Structural Framework of Sustainable Supplier Selection for Raw Materials in a Manufacturing Industry

Md. Ibn Sajid, MD. Sakawat Hossain Sohan, Nusrath Zahan and Md. Ariful Haque
Department of Industrial & Production Engineering
Rajshahi University of Engineering & Technology
Rajshahi-6204, Bangladesh
sajidnrp@gmail.com, sohanhosen76@gmail.com, nusrathzahantasnim@gmail.com,
arifulhaque.ruet@gmail.com

Abstract

Nowadays, in response to the desires of markets, stakeholders, and business organizations and growing public awareness of environmental concerns, companies have focused on their supply chains to improve their sustainability performance. In today's manufacturing business, finding a reputable supplier is of the highest significance, and sustainability is considered part of the process. An integrated AHP-PROMETHEE and CRITIC-PROMETHEE approach-based framework has been applied in this study for effectively evaluating and ranking prospective suppliers. The AHP (Analytical Hierarchy Process) and CRITIC (CRiteria Importance Through Inter-criteria Correlation) methods were used to establish the weights of the criteria in the instance of supplier selection, and after that, the PROMETHEE technique was used to rank the suppliers. The proposed framework has been implemented in a manufacturing industry, which examined five sustainable supplier choices of the industry. The top sustainable supplier selection criteria were price, quality, resource consumption and geographical location in this research. The study presented in this research may help managers and other business professionals discover important supplier selection criteria and pinpoint the best supplier for supply chain sustainability while preserving market competitiveness.

Keywords
Sustainability, Supplier selection, AHP, CRITIC, PROMETHEE.

1. Introduction
In the past decade, academic research as well as practical applications have given a lot of attention to the sustainability of the supply chain. Most businesses are compelled to take sustainability into account when evaluating their performance due to the intensifying global competitiveness and pressure from many supply chain stakeholders, particularly governmental policy makers and social and environmental activists. Supply chain sustainability refers to a company's efforts to think about the effects that its products will have as they move through the supply chain, from the acquisition of raw materials to manufacturing, distribution, storage, and every transportation link in between. The goal is to have a positive impact on the local population and community while reducing the adverse effects on the environment brought on by elements such as energy use, water use, and waste creation. In addition to the usual revenue and profit-related concerns for corporate supply chains, these challenges arise. Companies throughout the world have made efforts to reduce their carbon emissions, minimize waste, and promote working conditions. Through the analysis of sustainability indicators in supply chain management (SCM) systems, they maintain a careful check on a variety of programs that, for example, promote the use of renewable energy, recycle goods and materials, or encourage suppliers to take greater social responsibility. The operational and strategic performance of a company is significantly impacted by the choice of suppliers. Additionally, reliable suppliers can lower manufacturing and inventory costs, raise the standard of the product, increase its flexibility, and meet the demands of the customer. The process of choosing the best suppliers that can provide the required quantity and quality at the appropriate pricing is known as supplier selection. Economic, environmental, and social criteria were taken into account in this research on choosing sustainable suppliers. Consequently, choosing a supplier is a multi-criteria decision-making (MCDM) dilemma. As there are so many competing criteria to take into consideration when choosing a sustainable supplier, such as product pricing, product quality, lead time for delivery, supplier flexibility, and environmental requirements, the issue only gets worse. MCDM tools must be used to assist such decisions. There are many MCDM supporting tools are available for sustainable supplier selection like AHP, TOPSIS, VIKOR, CRITIC, Best-Worst, DEMATEL, PROMETHEE and

others. In this research, the Analytical Hierarchy Process (AHP), Criteria Importance through Inter-criteria Correlation (CRITIC) and Preference Ranking for Organization Method for Enrichment Evaluation (PROMETHEE) methods have been integrated. This research integrates sustainable dimensions like economic, environmental and social factors that will help the company make the system environmentally friendly, better public image and customer satisfaction. As sustainability improves the company reputation and further legitimates of the organization. In addition to sustainability, also includes Service & Communicational criteria which will help the company's dynamic production rate and reduce production stoppages. In order to evaluate and rank potential suppliers effectively, an integrated AHP-PROMETHEE and CRITIC-PROMETHEE based framework is used. It also provides a visual representation of the alternatives strengths and weaknesses attributes in accordance to the criteria. This study will help managers and business professionals find suppliers who can maintain a steady flow of resources and goods through the supply chain.

1.1 Problem Statement

Global living standards are rising in a way that has never happened before in human history because the expansion of developing economies. The world's resources and environment cannot support this expansion unless supply chains become more sustainable. Lack of sustainability in the supply chain will have negative effects on the global system, including rising costs, longer manufacturing lead times, gas emissions, risks to human health and safety, violations of human rights, loss of waste materials and declines in product quality, material availability, flexibility, and production capacity. In addition to these issues, a lack of raw material supply can hinder or even stop an industry's entire production chain. So, it is important to choose suppliers who work to improve the condition of the economy, society, and environment of the markets where their future growth is most likely to occur, while also ensuring that they have access to the raw materials they need to support that growth.

1.2 Objectives

The goal of this paper is to choose the most sustainable suppliers in the manufacturing industry among a lot of alternative suppliers. In this purpose a structural framework is built for the sustainable supplier selection. The structural framework is applied to rank the effective suppliers with respect to sustainability by using multi-criteria decision-making (MCDM) method in an industry. According to rank, the best and worst supplier is selected in this paper.

