier evaluation criteria.

### **1.1 Objectives**

- i. To develop an integrated supplier selection procedure based on a multi-criteria evaluation of suppliers.
- ii. To get an insight into whether the application of the Hybrid Multi-Criteria Decision Making (MCDM) approach would be useful to select suppliers.
- iii. To investigate a real industrial case study of a conventional and hybrid MCDM method regarding supplier selection in the cement industry of Bangladesh.

## **2. Literature Review**

Supplier selection is a very important process in supply chain management, which requires consideration of different, often opposed, factors. Traditional supplier selection has been re-invented into more systematic and data-driven processes to ensure selection is carried out in a strategy and performance-driven manner. Recent studies have focused on the development of hybrid multi-criteria decision-making (MCDM) to combine both qualitative and quantitative indicators to enhance the accuracy of decision-making and reduce the level of subjectivity (Gupta et al., 2021; Kaviani et al., 2020).

### **2.1 Models and Criteria for Supplier Selection**

There have been a number of authors who have come up with attempts to provide a standard for supplier evaluation. Li et al. (2020) operationalized constructs and built interactions between the constructs in the selection process. Similarly, through the description of a model of stepwise implementation, Memari et al. (2019) provided a decision support model for implementation. The structural characteristics of the purchasing organization have also been found to be influential factors in supplier selection (Talapatra & Uddin, 2019). Furthermore, Talapatra et al. (2022) raised that the supplier decisions have a significant impact on the product quality and the customer satisfaction, especially in the service industry, specifically in the restaurant industry. These findings suggest the importance of linking the supplier selection process to strategic business goals, devising sustainable relationships that foster the enhancement of the operating system (Guarnieri et al., 2019).

While it is necessary to have criteria, it is also important to adopt a suitable methodology to evaluate prospective suppliers. As Ristono et al. (2018) and Mukherjee et al. (2016) observed, organizations need appropriate models that will guide the selection of a supplier that will meet their performance, quality, and sustainability objectives. This has

motivated researchers to work with hybrid MCDM methods, which have synergy potential between different analytical methods.

## **2.2 AHP and GRA Integration**

The Analytic Hierarchy Process has been widely applied to structure complex decision problems by determining the priority of the criteria. However, AHP is not appropriate when there is uncertainty and vagueness in the real-world decision-making process. In order to overcome these drawbacks, AHP has been commonly integrated into Grey relational analysis (GRA), which can cope with uncertain, imprecise, or incomplete information (Piya et al., 2021; Wang et al., 2017).

Methods: The hybrid AHP-GRA models are adopted by using AHP as the weighting method for the decision criteria and GRA for ranking the alternatives according to their relative closeness to an optimal solution (Rahman et al., 2018). This combination facilitates the supplier selection process towards being consistent and objective (Nadkarni et al., 2020). Parkouhi, Roshimejad, & Floup (2017) also presented the fuzzy AHP-based resilience modeling approach, considering GRA-VIKOR as a resilience-based approach to mitigate the supply chain risks (Sultana et al., 2014). These studies indicate that hybrid approaches are more reliable in decision-making and more flexible in an uncertain environment.

## **2.3 Use of Grey Relational Analysis (GRA)**

GRA is particularly suitable for managing scenarios of uncertainty, data inadequacy, and subjective evaluation. It is based on a sound mathematical theory and is well adapted to take into account ambiguous criteria. GRA needs to be integrated with other approaches in order to enhance decision-making. Stojiic et al. (2018) applied a grey-based rough set tool for a supplier selection method, and Sun et al. (2021) incorporated GRA with Intuitionistic Fuzzy Sets (IFS). Kaviani et al. (2020) and Chen et al. (2018) applied GRA with AFFA in the process industry and the Automotive industry, respectively, combined with Principal Component Analysis and entropy method, and Analytical Network Process (ANP), respectively.

Also, Bakhat et al. (2019) confirmed that GRA combined with uncertainty theory is more stable and efficient than the traditional fuzzy one with high sample sizes and assuming domain knowledge. Therefore, GRA remains not only an appropriate but also a valid part of hybrid MCDM supplier evaluation models.

## **2.4 TOPSIS and Its Variations**

Apart from these methods, yet another powerful MCDM method, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method, is frequently used for supplier selection. The method determines the best alternative as the alternative associated with the smallest distance between the alternatives, an ideal and an anti-ideal solution. Fuzzy versions of the TOPSIS have increased the ability of TOPSIS to confront ambiguity and uncertainty.

Qu et al. (2020a) applied the fuzzy TOPSIS in the green supplier selection of an electronics company and achieved satisfactory results. Fu (2019) combined fuzzy TOPSIS with multi-choice goal programming (MCGP), a multi-choice goal programming problem model to optimize supplier selection under an uncertain environment. Similarly, Naqvi et al. (2021) have integrated fuzzy TOPSIS with SWOT to determine the primary assessment criteria and handle vagueness in supplier information.

Comprehensive reviews have demonstrated that fuzzy TOPSIS outperforms fuzzy AHP when it is used in uncertainty environments (Rashidi et al., 2019). Furthermore, hybrid models such as AHP-ENTROPY-TOPSIS (Freeman & Chen, 2015), AHP-TOPSIS-QFD (Parkouhi et al., 2019), and Best-Worst method (BWM)-Fuzzy TOPSIS (Javad et al., 2020) have enhanced the accuracy in ranking and understanding decisions.

## **2.5 Application of the VIKOR Method**

The VIKOR criterion is used when seeking the best solutions to complex decisions with conflicting criteria. This approach is used for selecting and ranking the alternatives according to a compromise solution that minimizes the group dissatisfactions.

Rahardjo et al. (2023) used the DEMATEL Analytical Network Process (DANP) with VIKOR for supplier accountability evaluation, where weighted criteria were derived from DEMATEL and options were ranked by means

of VIKOR. Jharkharia et al. (2019) proposed a two-stage method of combining the Fuzzy C-means clustering method with VIKOR to rank and classify suppliers in an efficient manner. Li et al. [2020] proposed an extension of the model VIKOR by introducing linguistic parameters for handling the uncertainty in the supplier evaluation process. Similarly, Joshi et al. (2019) proposed a hybrid model of VIKOR and intuitionistic fuzzy sets towards a more accurate approach. These studies testify that VIKOR works in several industrial situations.

## 2.6 PROMETHEE-II and Its Use in Decision Models

The Preference Rating Center Method for Enrichment Evaluation (PROMETHEE-II) is another popular MCDM technique for ranking alternatives. It is an exhaustive preference ordering by using pairwise comparisons of criteria. Fan et al. (2020) developed a linguistic PROMETHEE approach to make the evaluation of potential logistics service providers, and Ghadernejad et al. (2019) combined AHP and PROMETHEE approaches for the selection of equipment.

Sudipa et al. (2020) applied the PROMETHEE-II method to rank the social media platforms, finding Facebook to be the most influential social media platform for online business. Abdullah et al. (2019) used PROMETHEE to rank green suppliers and discovered that Supplier A1 was the best supplier. Gul et al. (2018) proposed a fuzzy PROMETHEE model for material ranking and verified it using comparison with fuzzy VIKOR, fuzzy TOPSIS, and fuzzy ELECTRE models. Wang et al. (2020) further validated the applicability of PROMETHEE-II for textile supplier ranking, thereby showing the versatility of the method across industries.

## 2.7 Research Gap

The reviewed literature reveals a growing preference for hybrid MCDM methods over the traditional single technique approaches. Integrations like AHP - GRA, fuzzy TOPSIS, VIKOR - DEMATEL, and fuzzy PROMETHEE-II have proved effective in managing uncertainty, dealing with data that is ambiguous, and improving the accuracy of decisions. These techniques help decision-makers rate suppliers more holistically using analytical rigor with flexibility.

