SUST J Sci Tech, Vol 32(2) 2022, 38 - 50 ISSN 1682-895X

A Combined BWM & TOPSIS Approach for Supplier Selection: A Case Study of a Pharmaceutical Company in Bangladesh

(Submitted: 13.09.2022 ; Accepted: 00000000)

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Abstract

Supplier selection is a critical activity having a substantial impact on the efficiency and effectiveness of the entire supply chain. As the procurement of pharmaceutical raw materials involves multiple global suppliers, proper evaluation and selection of the best supplier are necessary for optimizing costs, enhancing productivity, and increasing profitability. The purpose of this article is to present a comprehensive method of pharmaceutical supplier selection using the combination of the Best Worst Method (BWM) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). A case study was conducted at a pharmaceutical company in Bangladesh to check the viability of the method. In this study, an extensive literature review and expert opinion initially identified a set of eight evaluation criteria, which were then weighted and ranked by their importance using BWM. Then TOPSIS was applied to calculate the overall performance scores of seven suppliers against all the criteria and determine the best possible one for the case company. The proposed framework can be considered an innovative approach for the pharmaceutical industry as the findings indicate that the combined BWM and TOPSIS method is easily applicable and provides an effective solution to multi-criteria (tangible and intangible) supplier selection problems.

Keywords: Supplier Selection; Pharmaceutical Industry; BWM; TOPSIS; Multi-Criteria Decision-Making

1. Introduction

Supplier selection has always been a very crucial decision for any manufacturing firm to survive and thrive in this globally competitive market (Alamroshan et al., 2022). It significantly affects the efficacy and efficiency of the entire supply chain. The manufacturer most likely spends more than 60% of its entire sales on purchased goods and services. Additionally, up to 70% of the expenses for the finished product are material costs. Therefore, identifying the right suppliers can lead to lower purchasing prices, lower supply risk, and better product quality (Forghani et al., 2018)

As the quality, cost, lead time, and other quantitative and qualitative criteria for a purchased raw material have a direct impact on the final manufactured product, strategic sourcing has been one of the key elements of an effective supply chain. But strategic sourcing requires the consideration of many variables and a robust evaluation process that can ensure the selection of the best supplier among all alternatives. The outcomes obtained from a thorough evaluation process ultimately result in better products, which leads to minimized costs, increased profitability, and improved customer satisfaction. Almost every manufacturing business relies largely on its suppliers for raw materials and process machinery. However, selecting a supplier and completely relying on them has some disadvantages, as it shifts bargaining power from the firm to the supplier. Furthermore, a single supplier cannot possess the

technical expertise required to meet all of the firm's needs (Hastig & Sodhi, 2020). A supplier will never be flawless in every case or meet every criterion perfectly. For instance, one provider may offer a high-quality product at a much higher price, while another may offer the same thing at a lower price, but the quality is not quite as excellent as the first one. So, an optimization technique for these two criteria is required to choose the best one. Nevertheless, in reality, a variety of factors serve as variables against which potential vendors must be assessed. As a result, when a requirement emerges, the company must look for alternatives, compile a list of potential suppliers, and select the best one based on several factors.

This research was conducted on a pharmaceutical company in Bangladesh. The pharmaceutical business of Bangladesh is one of the most advanced hi-tech industries in the country's economy, providing over 97 percent of the country's total medicinal needs (Rahman

& Howlader, 2022). To manufacture drugs, pharmaceutical companies regularly purchase APIs (Active Pharmaceutical Ingredients) from various suppliers, and almost all of them are foreign suppliers, as there are just a few APIs being manufactured in Bangladesh currently. The API supplier for a given medicine must be determined and communicated with regularly. As a result, selecting a supplier for a pharmaceutical drug is pivotal, and many tangible (cost, lead time, etc.) and intangible (quality, service, etc.) aspects must be examined to find a sustainable supplier. MCDM (Multi-Criteria Decision-Making) tools and techniques can give a perfect solution here.

Supplier selection is a multifaceted problem that requires the use of one or more MCDM techniques to solve (Manivel & Ranganathan, 2019). In this paper, a newly introduced BWM tool is employed in conjunction with TOPSIS, a widely used MCDM tool. BWM is utilized to determine criteria weights, while TOPSIS is used to rank suppliers. As these two techniques generally have different outcomes, the use of any one of these does not provide the necessary solution. BWM can be used for determining criteria weights, but it can not be used to use the weights to rank various alternatives. Similarly, although TOPSIS can provide the final ranking, it is not possible to get the initial basis for the ranking- the criteria weights. But the combined approach uses both the methodologies of these tools to select the best alternative.

This paper aims to develop a simple and uncomplicated supplier selection model that can be used easily to evaluate the best possible supplier for an organization. The objectives herein can be summarized as follows:

- Evaluation of the 8 most important criteria required for the selection of a supplier for a pharmaceutical company.
- Determination of relative weights for the selected criteria.
- Ranking the potential suppliers based on their performance on each criterion and identifying the best one.

Although BWM and TOPSIS- both the techniques, separately and in a combined manner, have been employed in various research works worldwide, it has been developed for this article to obtain the objectives. Thus, the significance of this paper lies in the application of this combined approach to rank the suppliers according to their specifications on the selected criteria.

The remainder of this paper is structured as follows: Section 2 highlights an extensive literature review; the methodology and tools are explained in Section 3. Then section 4 contains the data collection procedure and analysis of the data, and section 5 details the results and discussions. Finally, conclusions and recommendations for future research are discussed in Section 6.