2. Literature Review

In the supply chain, choosing sustainable suppliers is a significant and important decision that can affect the supply chain's overall sustainability. The selection of sustainable suppliers for the Iranian textile sector was the topic of Fallahpour et al. (2017) study. The analysis of the survey questions was used to choose a sustainable supplier to start with. Second, a hybrid model that combines FTOPSIS and FPP was proposed. The factors used to identify suppliers were weighted using FPP. FTOPSIS was used to rank this criterion and pinpoint the optimum provider. Future environmental protection initiatives will give carbon control priority. Choosing sustainable suppliers for Bangladeshi firms that manufacture ready-made clothing focused on Roy et al. (2020). Twenty sustainable sub-criteria were selected, which were divided into categories for the economy, environment, society, and transportation. In this research, the fuzzy AHP approach was used to calculate the weighted criterion, and the PROMETHEE method was used to decide which provider was the best. In the future, sectors other than RMG may be taken into account when examining sustainable suppliers. Additional MCDM methods like CRITIC, Entropy, TOPSIS, VIKOR, etc. may be employed for the best results. The challenge of selecting a contract manufacturer for the textile sector was solved by Adal and Işk (2017) using the CRITIC and MAUT techniques. The weights for these contract manufacturer selection criteria were determined using the CRITIC technique, and MAUT was used to determine the overall ranking of the manufacturer options. The drawback is that because it is only used for a certain segment, the amount of selection criteria and possibilities for contract manufacturers may be altered. Additionally, Sensitivity analysis may be used to examine the effects of any changes in values.

For the purpose of choosing sustainable suppliers, Rao et al. (2017) developed a decision-making procedure based on the linguistic 2-tuple grey correlation degree. Following that, the providers are graded based on a 2-tuple grey correlation degree method. This suggested approach converts the hybrid attribute values, which include real numbers, intermediate numbers, and linguistic fuzzy variables, into linguistic 2-tuples. The drawback is that this approach is unable to address the difficulties associated with choosing sustainable providers when language preferences are vague and incomplete. The requirements for sustainable suppliers were discussed by Tundys (2016) in the context of developing a green supply chain. The present list of factors is the result of research on sustainable supplier selection

criteria conducted in Polish firms and supply chains. The results of the study unequivocally show that economic variables are crucial. Among the investigated items, in addition to commercial practice, there were patterns of activity generation and promotion connected to green supply chains. The study found that in the domain of operational operations, notably vendor selection, the sustainable criteria are not utilized to pick suppliers positively. A mathematical approach was used by Rabieh et al. (2019) to choose the sustainable providers and distribute their orders. In addition, the supply chain's general sustainability was improved in order to choose the top suppliers and distribute their orders. A fuzzy TOPSIS technique based on Delphi was employed to carry out this process. The limitations is that they do not take demand and capacity uncertainties into account. In circular supply chains, Kannan et al. (2020) evaluated and rated sustainable suppliers by fusing the fuzzy best-worst approach with the interval VIKOR methodology. The disadvantage is that throughout the weighing process, the dependency between the criteria was not taken into consideration. It is possible to determine the weights of the criteria more accurately by accounting for their interrelation. Besides Allocating orders to sustainable circular suppliers is a new concept that has received little attention in the study.

Numerous studies have described supplier selection and evaluation criteria as a multi-criteria decision-making dilemma. Twenty distinct categories of criteria were selected for this investigation Ghobadi's (2019). Four categories, including communication, quality, finances, and services, were used to categorize these criteria. In this case, the criteria are ranked using data from many studies. No ranking models are used in this investigation. To get the greatest results, several ranking models should be utilized in the future, such PROMETHEE and TOPSIS. An integrated steel mill that employs a third-party carrier to deliver a sizable quantity of MRO (maintenance, repairs, and operations) items from its suppliers was the subject of Sarkar & Mohapatra (2008) study. To make the most of the vehicle capacity that is utilized to deliver goods in specified amounts, they created an exchange approach to identify a selection of providers. The disadvantage is that they fail to take into account the best route for a vehicle visiting a given list of providers while hauling a certain item load.

Supplier selection process are performed in various sectors. Focusing on a supply chain network that employs both an auxiliary warehouse and the project site storage facility to handle inventories, Mohammadnazari & Ghannadpour (2021). They created a mathematical model that has been suggested as a tool to assist contractors in effectively managing their inventory and selecting the right suppliers based on environmental concerns. A scenario of supplier assessment problems at an Indonesian glove company in Yogyakarta that utilized actual sheep leather as its main raw material was the topic of Astanti et al. (2020) study. To address the issue, which makes use of three distinct kinds of fuzzy AHP, they employed both the Analytical Hierarchy Process (AHP) and the Fuzzy AHP. This research made clear how the Fuzzy AHP should not have been employed, especially when professional responders were engaged to help the decision-making process. They just took a few factors into account, which is insufficient. They thus need further research that is as pertinent. A thorough supplier selection method that considers inventory management and incoming transportation was provided by Saputro et al. (2021). They offer a solution to the supply interruption issue in simulation-optimization. Decisions about inventories were made analytically, whilst choices regarding suppliers were made using a genetic algorithm. Discrete-event simulation was utilized to evaluate overall performance and adjust the lead time dynamically in response to disruptions. The study's flaw is that it uses worst-case scenarios since all suppliers expect difficulties, and during disruptions, no extra order amounts are split among other providers.

A thorough approach that is methodical and covers both qualitative and quantitative criteria was offered by Jafari Songhori et al. (2011). They also emphasized the need for methods that consider multiple transportation options when deciding which suppliers to choose and where to place orders across a range of discrete time periods. The disadvantage is that a fuzzy Data Envelopment Analysis model could be created in an effort to obtain sharp efficiency during the model selection phase. The factors impacting supplier selection and the supplier selection process were identified by Mwikali et al. (2012). Cost criteria, technical competence, quality assessment, organizational profile, service levels, and risk factors in that order of relative importance were the main drivers of supplier evaluation. This research discovered that cost criteria, among other things, have an impact on profit margins, making them a crucial factor determining supplier selection. The supplier's standing, material quality, and technical aptitude are all carefully taken into account. A unique framework was developed by Suraraksa and Shin (2019) to combine the supplier selection and monitoring stages. They looked at the differences between supplier monitoring and supplier selection criteria. The results provide managers, practitioners, and decision-makers in the automotive industry with in-depth understanding of the parameters that will help them choose the best suppliers and monitor those suppliers performance. The drawback is that it is difficult to extrapolate ranks and relative weights of crucial components from the findings of comparative analysis. In order to show their results, the proposed framework should also be applied to other sectors.