Despite the large number of studies done on hybrid models, no study has been done yet on the potential of combining all four major techniques, GRA, TOPSIS, VIKOR, and PROMETHEE-II in a unified model. Such an integrated approach could provide a more holistic and robust decision-making model for supplier selection operations under a complex and uncertain environment (Table 1).

Table 1. Summary of MCDM methods used in supplier selection and identified research gaps.

<b>MCDM Method</b>	<b>Application in Literature</b>	<b>Research Gap Identified</b>
GRA	Used individually in various supplier selections	No study has explored the combined use of GRA, TOPSIS, VIKOR, and PROMETHEE-II for supplier selection
TOPSIS	Employed in cases with multiple criteria considerations	The unique application of these methods together in a single framework remains unexplored.
VIKOR	Applied in situations with vague or uncertain criteria	This study introduces a novel framework combining these methods for cement industry in Bangladesh
PROMETHEE-II	Utilized in supplier selection, but not in combination with other methods	Demonstrates the practical value of the combined approach in real-world scenarios

In this study, a complex and comprehensive framework of supplier selection is elaborated, and it is made up of four methods. The proposed framework is empirically tested on a case study of cement production in Bangladesh. The practical experiment will be divided into the comparison of the results of the proposed methods with the application and sensitivity test, leading to the stability of the results achieved with the help of the proposed framework. Based on the findings, it can be concluded that this model is very good and can be used practically, and in addition, it can be an effective tool in the evaluation and selection of suppliers in the industrial sector.

### 3. Methodology

The authors combine four different Multi-Criteria Decision-Making (MCDM) tools in this research, namely, the Grey Relational Analysis (GRA), Technique of Order of Preference by Similarity to Ideal Solution (TOPSIS), VIKOR, and PROMETHEE-II. The interpretation behind choosing the four methods is based on the complementary strengths and capabilities of the methods in assessing suppliers (Sahu et al., 2022). GRA methods are chosen due to the capability to address a situation with incomplete or uncertain information, which is mostly the case with supplier selection, as not all parameters can be measured. TOPSIS is selected because it is efficient in making the best decision with reference to the ideal solution. The technique finds some special uses in the comparison of suppliers in terms of different performance metrics. VIKOR is included because of its success in conflicting criteria, which is a normal situation in selecting a supplier where a trade-off between two or more supplier characteristics is necessary. PROMETHEE-II is applied due to its holistic ranking mechanism, which offers a complete picture of the supplier performance based on multiple criteria (Wang et al., 2020) (Figure 1).

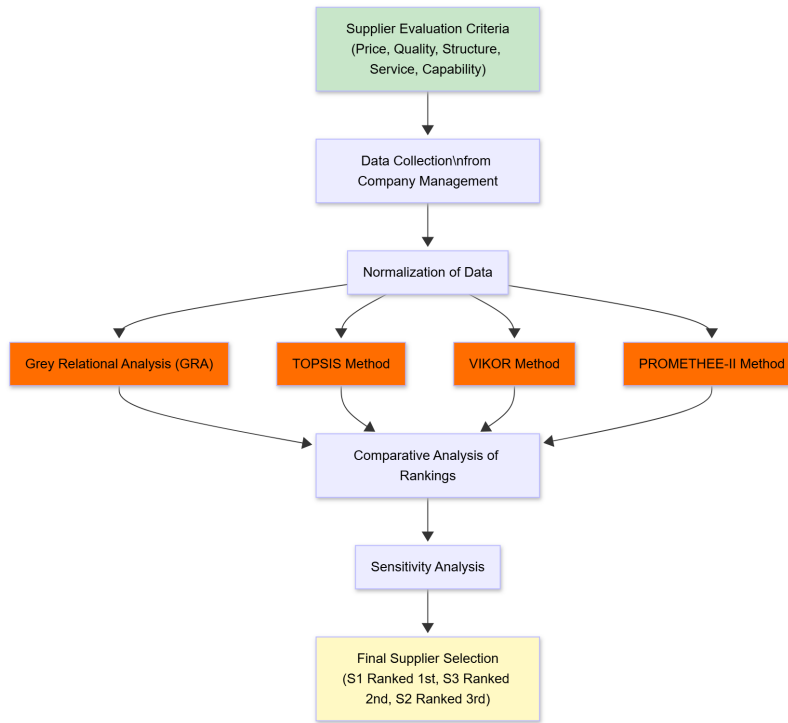


Figure 1. Methodology Working stage

The combination of these techniques (fig. 2) offers a multi-dimensional and powerful supplier selection procedure such that the assessment process is well-rounded and that the diverse aspects of supplier performance are put into consideration. The criteria of depth of analysis and manageability are the main reasons why the focus of the study was on three suppliers. Assessment of fewer suppliers gives it an opportunity to have a more thorough and closer analysis. The research may explore in more detail the capacities and performance of each supplier, as well as three suppliers, as opposed to offering a shallow description of a larger sample. These three suppliers were selected because they are prominent and representative of the situation in the Bangladesh cement manufacturing industry. This sample is selected to guarantee that the results are useful and applicable to major participants in the industry. Primary data was collected by conducting consultations with the top management of the cement manufacturing company in Bangladesh. The suppliers had been compared with five criteria: price, quality system, general and organizational structure, service facility, and manufacturing ability (Saputro et al., 2023) (Figure 2).

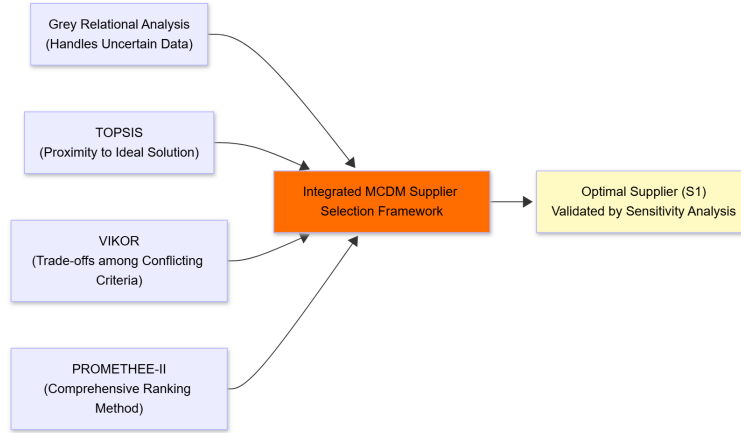


Figure 2. Integrated hybrid MCDM framework for supplier selection using GRA, TOPSIS, VIKOR, and PROMETHEE-II methods.

### 3.1 Grey Relational Analysis (GRA)

The first theory to suggest a treatment of dealings with situations with partial information was the grey theory, first suggested by Ju-Long (1982). The mathematical analysis power of the grey theory is high in order to analyze uncertainty using unbiased information. The application of the Grey Relational Analysis (GRA) will be effective in dealing with matters with problems of uncertainty where a lot of data is lacking. Lin et al. (2004) propose that this is one of the fundamental elements of the grey theory. It has specific applications when it comes to MCDM (Multiple Criteria Decision Making), where partial information and uncertainty are characteristic factors in the problem. There are numerous benefits of the use of GRA on the conventional approaches used in MCDM, mainly that it operates on limited information. Basically, GRA is used to ascertain the similarity of the association among different sequences through the adoption of the grey relational grade in the assessment of the various options. The relational grade of an alternative is the greater the ranking of the alternative in the assessment. Grey relational analysis is used to choose the most suitable supplier, and its steps take the following form:

Step 1: Find out the major decision matrix X.

Step 2: Data set normalization: Since the units of data on each of the criteria are not equal, normalization of data is achieved to bring them to the same level. Normalization evenly and uniformly distributes data sent into the input to an operational range. There are two ways of normalizing the set of data series:

The value can be calculated using the following formula, the larger

$$x^*_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})}$$

The calculation method can be employed to determine the worth of the smaller digit.

$$x^*_{ij} = \frac{\max(x_{ij}) - (x_{ij})}{\max(x_{ij}) - \min(x_{ij})}$$

Where  $i = 1, \dots, m$  is the number of alternatives or suppliers, and  $j = 1, \dots, n$  is the criterion for the alternatives or suppliers.  $x_{ij}$  denotes the original sequence,  $x^*_{ij}$  denotes the sequence after normalization,  $\max(x_{ij})$  denotes the largest value of  $x_{ij}$ , and  $\min(x_{ij})$  denotes the smallest value of  $x_{ij}$ .

Step 3: To determine the grey relational coefficient, normalize the data. Once the data has been normalized, the coefficient can be determined to determine how closely the actual results match the best results. The formula used to calculate the grey relational coefficient is as follows:

$$\xi_{ij} = \frac{\Delta_{min} + \xi \Delta_{max}}{\Delta_{ij} + \xi \Delta_{max}}$$

First, the absolute difference is calculated. Where,  $\Delta_{ij}$  is the absolute difference, i.e., the dissimilarity between a standardized entity and its corresponding sequence of references. The formula calculates it.

$$\Delta_{ij} = \| x_{0j} - x^*_{ij} \|$$

$\Delta_{min}$  and  $\Delta_{max}$  = the range between the smallest and largest absolute differences  $\Delta_{ij}$ ,  $\xi$  = distinguishing or identification coefficient, and the range is between 0 and 1. Typically, the value of  $\xi$  is assumed to be 0.5.

Step 4: The computation of the grey relational grade involves the application of a particular formula. This formula is used to determine the grey relational grade.

Where,  $\gamma_i$  = the grey relation grade for the  $i^{th}$  alternative, the overall quality of suppliers can be ranked by using the grey relational grade, which is determined by =  $n$  criteria and the weight given to each criterion,  $w_j$ . The highest value of grey relational grade gives rank 1, the second highest value gives rank 2, and so on. The bed rearrangement problem is found in the

$$\gamma_i = \frac{1}{n} \sum_{j=1}^n w_j \xi_{ij}$$

### 3.2 TOPSIS

The TOPSIS method was created by Hwang and Yoon in 1981 and has proven to be an exceptional tool for decision-making. The method enables selecting the most appropriate option by evaluating the proximity to the positive ideal solution that represents the most beneficial criteria value and the distance from the negative ideal solution that represents the highest cost criteria value. With both ideal solutions, TOPSIS can effectively identify the best alternative that balances benefits and costs. This makes it an incredibly valuable tool for decision-makers seeking to optimize their choices.

The following steps are followed in applying TOPSIS:

Step 1: Acquire the primary decision matrix X: This matrix is determined by gathering data in consultation with several expert opinions.

Step 2: Normalization of the decision matrix: Normalization is done to eliminate the units of various criteria so that all criteria can be comparable. Here, the normalization is obtained using the Euclidean method. The formula for normalization is given by:

$$x^*_{ij} = \frac{x_{ij}}{\sqrt{\sum_i^m x_{ij}^2}}$$

Where,  $i=1, \dots, m$ =number of alternatives or suppliers, and  $j=1, \dots, n$ = criteria of the respective alternatives or suppliers.  $x_{ij}$  denotes the original sequence,  $x^*_{ij}$  denotes the sequence after normalizing.

Step-3: To obtain the weighted normalized decision matrix V, the normalized decision matrix is to be multiplied by the weight with which each column is weighted, denoted  $w_j$ .

Step-4: Find out the optimal favourable situation (Positive Ideal Solution) PIS  $V^*$  and also unfavourable negative ideal solutions (Negative Ideal Solution NIS) represented by ( $V^-$ ) by using the weighted decision matrix ( $V$ ).

$V^* = v_j$  = The highest value for each weighted decision matrix V column.

$V^- = v_j$  = The lowest value for each column of the decision matrix V that has been weighted.

**Step-5:** The assessment of the alternatives' separation is accomplished by contrasting them with both the (PIS) positive ideal solution ( $V^*$ ) and the (NIS) negative ideal solution ( $V^-$ ).

$$D_i^* = \sqrt{\sum_j^n (v_{ij} - v_j^*)^2}$$

$$D_i^- = \sqrt{\sum_j^n (v_{ij} - v_j^-)^2}$$

Where  $D_i^*$  denotes the measure of the positive ideal solution's distance, while  $D_i^-$  denotes the measure of the negative ideal solution's distance.

Step 6: For every alternative, the degree of proximity to the ideal solutions is calculated using the specified formula:

$$C_i^* = \frac{D_i^-}{(D_i^- + D_i^*)}$$

Where,  $C_i^*$  is the degree of relative proximity to the ideal solutions. The last step of ranking is in terms of the value of  $C_i^*$ . The maximum value of  $C_i^*$  will provide rank 1 to an alternative, the second-highest value will provide rank 2, and so on.

### 3.3 VIKOR

In 1998, Opricovic presented the VIKOR methodology as an idea to overcome Multi-Criteria Decision-Making (MCDM) challenges. The name "VIKOR" was formed using the concept of finding a compromise among different criteria to get to a reasonable decision. The VIKOR method is a multi-criteria decision-making instrument that uses a combination of ordering and option selecting to determine the decision based upon conflicting goals. A key objective is to find the best possible option that maximizes the satisfaction of the greatest number of interested parties and does not meet the needs of other interested parties. The VIKOR method measures the degree to which an alternative solution approximates the optimal solution, and therefore, decision-makers can identify a reasonable solution that will maximize the overall utility of all interested parties and promote objectivity during the decision-making process. As such, VIKOR may be particularly beneficial when dealing with uncertainty in the data or subjectivity by decision makers. In general, VIKOR provides decision makers with a powerful, practical, and complete methodology to enhance their decision-making processes.

The VIKOR method implies the application of the following steps:

Step 1: Obtaining the initial decision matrix X.

Step 2: Some of the steps that may be undertaken during a decision about the elements of the matrix include the process of normalization, which will lead to the removal of unit measures of different criteria. This makes it easy to compare all criteria effectively and therefore makes it easier to reach a logical and unbiased decision. The Euclidean method of normalization is used here. This expression is the formula of normalization:

$$x^*_{ij} = \frac{x_{ij}}{\sqrt{\sum_i^m x_{ij}^2}}$$

Where  $i = 1, \dots, m$  is the number of substitutes or suppliers, and  $j = 1, \dots, n$  is the criteria for the alternatives or suppliers.  $x_{ij}$  denotes the original sequence,  $x^*_{ij}$  denotes the sequence after normalization.

Step-3: Calculate the  $S_i$  (the highest group satisfaction) and  $R_i$  (the lowest personal disappointment of the adversary) values,  $i = 1, 2, \dots, m$ , by the relations

$$S_i = \sum_{j=1}^n \frac{w_j(x_j^* - x_{ij})}{x_j^* - x_j^-}$$

$$R_i = \max_j \left[ \frac{w_j(x_j^* - x_{ij})}{x_j^* - x_j^-} \right]$$

The TOPSIS method is a tool for decision-making that enables the selection of the most suitable option among a group of alternatives. Understanding TOPSIS requires defining important terms such as  $S_i$ , the distance measure of the  $i$ th option to the positive ideal solution representing the most favorable combination. On the other hand,  $R_i$  denotes the distance rate for the alternative ranked  $i^{th}$  concerning the negative ideal solution, which signifies the least desirable combination. The significance of the criteria  $j$  is represented by  $w_j$ , and  $x_j^*$  and  $x_j^-$  indicate the positive and negative ideal solutions for the  $j^{th}$  criterion, respectively.