From the above study, it is found that many papers used only one method, don't consider absolute reference of the criteria, and past data for their research. They used a few criteria and sub-criteria for their research. In this research, adequate criteria are selected for getting a best result. We will use AHP and CRITIC method for weighted the criteria then PROMETHEE method is used for aggregating these criteria to rank the supplier and select the best supplier. The methods are performed by a MCDM aid software named Visual PROMETHEE.

3. Methods
3.1 Criteria
The criteria were selected from reviewing the literature review. The criteria were primarily divided into four categories like economic, environmental, social and service & communicational. Economic criteria refer to the ability for the supplier to supply the product economically. Price (C1), quality (C2), technical capacity (C3), production capacity (C4) and flexibility & delivery (C5) are the sub-criterion in this section. More the economic value gives more acceptable of the suppliers. Environmental criteria refer to how the supplier supply the product to the industry with less pollution in the environment. Environmental management system (C6), waste management (C7), resource consumption (C8), green packaging and labeling (C9) are the sub-criteria in this section. The supplier should also consider environmental impact to supply the product. Social criteria refer to the supplier should also consider the sociological factors to supply the product. Health & safety (C10), employment practices (C11), right of stock holder (C12), information disclosure (C13) are the sub-criteria in this section. Service & Communicational criteria plays a great impact to ensure the continual flow of resources and goods through the supply chain. Geographical location (C14), replenishment lead time (C15), reliability (C16), vehicles capacity (C17), risk management (C18), alternative transportation (C19), and storage capacity (C20) are the sub-criteria in this section.

3.2 Structural Framework of the Proposed Research
This research was carried out using a three-phase process. At first phase, the criteria were selected from literature review and a survey questionnaire was prepared based on the criteria. Then a survey report was prepared by surveying from the expertise people. The weights of the criterion have been assessed in the second phase using AHP & CRITIC method. Finally, the third phase concluded with the application of the PROMETHEE method to rank the suppliers in accordance with the criterion and weight. The structural framework for choosing sustainable suppliers is presented in Figure 1.
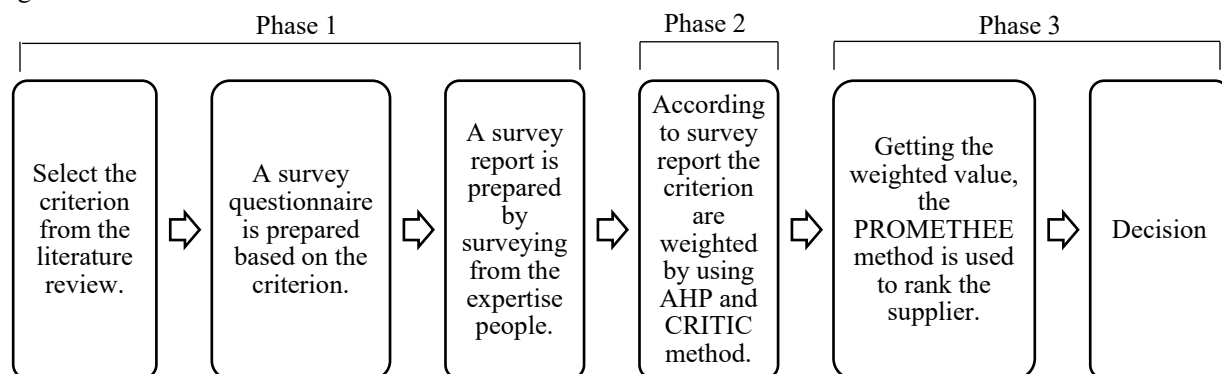

Figure 1. Structural framework of the proposed research.

3.2 AHP Method
AHP means Analytic Hierarchy Process which solves complex decision problem. It uses math and psychology. The steps for AHP method are given below:

Step 1: At first, the goal, criteria, and sub-criteria were selected for the research.
Step 2: Then a pair-wise comparison matrix was created by the survey analysis. It used Saaty's scale for comparing two criteria Saaty (2008). Then a normalized pair wise matrix was created by dividing each value of the pair-wise matrix by the sum of the column values for each criterion.
Step 3: The criteria weight was calculated by average value of each row value in normalized pair-wise matrix. Then each criteria weight was multiplied by each value of the normalized pair-wise matrix.
Step 4: Then the weighted sum value was calculated by the sum of each row in pair-wise matrix was calculated.

Step 5: Then the maximum Eigen value denoted as λ_{max} was calculated by averaging the divided value of weighted sum value and criteria weight. Using Eq. (3.1) to find out Consistency Index (C. I.).

$$\text{C. I.} = \frac{\lambda_{max} - n}{n - 1} \tag{3.1}$$

Where, n = no of criteria

Step 6: Using Eq. (3.2) to find out Consistency Ratio (C. R.) and check if it is below 10% or not. If it is below 10% then it is accepted otherwise is rejected. R. I. means Random Index number which was obtained by Random Index table provided by the www.spicelogic.com.

$$\text{C. R.} = \frac{\text{C.I.}}{\text{R.I.}} \tag{3.2}$$

3.3 CRITIC Method

CRITIC means CRiteria Importance Through Inter-criteria Correlation. It is a MCDM tool that use to determine the weighted of the criteria. The steps of this method are given below:

Step 1: The several criteria, sub-criteria and goals were selected for the research.

Step 2: Best and worst criteria was selected from the criterion and using Eq. (3.3) for creating normalize decision matrix.

$$\overline{X_{i,j}} = \frac{X_{i,j} - X_j^{worst}}{X_j^{best} - X_j^{worst}} \tag{3.3}$$

Where, i, j = row and column number.

Step 3: Using Eq. (3.4) to calculate the standard deviation denoted as σ then a $n \times n$ linear correlation matrix was created.

$$\sigma_j = \sqrt{\frac{(X_{i,j} - \overline{X}_j)^2}{n - 1}} \tag{3.4}$$

where, $\overline{X}_j$ = mean value of the matrix, n = number of linguistic variables.

Step 4: Measure of conflict was determined by subtracting one to the value in step 3. Then the quantity of information in relation for each criterion was determined by the Eq. (3.5).

$$C_j = \sigma_j \times \sum_{k=1}^{n}(1 - r_{j,k}) \tag{3.5}$$

Where, C_j = quantity of the information, k = 1, 2, 3……. n.