**Step-4:** Compute the value  $Q_i$ ,  $i = 1, 2, \dots, m$ , by the relation

$$Q_i = \frac{v(S_i - S^*)}{(S^- - S^*)} + \frac{(1 - v)(R_i - R^*)}{(R^- - R^*)}$$

Where  $S^* = \min S_i$  and  $S^- = \max S_i$

Where  $R^* = \min R_i$  and  $R^- = \max R_i$

The significance of the strategy of  $S_i$  and  $R_i$  is denoted by the weight of  $v$ . It is typically assigned a value of 0.5.

**Step 5:** Determine the prioritization of options based on their respective  $Q$  values. The lowest value of  $Q$  gives rank 1, the second lowest value gives rank 2, and so on.

### 3.4 PROMITHEE-II

The Promethee-II method offers a comprehensive ranking of alternatives through a step-by-step approach. The following steps are involved in this method:

**Step 1:** Preparing the primary decision matrix.

**Step 2:** Normalize the primary decision matrix.

For beneficial criteria (Table 2):

Table 2. Beneficial criteria

Alternatives	Price (C1)	Quality system of the supplier (C2)	General and organizational structure (C3)	Service facility (C4)	Manufacturing capability (C5)
Supplier 1 (S1)	7	8	8	9	7
Supplier 2 (S2)	8	7	8	7	8
Supplier 3 (S3)	6	8	7	8	7
Weight	0.1432	0.3456	0.2420	0.1628	0.1064

$$A_{ij} = \frac{[x_{ij} - \min(x_{ij})]}{[\max(x_{ij}) - \min(x_{ij})]}$$

For criteria that are non-beneficial:

$$A_{ij} = \frac{[\max(x_{ij}) - x_{ij}]}{[\max(x_{ij}) - \min(x_{ij})]}$$

Step 3: Determining the evaluative contrast between the  $i^{\text{th}}$  option and the remaining alternatives.

Step 4: (i) Determining the preference function,  $P_j(a,b)$ , is being calculated.

$$P_j(a,b) = 0 \text{ if } A_{aj} \leq A_{bj}$$

$$P_j(a,b) = (A_{aj} - A_{bj}) \text{ if } A_{aj} \geq A_{bj}$$

(ii) Determination of the combined value of the preference function,  $\pi(a,b)$ , is being computed.

$$\pi(a,b) = \left[ \sum_{j=1}^n w_j P_j(a,b) \right] / \sum_{j=1}^n w_j$$

Step 5: Analysing the incoming and outgoing flows with a higher rank.

Finding an alternative to the flow of  $a^{\text{th}}$  can be challenging, referred to as "leaving the flow."

Table 2. Suppliers, criteria with associated ratings and weights.

$$\varphi^+ = \frac{1}{m-1} \sum_{b=1}^m \pi(a,b)$$

Entering the state of flow of  $a^{\text{th}}$  alternative

$$\varphi^- = \frac{1}{m-1} \sum_{b=1}^m \pi(b,a)$$

Step 6: Calculate net outranking flow and determine alternatives' ranking.

### 3.5 Case Study

The investigation was conducted at a cement factory belonging to Lafarge Holcim Bangladesh Limited (<https://www.lafargeholcim.com.bd>) for the case study. It is located in Mongla Port, Bagerhat, Bangladesh. The company's ability to generate profit or achieve success was obstructed by selecting the appropriate supplier. Supplier selection for the public company generally involves calling a public tender with some survey on the factory, initial screening, and monitoring the actual status. The supplier is finally selected by negotiation with some primary elements, for instance, quality, cost, and service level. Among these elements, cost is usually given the highest priority. There were three suppliers for this company, namely supplier 1 (S1), supplier 2 (S2), and supplier 3 (S3). This study has been launched to select one of the best suppliers for this company. All necessary data have been collected in consultation with the top management, and finally, five criteria for each supplier have been determined. The criteria are price (PR), quality system of the supplier (QS), general and organization structure (GS), service facility (SF), and manufacturing capability (MC). The weights associated with each criterion, corresponding to the suppliers, have been gathered from the decision maker's opinion of the company. A framework using GRA, TOPSIS, and VIKOR has been used, and the best supplier has been selected using this framework. A sensitivity analysis was conducted to evaluate the impact of the criteria on the selection of suppliers. This analysis aimed to assess the extent of variation in

the importance of different factors in the supplier selection process. Table 1 presents the ratings and weights of all suppliers and criteria provided by the company's top management.

### 3.6 Calculation and Result Analysis

The supplier selection framework consists of GRA, TOPSIS, VIKOR, and PROMETHEE-II. The step-by-step calculations for each method are shown below:

#### 3.6.1 Supplier Selection Framework consists of a step-by-step GRA method

**Step 1:** Table 3 presents the decision matrix for selecting the optimal supplier from Table 2. The matrix includes three suppliers, S1, S2, and S3, and seven criteria, namely C1, C2, C3, C4, C5, C6, and C7, for each supplier.

Table 3. Initial decision matrix for the GRA Method

Alternatives	C1	C2	C3	C4	C5
S1	7	8	8	9	7
S2	8	7	8	7	8
S3	6	8	7	8	7

**Step 2:** Normalized values are obtained by applying the normalization technique to the data set, and these values, with reference sequences, are shown in Table 4. It is used to calculate the absolute difference, which is further needed to calculate the grey relational coefficient. The normalized entity is compared to its reference sequence to determine the absolute difference, as listed in Table 5. The resulting difference is then calculated using the minimum and maximum values of the absolute differences.

Table 4. Normalized values with reference sequence for the GRA Method

Alternatives	C1	C2	C3	C4	C5
S1	0.500	1.000	1.000	1.000	0.000
S2	0.000	0.000	1.000	0.000	1.000
S3	1.000	1.000	0.000	0.500	0.000
Reference sequence	6	8	8	9	8

Table 5. Absolute differences for the GRA Method

Alternatives	C1	C2	C3	C4	C5
S1	5.500	7.000	7.000	8.000	8.000
S2	6.000	8.000	7.000	9.000	7.000
S3	5.000	7.000	8.000	8.500	8.000
$\Delta_{max}$	5.000	7.000	7.000	8.000	7.000
$\Delta_{min}$	6.000	8.000	8.000	9.000	8.000

**Step 3:** After data normalization, grey relational coefficients are calculated (Table 6).

Table 6. Grey relational coefficients for the GRA Method

Alternatives	C1	C2	C3	C4	C5
S1	0.941	1.000	1.000	1.000	0.917
S2	0.889	0.917	1.000	0.926	1.000
S3	1.000	1.000	0.917	0.962	0.917

**Step 4:** To calculate the grey relational grade for each supplier, we take the average of the grey relational coefficients for every performance criterion mentioned in Table 7. Grey relation grade ranks the supplier according to its value for the suppliers. Here, supplier 1 has the highest value of 0.1965 and is ranked 1, supplier 3 has the second highest value

of 0.1929 and is ranked 2, and supplier 3 has the lowest value of 0.1886 and is ranked 3.

Table 7. Grey relational grade (GRG)

	S1	S2	S3
GRG	0.1965	0.1886	0.1929
Rank	1	3	2

### 3.6.2 TOPSIS method

**Step 1:** Table 8 displays the decision matrix created to choose the top supplier from the options listed in Table 1.

Table 8. Primary decision matrix for the TOPSIS Method

Alternatives	C1	C2	C3	C4	C5
S1	7	8	8	9	7
S2	8	7	8	7	8
S3	6	8	7	8	7

**Step 2:** Table 9 displays the normalized values obtained on the dataset by applying the normalization technique. The reference sequence is used to calculate the absolute difference, which is further needed in the calculation of the grey relational coefficient.