Step 5: Using Eq. (3.6) to find weighted criteria.

$$w_j = \frac{C_j}{\sum_{k=1}^{n} C_j} \tag{3.6}$$

Where, w_j = weighted criteria

3.4 PROMETHEE I & II Method

PROMETHEE means Preference Ranking Organization Method for Enrichment Evaluation. It is also a multi-criteria decision analysis method. It is used for ranking the suppliers. The steps are given below:

PROMETHEE I

Step 1: At first, the sub-criteria weight was found out from the AHP and CRITIC method.

Step 2: Beneficial and non-beneficial criteria were selected from the respective criterion then normalized evaluation matrix was created using the Eq. (3.7) & Eq. (3.8)

$$R_{i,j} = \frac{[x_{i,j} - \min(x_{i,j})]}{[\max(x_{i,j}) - \min(x_{i,j})]} \quad \text{(for beneficial criteria)} \tag{3.7}$$

$$R_{i,j} = \frac{[\max(x_{i,j}) - x_{i,j}]}{[\max(x_{i,j}) - \min(x_{i,j})]} \quad \text{(for non-beneficial criteria)} \tag{3.8}$$

Where, x = value of criteria, i, j = number of rows and column, R = range value which below between 0 and 1.

Step 3: The difference between each alternative to the other alternative was calculated then find out the preference function to check the difference was less than or equal to zero or not. If it was less than or equal to zero then it taken as zero otherwise it was same as the range value in step 2.

Step 4: The aggregate preference function was calculated by using Eq. (3.9).

$$\Pi(a, b) = \frac{\sum_{j=1}^{n} w_j \times P_j(a,b)}{\sum_{j=1}^{n} w_j} \tag{3.9}$$

Where, w_j = weighted criteria

Step 5: The leaving and entering value denoted as φ+ (a) and φ- (a) was calculated by summing the row and column on the matrix. Then compare one alternative to the other alternatives using three condition and developed a ranking model.

Condition 1: Alternatives a was preferred over alternatives b, aPb

aPb if: $\varphi^+(a) > \varphi^+(b)$ and $\varphi^-(a) < \varphi^-(b)$; or $\varphi^+(a) > \varphi^+(b)$ and $\varphi^-(a) = \varphi^-(b)$;

or $\varphi^+(a) = \varphi^+(b)$ and $\varphi^-(a) < \varphi^-(b)$.

Condition 2: Indifferent situation, aIb

aIb if: $\varphi^+(a) = \varphi^+(b)$ and $\varphi^-(a) = \varphi^-(b)$.

Condition 3: Incomparable situation, aRb

aRb if: $\varphi^+(a) > \varphi^+(b)$ and $\varphi^-(a) > \varphi^-(b)$; $\varphi^+(a) < \varphi^+(b)$ and $\varphi^-(a) < \varphi^-(b)$.

PROMETHEE II

Step 1 to Step 4: Same as PROMETHEE I method.

Step 5: The leaving and entering value denoted as φ+ (a) and φ- (a) was calculated by averaging the row and column on the matrix. Then net out ranking value was calculated by subtracting the leaving and entering value. Denote the net out ranking value as descending order as 1, 2, 3………. n.

4. Data Collection

The data was collected primarily about the importance of the criterion in case of supplier selection from the expertise of the supply chain department through survey questionnaire and personal interview. The alternative supplier's performance with respect to criteria was collected primarily from a manufacturing company. The linguistic scale was used to evaluate the importance of the criteria in case of supplier selection and the alternative supplier's performance with respect to criteria.

5. Results and Discussion

In this research visual PROMETHEE a MCDM aid software was used to rank and visualized the effective supplier. Visual PROMETHEE naturally follow the PROMETHEE I & II method to show the effective result. It shown the result as PROMETHEE I partial ranking, PROMETHEE II complete ranking, PROMETHEE network, PROMETHEE flow table and action profile. The weighted criteria obtained from AHP and CRITIC method put in visual PROMETHEE software to find out the rank of the effective supplier. The weighted criteria are shown at Table 1.

Table 1. Weighted criteria of AHP & CRITIC method.

Criteria	AHP method	CRITIC method
C1	0.086	0.052
C2	0.146	0.067
C3	0.055	0.043
C4	0.060	0.038
C5	0.082	0.056
C6	0.012	0.035
C7	0.017	0.041
C8	0.014	0.088
C9	0.012	0.037
C10	0.024	0.038
C11	0.008	0.048
C12	0.016	0.036
C13	0.024	0.063
C14	0.088	0.090
C15	0.120	0.055
C16	0.113	0.059
C17	0.034	0.041
C18	0.034	0.035
C19	0.019	0.037
C20	0.037	0.040

5.1: Integrated AHP-PROMETHEE Method

In PROMETHEE I partial ranking at Figure 2, supplier 5 is preferred in all other suppliers. Supplier 1 & 2 shown the indifferent situation as a result it intersects to one another. On the other hand, in PROMETHEE II complete ranking at Figure 3, supplier 5 is preferred than other suppliers, supplier 1 and 2 are closely related.
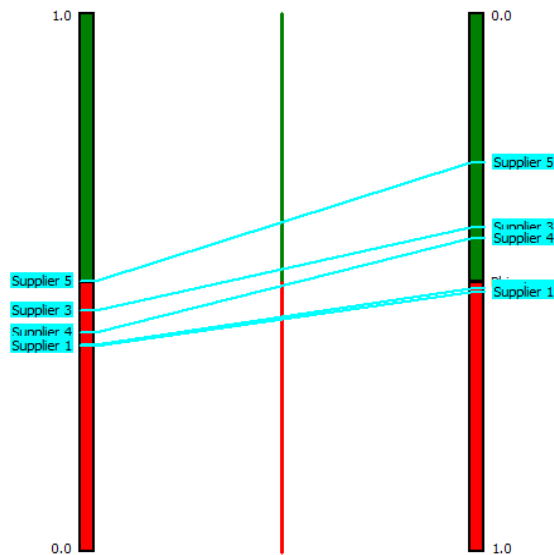

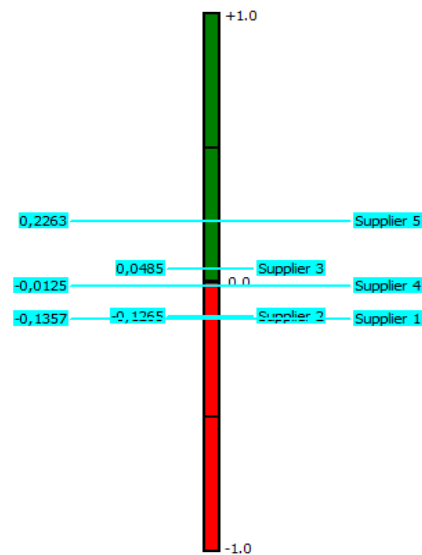Figure 2. PROMETHEE I partial ranking.   Figure 3. PROMETHEE II complete ranking.

In PROMETHEE network at Figure 4, it represents the alternative display of PROMETHEE I method. Here the alternatives are represented by the node and preference are represented by the arrays. Here, supplier 5 is most preference than other suppliers, then supplier 3, then supplier 4, then supplier 2 or 1 is preferable.
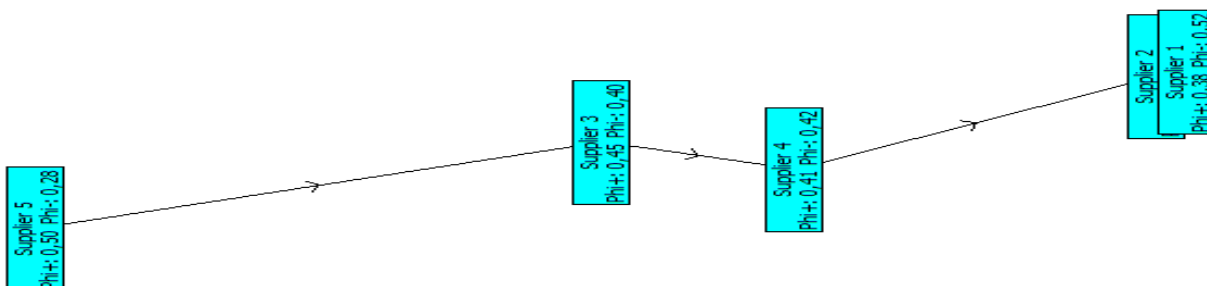
Figure 4. PROMETHEE network.

In PROMETHEE flow table at Table 2, it represents the rank value of the PROMETHEE II complete ranking. Supplier 5 has rank value 1, supplier 3 has rank value 2, supplier 4 has rank value 3, supplier 2 has rank value 4, and supplier 1 has rank value 5. The PROMETHEE II demonstrates supplier 5 outperforms alternative options. This present that supplier 5 is the most suitable supplier under the current conditions.

Table 2. PROMETHEE flow table.

Rank	Action	φ	φ^+	φ^-
1	Supplier 5	0.2263	0.5028	0.2765
2	Supplier 3	0.0485	0.4467	0.3982
3	Supplier 4	-0.0125	0.4058	0.4183
4	Supplier 2	-0.1265	0.3842	0.5108
5	Supplier 1	-0.1358	0.3815	0.5172

In action profile, it displayed a graphical representation of the selected action's single-criteria net flow score. Positive score represented the good feature and negative score represented the bad feature. In supplier 1 at Figure 5, price, delivery and flexibility, resource consumption, information disclosures, reliability, vehicle capability, risk management represented good features. On the other hand, quality, technical capacity, production capacity, environmental management system, waste management, green packaging & labeling, health & safety, employment practice, right of stock holder, geographical location, replenishment lead time, alternative transportation and storage capacity represented bad features.
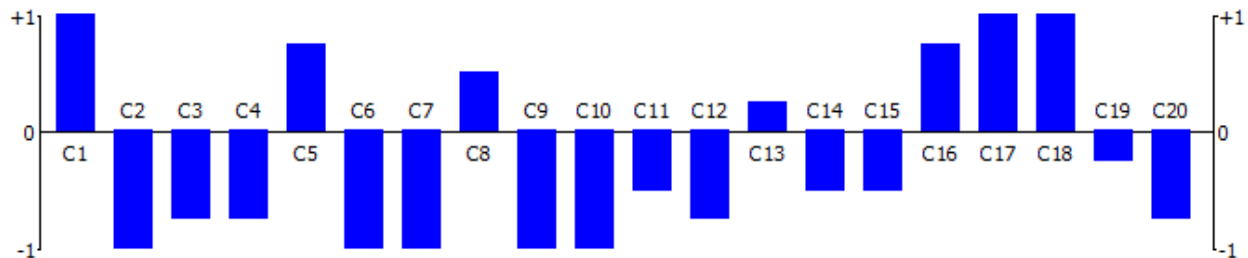

Figure 5. Action profile of supplier 1.

In supplier 2 at Figure 6, price, production capacity, waste management, resource consumption, health & safety, right of stock holder, information disclosures, geographical location, and alternative transportation represented good features. On the other hand, quality, technical capacity, delivery & flexibility, environmental management system, green packaging & labeling, employment practice, replenishment lead time, reliability, storage capacity represented bad features. Vehicle capacity and risk management represented neutral feature.
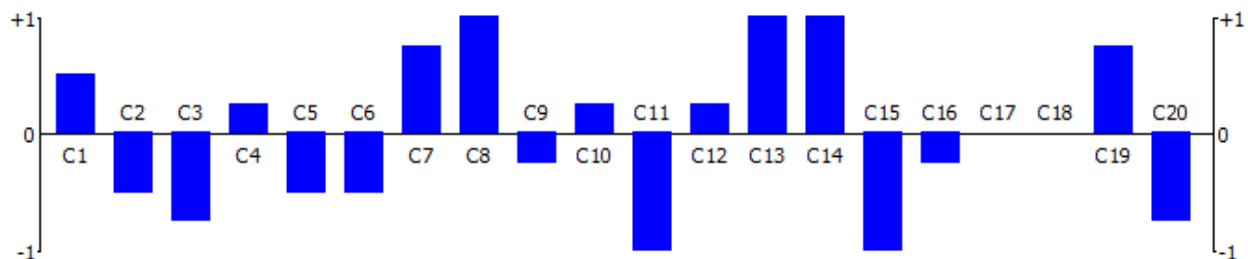

Figure 6. Action profile of supplier 2.