Table 9. Normalized decision matrix for the TOPSIS Method

Alternatives	C1	C2	C3	C4	C5
S1	0.5735	0.6013	0.6013	0.6462	0.5500
S2	0.6554	0.5262	0.6013	0.5026	0.6285
S3	0.4915	0.6013	0.5262	0.5744	0.5500
weights	0.1432	0.3456	0.242	0.1628	0.1064

**Step 3:** Table 10 displays the results of the weighted normalized decision matrix. Creating this matrix involved multiplying each column of the normalized decision matrix by its corresponding weight of the criteria.

Table 10. Both normalized decision matrices were weighted for the TOPSIS Method

Alternatives	C1	C2	C3	C4	C5
S1	0.0821	0.2078	0.1455	0.1052	0.0585
S2	0.0939	0.1818	0.1455	0.0818	0.0669
S3	0.0704	0.2078	0.1273	0.0935	0.0585

**Step 4:** The computation of Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS) was performed using the decision matrix with the weights indicated in Table 11.

Table 11. Determination of PIS and NIS for the TOPSIS Method

PIS and NIS	C1	C2	C3	C4	C5
$V^*$	0.0704	0.2078	0.1455	0.1052	0.0669
$V^-$	0.0939	0.1818	0.1273	0.0818	0.0585

**Steps 5 and 6:** Table 12 contains important information regarding how the desirable and undesirable solutions for the alternatives have been segregated, as well as the determination of the value of the relative closeness. The relative closeness is important in establishing the rank of the supplier, and consequently, the information is important for effective decision-making. Thus, in this case, supplier 1 was the highest valued supplier, having a relative closeness value of 0.7405, giving it a rank of 1; supplier 3 had a relative closeness value of 0.6142, giving it a rank of 2, and supplier 2 was the lowest valued, having a relative closeness value of 0.3223, giving it a rank of 3.

Table 12. Separation measures from PIS and NIS and relative closeness for the TOPSIS Method

	S1	S2	S3
$D_i^*$	0.0144	0.0421	0.0232
$D_i^-$	0.0411	0.0200	0.0369
$C_i^* = D_i^- / D_i^* + D_i^-$	0.7405	0.3223	0.6142
Rank	1	3	2

### 3.6.3 VIKOR method

**Step 1:** Table 13 displays the decision matrix built to determine the optimal supplier from the options presented in Table 13.

Table 13. Initial decision matrix for the VIKOR method.

Alternatives	C1	C2	C3	C4	C5
S1	7	8	8	9	7
S2	8	7	8	7	8
S3	6	8	7	8	7

**Step 2:** The process of normalization is applied to the dataset to obtain the normalized values. These normalized values are presented in Table 14, which includes both the positive and the negative ideal solutions. Including both solutions is necessary for calculating the S and R values.

Table 14. Matrix of normalized decision for the VIKOR Method.

Alternatives	C1	C2	C3	C4	C5
S1	0.5735	0.6013	0.6013	0.6462	0.5500
S2	0.6554	0.5262	0.6013	0.5026	0.6285
S3	0.4915	0.6013	0.5262	0.5744	0.5500
Max ( $x_j^*$ )	0.4915	0.6013	0.6013	0.6462	0.6285
Min ( $x_j^-$ )	0.6554	0.5262	0.5262	0.5026	0.5500
weight	0.1432	0.3456	0.242	0.1628	0.1064

Steps 3 and 4: The information in Table 15 displays the figures for S, R, and Q assigned to every supplier. S represents the proportion of the gap between the actual and the ideal positive solution. In contrast, R represents the proportion of the gap between the actual and the ideal negative solution. The rank of each supplier can be determined by computing the maximum group utility S and minimum individual regret R. The quality of the supplier, denoted as Q, is then evaluated using the values obtained from S and R computations. Based on the Q score, supplier 1 ranks lowest with a score of 0.000, while supplier 2 ranks second with a Q score of 0.6142. Supplier 3 has the highest Q score of 0.3223, placing it third.

Table 15. Values of S, R, and Q for the VIKOR Method

Alternatives	S	R	Q	Rank
S1	0.1780	0.1064	0.0000	1
S2	0.6516	0.3456	1.0000	3
S3	0.4298	0.2420	0.5493	2

### 3.6.4 PROMETHEE-II Method

**Step 1:** Initial decision matrix formulation. The decision-makers have collaborated to create an initial supplier selection decision matrix presented in Table 16.

Table 16. The matrix for making initial decisions in PROMETHEE-II

Alternatives	C1	C2	C3	C4	C5
S1	8	9	8	9	8
S2	6	7	7	8	7
S3	7	8	9	8	7

**Step 2:** The decision matrix has been normalized using equations and is now ready to be analyzed. Table 17 contains the resulting normalized decision matrix.

Table 17. Normalized decision matrix for PROMETHEE-II

Alternatives	C1	C2	C3	C4	C5
S1	1	1	0.5	1	1
S2	0	0	0	0	0
S3	0.5	0.5	1	0	0

**Step 3:** A comparison between different options was made, and the outcome was presented in Table 18, indicating the evaluative difference between each alternative and the other options.

Table 18. Evaluative difference of the  $i^{th}$  alternative with other alternatives for PROMETHEE-II

	C1	C2	C3	C4	C5
D(S1-S2)	1	1	0.5	1	1
D(S1-S3)	0.5	0.5	-0.5	1	1
D(S2-S1)	-1	-1	-0.5	-1	-1
D(S2-S3)	-0.5	-0.5	-1	0	0
D(S3-S1)	-0.5	-0.5	0.5	-1	-1
D(S3-S2)	0.5	0.5	1	0	0

**Step 4:** Aggregated preference function calculation. Table 18 presents the aggregated preference function. Aggregated preference function values have been calculated using Eq. (.....). The aggregated preference matrix of the supplier is represented in Table 19- Table 20.

Table 19. Calculation of the aggregated preference function

	C1	C2	C3	C4	C5	Aggregate preference function
Weight	0.1432	0.3456	0.242	0.1628	0.1064	
D(S1-S2)	0.1432	0.3456	0.121	0.1628	0.1064	0.879
D(S1-S3)	0.0716	0.1728	0	0.1628	0.1064	0.5136
D(S2-S1)	0	0	0	0	0	0
D(S2-S3)	0	0	0	0	0	0
D(S3-S1)	0	0	0.121	0	0	0.121
D(S3-S2)	0.0716	0.1728	0.242	0	0	0.4864

Table 20. Aggregate preference function matrix with leaving flow and entering flow

	S1	S2	S3	Leaving flow
S1	-	0.879	0.5136	0.6963
S2	0	-	0	0
S3	0.121	0.4864	-	0.3037
Entering flow	0.0605	0.6827	0.2568	

**Step 5:** Table 21 presents the values of leaving and entering outranking flows determined using Equations (?) and Equation (?), respectively.

Table 21. Ranking of suppliers based on net outranking flow in PROMETHEE-II

	Leaving flow	Entering flow	Net outranking flow	Rank
S1	0.6963	0.0605	0.6358	1
S2	0	0.6827	-0.6827	3
S3	0.3037	0.2568	0.0469	2

**Step 6:** After calculating the net outranking flows, the final ranking of the supplier can be determined. The supplier rankings are presented in Table 22, with S1 occupying the top spot, followed by S3 in second place, and S2 bringing up the rear.