In supplier 3 at Figure 7, quality, technical capacity, production capacity, environmental management system, green packaging & labeling, right of stock holder, geographical location, replenishment lead time, risk management and storage capacity represented good features. On the other hand, waste management, resource consumption, health & safety, information disclosures, reliability, vehicle capacity and alternative transportation represented bad features. Price, delivery & flexibility, employment practice represented neutral feature.
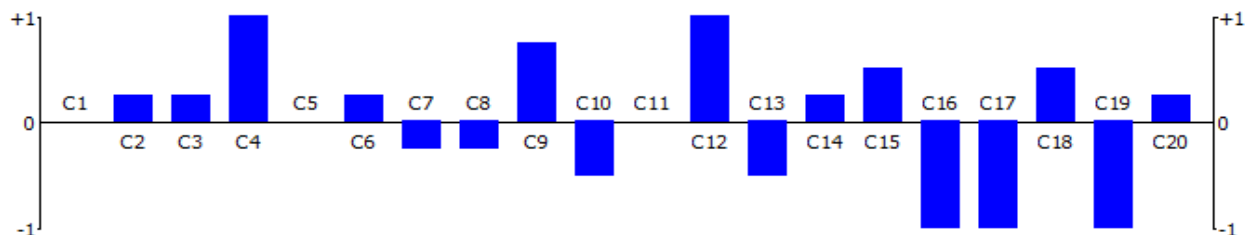

Figure 7. Action profile of supplier 3.

In supplier 4 at Figure 8, quality, technical capacity, production capacity, environmental management system, health & safety, employment practice, information disclosures, replenishment lead time, alternative transportation represented and storage capacity represented good features. On the other hand, price, delivery & flexibility, waste

management, resource consumption, green packaging & labeling, right of stock holder, geographical location, reliability, risk management represented bad features. Vehicle capacity represented neutral features.
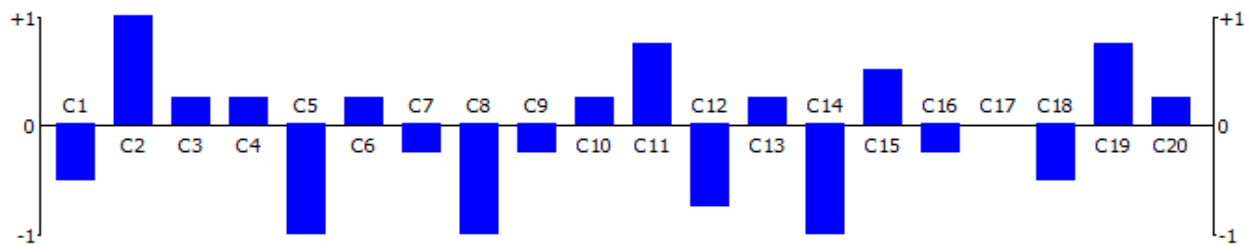

Figure 8**.** Action profile of supplier 4.

In supplier 5 at Figure 9, quality, technical capacity, delivery & flexibility, environmental management system, waste management, green packaging & labeling, health & safety, employment practice, right of stock holder, geographical location, replenishment lead time, reliability, and storage capacity represented good features. On the other hand, price, production capacity, resource consumption, information disclosures, risk management, alternative transportation represented bad features. Vehicle capacity represented neutral feature.
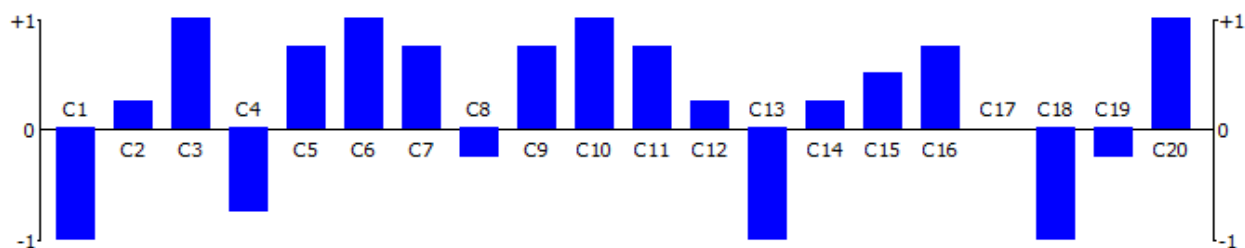

Figure 9. Action profile of supplier 5.

5.2 Integrated CRITIC-PROMETHEE Method

PROMETHEE I partial ranking at Figure 10, supplier 5 is most preferred than another supplier, supplier 1 & 4 shown incomparable situation. On the other hand, in PROMETHEE II complete ranking at Figure 11, supplier 5 is most preferred, supplier 1 & 4 is closely related.
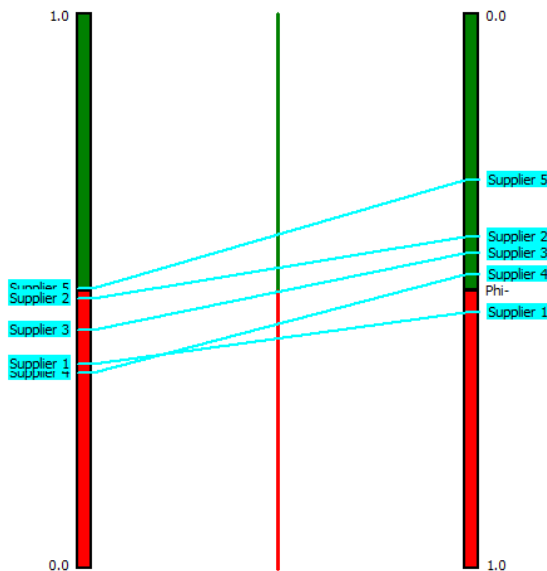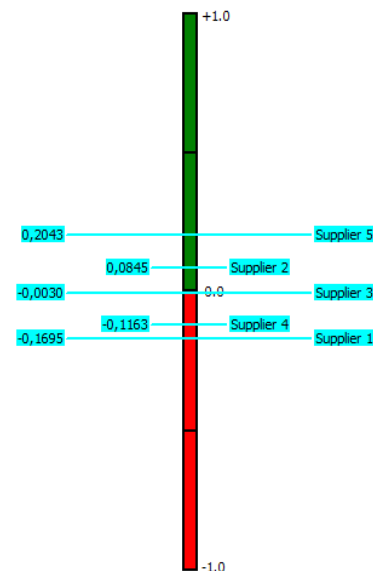

Figure 10. PROMETHEE I partial ranking.

Figure 11**.** PROMETHEE II complete ranking.

In PROMETHEE network at Figure 12, supplier 5 is most preferred, then supplier 2, then supplier 3, then supplier 4 or 1.
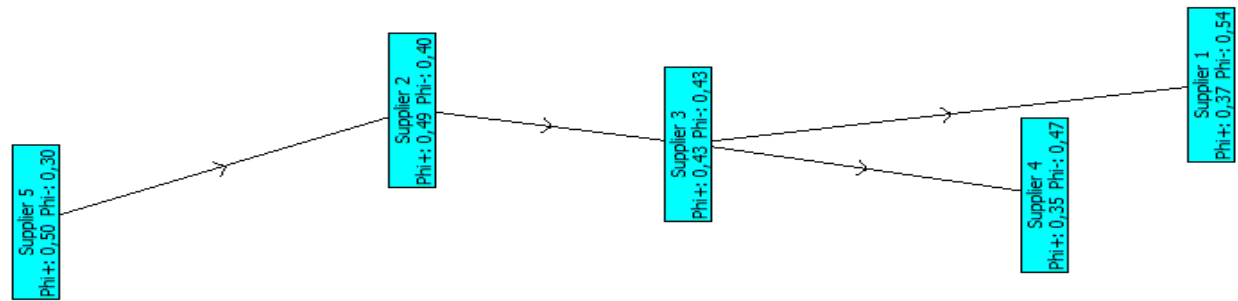

Figure 12. PROMETHEE network.

In PROMETHEE flow table at Table 3, supplier 5 has rank 1, supplier 2 has rank 2, supplier 3 has rank 3, supplier 4 has rank 4 and supplier 1 has rank 5. The PROMETHEE II demonstrates that supplier 5 outperforms alternative options. This shows that supplier 5 is the most suitable supplier under the current conditions.

Table 3. PROMETHEE flow table.

Rank	Action	φ	φ^+	φ^-
1	Supplier 5	0.2043	0.5035	0.2993
2	Supplier 2	0.0845	0.4858	0.4014
3	Supplier 3	-0.0030	0.4295	0.4325
4	Supplier 4	-0.1163	0.3534	0.4697
5	Supplier 1	-0.1695	0.3686	0.5381

The result of the action profile in integrated CRITIC-PROMETHEE method is same as the integrated AHP-PROMETHEE method.

Above all the analysis, it was clear that supplier 5 give the best result in comparing with other suppliers. The different criteria weight of AHP and CRITIC method that use in visual PROMETHEE software represented the same result. Both methods given the supplier 5 was most preferable than another supplier. The evaluation of the AHP-PROMETHEE and CRITIC-PROMETHEE techniques revealed that supplier 5 was the most sustainable supplier for the manufacturing company when all the criterion were taken into account.

5.3 Discussion
Choosing the best supplier from a number of alternatives based on a variety of criteria is a complex process. In this research, the weights of the evaluation criteria were determined using the AHP and CRITIC methods, and PROMETHEE was used to rank the sustainable suppliers. The consistency ratio of AHP method was 2.73% which is less than 10% that represents the acceptance of the process. The criteria weight was further used in visual PROMETHEE software as an input value. In PROMETHEE I partial ranking for AHP-PROMETHEE and CRITIC-PROMETHEE method supplier 5 was shown the most preferable ranked in all other suppliers. In AHP-PROMETHEE method supplier 1 and 2 was shown the indifferent situation where CRITIC-PROMETHE method supplier 1 and 4 was shown the incomparable situation. Here the supplier 5 is most preferred then other suppliers. In PROMETHEE II complete ranking for AHP-PROMETHEE and CRITIC-PROMETHEE, the supplier 5 shown the first ranked in all other suppliers. In PROMETHEE network, it represents a visual ranking model for PROMETHEE I partial ranking. In AHP-PROMETHEE and CRITIC-PROMETHEE, supplier 5 was given the best performance by analyzing the overall network. In action profile, it represents the several bad and good features for each supplier for each criterion. By analyzing the overall suppliers, the supplier 5 has less bad feature by comparing the other suppliers. The evaluation of AHP-PROMETHEE and CIRTIC-PROMETHEE methodologies recommended that supplier 5 was the most sustainable for the company when all the criteria were considered.

6. Conclusion

The purpose of this research was to develop a structural framework of sustainable supplier selection for raw materials in a manufacturing industry. For research work primarily selected five suppliers for the alternative supplier's performance with respect to criteria. Several MCDM method was applied to find out the rank of different of suppliers. AHP and CRITIC was used to find out the weighted criteria for different criterion and MCDM aid software named visual PROMETHEE was used to rank the supplier. The weighted criteria from the AHP and CRITIC methods were put into the visual PROMETHEE software to determine the rank of alternative suppliers. Both the integrated AHP-PROMETHEE and CRITIC-PROMETHEE methods give that supplier 5 is preferred over other suppliers in PROMETHEE I partial ranking, PROMETHEE II complete ranking, and achieved first rank in PROMETHEE flow table. Furthermore, supplier 5 outperforms the other suppliers in the PROMETHEE network. According to the results analysis, supplier 5 is the best alternative supplier and supplier 1 is the worst supplier for the manufacturing company. In this research, top sustainable supplier selection criteria were price, quality, resource consumption, geographical location. These criteria had a high impact on supplier 5. As a result, supplier 5 was the most sustainable supplier for the manufacturing industry.