### 3.6.5 Comparative analysis of GRA, TOPSIS, and VIKOR

The comparative analysis of GRA, TOPSIS, VKIOR, and PROMETHEE-II methods is shown in Table 22. This comparative analysis has been shown to view how results vary in each method. Table 21 shows that GRA, TOPSIS, VIKOR, and PROMETHEE-II methods rank similarly for each supplier. Supplier S1 is ranked as 1, Supplier S2 is ranked as 2, and Supplier S3 is ranked as 3 by each method for supplier selection. So, this framework shows its effectiveness in supplier selection.

Table 22. Supplier ranking for GRA, TOPSIS, VIKOR, and PROMETHEE-II methods

Supplier name	Ranking			PROMITHEE-II
	GRA	TOPSIS	VIKOR	
S1	1	1	1	1
S2	3	3	3	3
S3	2	2	2	2

## 4. Results and Discussion

The following research represents an in-depth guide for selecting a suitable supplier within the context of a cement production firm in Bangladesh. In order to maximize the effectiveness of the supplier selection process, the proposed framework incorporates four effective methods of evaluation, namely, GRA, TOPSIS, VIKOR, and PROMETHEE-II. A combination of these methods is expected to enhance the performance of the supplier selection process (Taherdoost & Brard, 2019). Based on recommendations from the highest management level of the company, we have selected three suppliers, S1, S2, and S3, who meet the selection criteria of our five criteria. This is an example of an MCDM type of problem; both types of data exist, i.e., qualitative and quantitative data. We have utilized the framework to establish the ranking of supplier S1 as number one. The suppliers were ranked as equal in all methods. Supplier S3 was ranked second, and Supplier S2 third. GRA methodology is a strong tool for dealing with diverse problems, e.g., qualitative or quantitative data, due to numerous criteria that GRA considers, such as larger is better value, smaller is better value, etc. GRA provides a comprehensive solution for multiple use cases. Such a methodological approach allows determining a variety of requirements, including best maximized and optimally minimized, which ultimately establishes their broad applicability (Phate et al., 2021). Similarly, the TOPSIS method has proven to be very successful in computing the distance between the ideal solutions. As a whole, these methods present an effective set of tools to resolve complex problems. TOPSIS has considered the cost and benefit criteria.

TOPSIS has considered standards. The TOPSIS method has been identified as being particularly effective in demonstrating how close a solution is to the optimal solution, considering the cost-benefit factors. Thus, this strategy demonstrates its capability in correctly evaluating the best alternative in accordance with a thorough assessment of the different elements (Haddad et al., 2021). The TOPSIS method has provided the same ranking as previously mentioned. The VIKOR method has also been assessed using TOPSIS. It is superior to TOPSIS in evaluating conflicting criteria and providing good alternatives for the decision-maker. The VIKOR method has already undergone extensive testing, and the conflicts between the various criteria have been resolved. It provides acceptable alternatives for decision-makers and maintains a consistent positioning of suppliers, in cooperation with other methods, similar to GRA and TOPSIS (Mardani et al., 2019). The VIKOR method has produced the same ranks as GRA and TOPSIS among the suppliers. Additionally, PROMETHEE-II has produced the same rankings for suppliers as the previously mentioned three methodologies. Therefore, the four methods are effective in selecting suppliers, and in this study, the results of the process were obtained with all four methods. Therefore, integrating these methods into a system would be effective for supplier selection. However, the decision-making weight concerning each criterion of the decision-maker cannot be overlooked and may therefore directly impact the ranking position of the supplier (Xu et al., 2022).

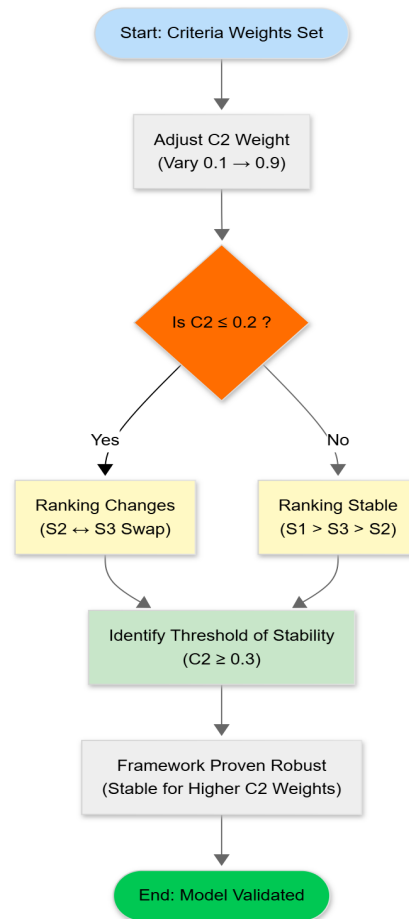


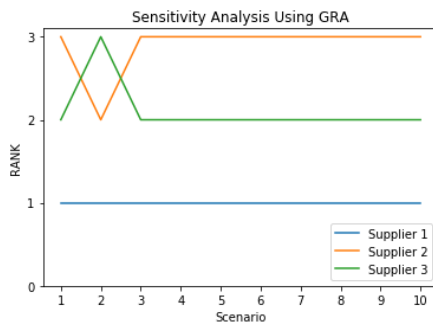
Figure 3. Sensitivity analysis

Sensitivity analysis will assist in knowing the rank of the suppliers in relation to the variation in the criteria rating and weights (Figure 3). The sensitivity analysis conducted in this study was done by altering the weights of the criteria. Criterion C2 has the greatest weight, and the disparity between its weight and that of the other criteria is quite high. This is why criterion C2 has been altered to 0.1 instead of 0.9 to see the workings of the supplier ranking. The proportionate change in the other criterion weights has also been modified, applied to the weight change in criterion C2. Table 23 is the outcome of the analysis of sensitivity. Based on this table, the supplier ranking of supplier S2 and supplier S3 also changes where the criterion weight is smaller than or equal to 2. The above criterion 3 weight reveals

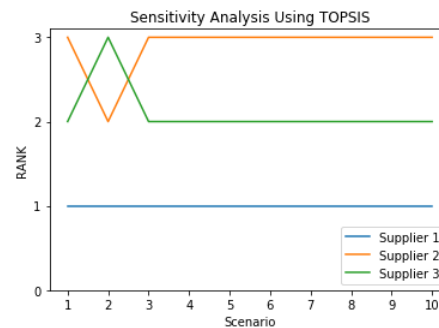
that there is no change in the supplier ranking. It was pointed out in the analysis that when the C2 weight is at or below 0.2, then the suppliers in the sequence were shifted, and also the suppliers with a weight above 0.3 were ranked the same way the suppliers were initially ranked. This highlights the significance of weighting criteria in ranking the suppliers during the selection (Mukhametzhanov & Pamučar, 2018). According to the sensitivity analysis, it is clear that the weight of the criteria contributes a lot to ranking the suppliers during the selection process. Although the adjustments of the weights of other criteria regarding criterion C2 might result in no change in the supplier ranking, it is worth mentioning that even minor variations in the weights of the criterion can affect the supplier ranking. Figure 4 also displays the sensitivity analysis.

Table 23. Sensitivity analysis results for supplier ranking across multiple weighting scenarios using GRA, TOPSIS, VIKOR, and PROMETHEE-II methods.