The manufacturing sector at steel industry has been the main focus of this research. This method can be applied other sectors such as, pharmaceutical businesses, leather producers, automakers, chemical plants, and cement manufacturers, The best alternatives will be chosen by using the TOPSIS, VIKOR, MARCOS, Best-Worst, DEMATEL, and Entropy methodologies, which can be used to compare the proposed framework to other multi-criteria decision-making techniques will be employed to identify the most suitable alternatives.

References

Astanti, R. D., Mbolla, S. E. and Ai, T. J., Raw material supplier selection in a glove manufacturing: Application of AHP and fuzzy AHP, *Decision Science Letters.*, vol. 9, no. 3, pp. 291–312, 2020.

Adalı, E. A. and Işık, A. T., Critic and Maut Methods for the Contract Manufacturer Selection Problem, *European Journal of Multidisciplinary Studies*, vol. 5, no. 1, pp. 93, 2017.

Consistency ratio and transitivity rule, Available: https://www.spicelogic.com/docs/ahpsoftware/intro/ahp-consistency-ratio-transitivity-rule-388, Accessed on November 25, 2022.

Fallahpour, A., Olugu, E. U., Musa, S. N., Wong, K. Y. and Noori, S., A decision support model for sustainable supplier selection in sustainable supply chain management, *Computers & Industrial Engineering*, 2017.

Ghobadi, M., Identification of selection criteria for suppliers of raw materials in the supply chain of the Kavir steel complex, *International Journal of Supply Chain Management,* vol. 8, no. 4, pp. 684–691, 2019.

Jafari Songhori, M., Tavana, M., Azadeh, A. and Khakbaz, M. H., A supplier selection and order allocation model with multiple transportation alternatives*, International Journal of Advanced Manufacturing Technology*, vol. 52, no. 1–4, pp. 365–376, 2011.

Kannan, D., Mina, H., Nosrati-Abarghooee, S. and Khosrojerdi, G., Sustainable circular supplier selection: A novel hybrid approach, *Science of The Total Environment*, vol. 722, pp. 137936, 2020.

Mwikali, R., Box, P. and Kavale, S., Factors Affecting the Selection of Optimal Suppliers in Procurement Management, vol. 2, no. 14, pp. 189–193, 2012.

Mohammadnazari, Z. and Ghannadpour, S. F., Sustainable construction supply chain management with the spotlight of inventory optimization under uncertainty, vol. 23, no. 7. Springer Netherlands, 2021.

Rao, C., Goh, M. and Zheng, J., Decision Mechanism for Supplier Selection under Sustainability, *International Journal of Information Technology & Decision Making.*, vol. 16, no. 1, pp. 87–115, 2017.

Roy, S. A., Ali, S. M., Kabir, G., Enayet, R., Suhi, S. A., Haque, T. and Hasan, R., A framework for sustainable supplier selection with transportation criteria, *International Journal of Sustainable Engineering*, vol. 13, no. 2, pp. 77–92, 2020.

Rabieh, M., Rafsanjani, A. F., Babaei L. and Esmaeili, M., Sustainable supplier selection and order allocation: An integrated delphi method, fuzzy topsis, and multi-objective programming model, *Science Iran.*, vol. 26, no. 4E, pp. 2524–2540, 2019.

Sarkar, A. and Mohapatra, P. K. J., Maximum utilization of vehicle capacity: A case of MRO items, *Computers & Industrial Engineering,* vol. 54, no. 2, pp. 185–201, 2008.

Suraraksa, J. and Shin, K. S., Comparative analysis of factors for supplier selection and monitoring: The case of the automotive industry in Thailand, *sustainability*, vol. 11, no. 4, 2019.

Saputro, T. E., Figueira, G. and Almada-Lobo, B., Integrating supplier selection with inventory management under supply disruptions, *International Journal of Production Research*, vol. 59, no. 11, pp. 3304–3322, 2021.

Saaty, T. I., Decision making with the analytic hierarchy process, *International Journal of Services Sciences*, vol. 1, no. 1, pp. 83-98, 2008.
Tundys, B., Sustainable supplier selection criteria in the context of developing of green supply chain ,no.July,2016.

Biographies

Md. Ibn Sajid is an undergraduate student in the department of Industrial & Production Engineering (IPE) at Rajshahi University of Engineering & Technology (RUET). His areas of interest in research include Supply Chain Management, Project and Environmental Management, Operation Management, Operation Research, Quality Control, Probability & Statistics.

MD. Sakawat Hossain Sohan is an undergraduate student in the department of Industrial & Production Engineering (IPE) at Rajshahi University of Engineering & Technology (RUET). His areas of interest in research include Supply Chain Management, Operation Management, Quality Control, Operation Research, Probability & Statistics, Project and Environmental Management.

Nusrath Zahan is currently working as an Assistant Professor in the department of Industrial & Production Engineering (IPE) at Rajshahi University of Engineering & Technology (RUET). She completed her B.Sc. in Industrial & Production Engineering from RUET. She was the Ex-Lecturer at Military Institute of Science and Technology (MIST). Her areas of interest in research include Additive Manufacturing, Project Management, Operations Research, Machine Learning, Scheduling and Combinatorial Optimization.

Md. Ariful Haque is currently working as a lecturer in the department of Industrial & Production Engineering (IPE) at Rajshahi University of Engineering & Technology (RUET), Bangladesh. He started his early academic career at the National Institute of Textile Engineering and Research under the department of IPE. Currently, he is pursuing his M.Sc. in Industrial and Production Engineering from the Department of IPE of Bangladesh University of Engineering & Technology (BUET), Bangladesh. He obtained his B.Sc. in Industrial & Production Engineering from RUET. His research area covers Operations Research, Production Management, Supply Chain Disruption, and Solid Waste Management.