Scenario	Weight					Ranking (GRA)			Ranking (TOPSIS)			Ranking (VIKOR)			Ranking (PROMETHEE-II)		
	C1	C2	C3	C4	C5	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
1	0.14 32	0.34 56	0.24 2	0.16 28	0.10 64	1	3	2	1	3	2	1	3	2	1	3	2
2	0.19 7	0.1	0.33 28	0.22 39	0.14 63	1	2	3	1	2	3	1	2	3	1	2	3
3	0.17 51	0.2	0.29 59	0.19 9	0.13 01	1	3	2	1	3	2	1	2	3	1	3	2
4	0.15 32	0.3	0.25 89	0.17 41	0.11 38	1	3	2	1	3	2	1	3	2	1	3	2
5	0.13 13	0.4	0.22 19	0.14 93	0.09 76	1	3	2	1	3	2	1	3	2	1	3	2
6	0.10 94	0.5	0.18 49	0.12 44	0.08 13	1	3	2	1	3	2	1	3	2	1	3	2
7	0.08 75	0.6	0.14 79	0.09 96	0.06 5	1	3	2	1	3	2	1	3	2	1	3	2
8	0.06 56	0.7	0.11 09	0.07 47	0.04 88	1	3	2	1	3	2	1	3	2	1	3	2
9	0.04 37	0.8	0.07 39	0.04 98	0.03 25	1	3	2	1	3	2	1	3	2	1	3	2
10	0.02 18	0.9	0.03 69	0.02 5	0.01 63	1	3	2	1	3	2	1	3	2	1	3	2



(a)



(b)

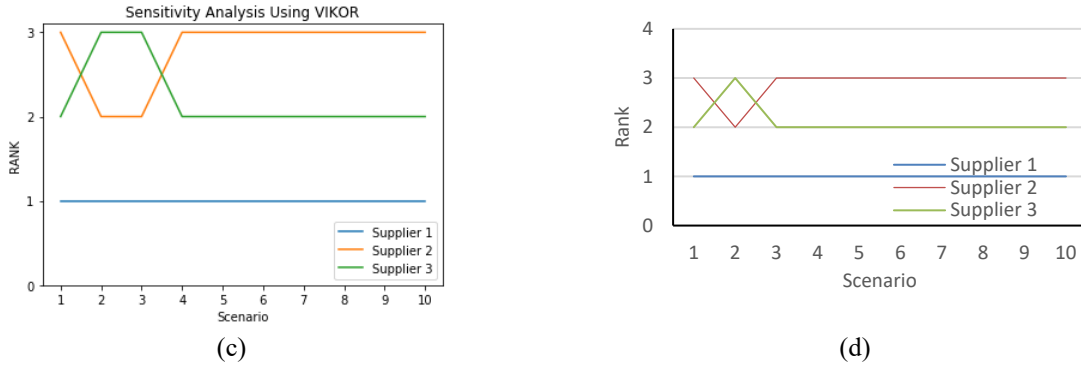


Figure 4. Result of sensitivity analysis scenario for (a) GRA, (b) TOPSIS, (c) VIKOR, (d) PROMETHEE-II

## 5. Conclusion

The success of any business literally depends on the selection of the supplier. In the competitive business environment, the selection of an appropriate supplier may significantly impact the general performance of a business. In order to overcome this issue, our study employs a sound framework of GRA, TOPSIS, VIKOR, and PROMETHEE-II as the supplier selection techniques. This model is the best in dealing with MCDM problems that require both qualitative and quantitative variables. This kind of approach enables companies to make the right decisions in the selection of their suppliers, and therefore, they can achieve high performance. The GRA approach has proven to have the capability of dealing with the uncertainty, fuzziness, and partial information situations where there is scanty information. TOPSIS is a superior instrument, which utilizes similarity to the most suitable option with the purpose of increasing the chances of picking the optimal alternative. This involves an increase in the quality of each alternative with regard to the proximity to the best solution. In this way, TOPSIS can define whether the selected option is feasible, and it can provide the most optimal outcomes according to the mentioned parameters. The VIKOR approach is also a better option on the issues that possess contradicting criteria, where a deficiency of precision exists in the information, and the decision maker is also subjective.

PROMETHEE-II is a sophisticated ranking system that makes use of multi-criteria net flow to provide precise results. Thus, the methodology presented in this study is the integration of databases of suppliers (defined by experts, past studies, in the case of GRA, TOPSIS, VIKOR, and PROMETHEE-II approaches) with comparisons and analyses of the criteria and alternative suppliers of three suppliers as the case study of the Cement Company. It was supported through sensitivity analysis, and it was discovered that supplier S1 would become the best supplier. This is the model that could be used to evaluate the suppliers in the other sectors.

To enhance the effectiveness of supplier selection, researchers can explore supplementing the techniques linked with soft computing and machine learning. Such methods include Fuzzy Inference Systems (FIS), Support Vector Machines (SVM), and Artificial Neural Networks (ANN). The techniques may be integrated with different multi-criteria decision-making processes to create superior, more stable models to assist in dealing with sophisticated supplier selection situations. Using these sophisticated tools, companies are able to achieve superior vendor selection and overall higher performance.

## Limitations

The study is based on a case study of a cement manufacturing company in Bangladesh, and as such, its generalization is limited to other industries or geographical areas. New combinations of GRA, TOPSIS, VIKOR, and PROMETHEE-II, but each method is limited in some way, and this can impact the quality of the overall framework. The company's top management should take into account the data that can be unfairly biased or not fully represent all aspects of the supplier selection process. The dynamic market environment that appears to trigger sudden changes (variable prices and supplier capacities) that can significantly impact the selection parameters of a supplier in the long term may be a factor that is being underestimated in the study. The study may not involve the impact of new technologies in the management of manufacturing and supply chain management, which can bring new standards in the supplier choice. The developed framework is then tested for its applicability in other sectors and geographical locales in order to demonstrate future research and to show the value of the framework. More advanced analysis tools, such as machine

learning or artificial intelligence, would be a valuable addition that enables a better understanding and further optimization of the decision-making process. Future studies may also focus on creating models to keep up with dynamic market conditions and technological advancements, so the process is in sync.

## **Acknowledgements**

We want to acknowledge the management of Lafarge Holcim Bangladesh Limited for the inestimable cooperation and support offered to us during this project.

## **References**

- Abdullah, L., Chan, W., and Afshari, A., *Application of the PROMETHEE method for green supplier selection: A comparative result based on preference functions*, Journal of Industrial Engineering International, Vol. 15, pp. 271–285, 2019.
- Abeyssekara, N., Wang, H., and Kuruppuarachchi, D., *Effect of supply-chain resilience on firm performance and competitive advantage*, Business Process Management Journal, Vol. 25, No. 7, pp. 1673–1695, doi:10.1108/BPMJ-09-2018-0241, 2019.
- Bakhat, R., and Rajaa, M., *Developing a novel grey integrated multi-criteria approach for enhancing the supplier selection procedure: A real-world case of a textile company*, Decision Science Letters, Vol. 8, No. 3, pp. 211–224, 2019.
- Chai, J., and Ngai, E. W., *Decision-making techniques in supplier selection: Recent accomplishments and what lies ahead*, Expert Systems with Applications, Vol. 140, Art. No. 112903, 2020.
- Chen, Y., Wang, S., Yao, J., Li, Y., and Yang, S., *Socially responsible supplier selection and sustainable supply chain development: A combined approach of TISM and fuzzy ANP*, Business Strategy and the Environment, Vol. 27, No. 8, pp. 1708–1719, 2018.
- Fan, J., Guan, R., and Wu, M., *Z-MABAC method for the selection of third-party logistics suppliers in a fuzzy environment*, IEEE Access, Vol. 8, pp. 199111–199119, 2020.
- Freeman, J., and Chen, T., *Green supplier selection using an AHP–Entropy–TOPSIS framework*, Supply Chain Management: An International Journal, Vol. 20, No. 3, pp. 327–340, 2015.
- Fu, Y. K., *An integrated approach to catering supplier selection using AHP–ARAS–MCGP methodology*, Journal of Air Transport Management, Vol. 75, pp. 164–169, 2019.
- Ghadernejad, S., Jafarpour, A., and Ahmadi, P., *Integrated FDAHP–PROMETHEE approach for optimal coal seam selection*, International Journal of Mining and Geo-Engineering, Vol. 53, No. 1, pp. 15–23, 2019.
- Goker, N., Dursun, M., and Albayrak, Y. E., *Agile supplier evaluation using a fuzzy decision-making procedure*, in Proceedings of the INFUS 2019 Conference, Springer, pp. 457–463, 2020.
- Guarnieri, P., and Trojan, F., *Supplier selection based on social, ethical, and environmental criteria: Evidence from the textile industry*, Resources, Conservation and Recycling, Vol. 141, pp. 347–361, 2019.
- Gul, M., Celik, E., Gumus, A. T., and Guneri, A. F., *A fuzzy logic-based PROMETHEE method for material selection problems*, Beni-Suef University Journal of Basic and Applied Sciences, Vol. 7, pp. 68–79, 2018.
- Gupta, A. K., and Gupta, N., *Strategic sourcing: Selection of suppliers using a Delphi–AHP approach*, in Proceedings of the IEEE IEEM Conference, pp. 1194–1197, 2021.
- Haddad, A., Da Costa, B. B. F., De Andrade, L. S., Hammad, A. W. A., and Soares, C. A. P., *Application of fuzzy TOPSIS for supplier selection with HSE focus*, Infrastructures, Vol. 6, No. 8, Art. No. 105, 2021.
- Heberling, M., *The rediscovery of modern purchasing*, International Journal of Purchasing and Materials Management, Vol. 29, No. 3, pp. 47–53, 1993.
- Hwang, C.-L., and Yoon, K., *Multiple attribute decision-making methods and applications*, Springer, Berlin, 1981.
- Isnaini, D. B. Y., Nurhaida, T., and Pratama, I., *Supply chain dynamic capabilities and sustainable performance*, International Journal of Supply Chain Management, Vol. 9, No. 1, pp. 97–105, 2020.
- Jain, V., Sangaiah, A. K., Sakhuja, S., Thoduka, N., and Aggarwal, R., *Supplier selection using fuzzy AHP and TOPSIS*, Neural Computing and Applications, Vol. 29, pp. 555–564, 2018.
- Javad, M. O. M., Darvishi, M., and Javad, A. O. M., *Green supplier selection using BWM and fuzzy TOPSIS*, Sustainable Futures, Vol. 2, Art. No. 100012, 2020.
- Jharkharia, S., and Das, C., *Low-carbon supplier development using fuzzy clustering*, Benchmarking: An International Journal, Vol. 26, No. 1, pp. 73–96, 2019.
- Joshi, R., and Kumar, S., *Supplier selection using intuitionistic fuzzy VIKOR*, Journal of Applied Mathematics and Computing, Vol. 60, pp. 27–50, 2019.
- Ju-Long, D., *Control problems of grey systems*, Systems and Control Letters, Vol. 1, No. 5, pp. 288–294, 1982.

- Kaviani, M. A., Karbassi Yazdi, A., Ocampo, L., and Kusi-Sarpong, S., *Grey-based MCDM approach for supplier evaluation*, *Kybernetes*, Vol. 49, No. 2, pp. 406–441, 2020.
- Leblebicioğlu, B., and Keskin, A., *Supplier selection criteria evaluation using fuzzy DEMATEL*, *Avrupa Bilim ve Teknoloji Dergisi*, No. 23, pp. 236–242, 2021.
- Li, Y., Diabat, A., and Lu, C. C., *Leagile supplier selection in Chinese textile industries*, *Annals of Operations Research*, Vol. 287, pp. 303–322, 2020.
- Lou, Z., Ye, A., Mao, J., and Zhang, C., *Supplier selection, control mechanisms, and innovation*, *Journal of Business Research*, Vol. 139, pp. 81–89, 2022.
- Mardani, A., Zavadskas, E. K., Govindan, K., Senin, A. A., and Jusoh, A., *VIKOR technique: A systematic review*, *Sustainability*, Vol. 8, No. 1, Art. No. 37, 2016.
- Mukhametzhanov, I. Z., and Pamučar, D., *Sensitivity analysis in MCDM problems*, *Decision Making*, Vol. 1, No. 2, 2018.
- Mukherjee, K., *Supplier selection criteria and methods: Past, present and future*, *International Journal of Operational Research*, Vol. 27, No. 1–2, pp. 356–373, 2016.
- Naqvi, M. A., and Amin, S. H., *Supplier selection and order allocation: A literature review*, *Journal of Data, Information and Management*, Vol. 3, No. 2, pp. 125–139, 2021.
- Opricovic, S., and Tzeng, G.-H., *Compromise solution by MCDM methods*, *European Journal of Operational Research*, Vol. 156, No. 2, pp. 445–455, 2004.
- Parkouhi, S. V., Ghadikolaie, A. S., and Lajimi, H. F., *Resilient supplier selection in a grey environment*, *Journal of Cleaner Production*, Vol. 207, pp. 1123–1137, 2019.
- Sahu, A., Sharma, M., Raut, R. D., Antony, J., and Tortorella, G. L., *Integrated MCDM framework for supplier selection*, *The TQM Journal*, Vol. 35, No. 4, pp. 964–1006, 2022.
- Saputro, T. E., Figueira, G., and Almada-Lobo, B., *Hybrid MCDM and simulation-optimization for supplier selection*, *Expert Systems with Applications*, Vol. 219, Art. No. 119624, 2023.
- Wang, C. N., Viet, V. T. H., Ho, T. P., Nguyen, V. T., and Nguyen, V. T., *Multi-criteria decision model for supplier selection in the textile industry*, *Symmetry*, Vol. 12, No. 6, Art. No. 979, 2020.
- Xu, Y., Jin, L., Chen, Z., Yager, R. R., and Špirková, J., *Weight vector generation in MCDM with uncertain information*, *Mathematics*, Vol. 10, No. 4, Art. No. 572, 2022.

## **Biographies**

**Mustafizur Rahman** is a PhD researcher in Computational Science at The University of Texas at El Paso (UTEP), USA and an Assistant Professor (on study leave) of the Department of Industrial and Production Engineering, Jashore University of Science and Technology (JUST), Bangladesh. His research focuses on supply chain optimisation, risk and resilience engineering, data-driven decision analysis, and sustainable manufacturing systems. With publications in Springer, Elsevier, Inderscience, Emerald and other Scopus-indexed journals, he has contributed to the advancement of analytical and hybrid MCDM methods in industrial decision-making. Rahman had previously worked for leading industries such as Walton Hi-Tech Industries Ltd. and PRAN-RFL Group and had also earned a national research grant in Bangladesh.

**Sarojit Kumar Biswas** is currently working as an Assistant Professor in the Department of Industrial and Production Engineering at Jassore University of Science and Technology (JUST), Bangladesh. He received his B.Sc. in Industrial and Production Engineering from Rajshahi University of Engineering and Technology (RUET) in 2012. His research interests focus on Supply Chain Optimization, System Dynamics, Production Scheduling and Ergonomics. He published his research in several international conferences and journals.

**Md. Mahafuj Anam Murad** is an undergraduate student of the Department of Industrial and Production Engineering, Jashore University of Science and Technology (JUST), Bangladesh. His area of research interest is Supply Chain Management, Process Optimization, Virtual Reality (VR), Digital Twin & Sensor-Based Modelling for Industrial Applications. He has worked on several ergonomics, supply chain optimization and human-machine interaction related research projects. Murad has presented and published his work at national and international conferences. He also went through industrial training institutions of the Bangladesh Industrial Technical Assistance Centre (BITAC) and the Bangladesh Knitwear Manufacturers and Exporters Association (BKMEA), where he learned about practical knowledge of production systems and industrial operations.