2. Literature Review

Supplier selection is a vital step in modern supply chain management. Companies are more conscious of supplier selection procedures for their raw materials nowadays. That is why, over the last three decades, researchers have suggested a slew of supplier selection models based on a variety of multi-criteria decision-making approaches. They used both single and combination models to select vendors. In addition, those works are industry-specific too (electronics, automotive, textiles, pharmaceuticals, chemicals, and so forth). Since we are primarily interested in supplier selection in the pharmaceutical industry, we have studied articles based on the pharmaceutical industry.

In order to find the best supplier for the pharmaceutical industries, researchers employed various multicriteria decision-making techniques. Forghani et al., (2018) used principal component analysis (PCA), Z- TOPSIS, and mixed integer linear programming (MILP) methods for evaluating supplier selection criteria and suppliers. Badi & Ballem (2018) presented a multiple-criteria decision-making analysis using modified BWM (Best-Worst method) and MAIRCA (Multi-Attribute Ideal-Real Comparative Analysis) methods. Pelissari et al., (2019) proposed a model for pharmaceutical supplier selection under multiple uncertainties and heterogeneous information which is based on an integration of the FlowSort and SMAA methods and Fuzzy theory. Manivel & Ranganathan (2019) analyze the alternatives, criteria, and sub-criteria of the supplier selection process by multi-criteria decision-making approach of the Fuzzy Analytic Heuristic Process (FAHP) and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS) methods. Emec et al., (2019) utilized AHP and fuzzy VIKOR methods for selecting suppliers of DNA-RNA-protein isolation devices which will be used in a laboratory that conducts scientific research in the Atatürk University Faculty of Medicine.

Sabbaghi, (2020) aimed to provide a checklist for selecting suppliers in drug production projects using TOPSIS. Stević et al., (2020) developed Measurement Alternatives and Ranking according to the Compromise Solution (MARCOS) method for a sustainable supplier selection in the healthcare industry (in a polyclinic) in Bosnia and Herzegovina. Goh et al., (2020) adopted fuzzy AHP and fuzzy TOPSIS for supplier selection. Sumrit, D. (2020) developed the MCDM framework consisting of Fuzzy Delphi, Fuzzy Step-wise Weight Assessment Ration Analysis (SWARA), and Fuzzy Complex Proportional Assessment of Alternatives (COPRAS) to identify appropriate suppliers of Vendor-managed inventory (VMI) collaboration in a healthcare organization. Yazdani et al., (2020) proposed an integrated decision-making model consisting of a decision-making trial and evaluation laboratory

(DEMATEL), best-worst method (BWM), and a modified version of evaluation based on distance from average solution (EDAS) methods for the supplier selection problem of a hospital in Spain.

Furthermore, Qazvini et al., (2021) developed an integrated two-stage approach based on the Fuzzy Analytic Hierarchy Process (FAHP) and multi-objective mixed-integer linear programming to select suppliers for a pharmaceutical chain in Iran. Tu et al., (2021) designed a logistics service provider selection scheme based on a novel weighted density-based hierarchical cluster analysis (WDBHCA) with the integration of the analytic hierarchy process (AHP) for the healthcare industry. Patidar & Sukhwani, (2021) developed a method to evaluate and select the most efficient suppliers based on a technique for order preference by similarity to ideal solution method (TOPSIS) and showed a successful application of FUZZY TOPSIS to an actual supplier selection problem in Indian pharmaceutical industry. Forghani et al., (2022) formulated two multi-objective mixed-integer non-linear programming (MOMINLP) models, consisting of the Best-Worst Method (BWM), to select the best suppliers with the highest scores, the lowest total cost, and the highest quality. The feasibility of models is analyzed in a pharmaceutical industry. Alamroshan et al., (2022) Developed an efficient hybrid fuzzy decision-making approach based on the Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL), Fuzzy Best-Worst Method (FBWM), Fuzzy Analytic Network Process (FANP), and Fuzzy Vlse Kriterijumsk Optimizacija Kompromisno Resenje (FVIKOR) methods.

In recent years, several studies have been conducted on supplier selection in Bangladesh too. Ghosh et al., (2018) suggested a multiproduct, multi-vendor vendor selection model based on AHP and Integer Linear Programming (ILP). A case study for raw material providers in Bangladesh's textile industry was used to test the model's validity. Rahman & Haldar (2018) used the AHP approach to discover the best supplier for Bangladesh's jute sector. Ghosh et al., (2019) focused on developing a generic model utilizing fuzzy TOPSIS based on the buyer's preferences to select the best-knit fabric supplier in the local ready-made garment industry. Rahman et al., (2019) proposed a Fuzzy AHP-based supplier selection model and validated the method using a case study on an apparel manufacturing company. Ahmed & Karmaker (2019) suggested a Delphi-based analytic hierarchy process (AHP) approach to tackle the problem of supplier selection for a super-shop in Bangladesh. Azad (2019) utilized TOPSIS for the evaluation and selection of the best vendor. Roy et al., (2020) proposed a framework to assess sustainable supplier selection methods using a fuzzy AHP and the preference ranking organization method for enrichment evaluation (PROMETHEE) that was implemented in a ready-made garment company in Bangladesh. Sarder & Khan (2020) used AHP and TOPSIS methods to find the right chemical supplier for the leather industry. Emon (2022) developed a supplier selection model based on the Fuzzy VIKOR method in the food supply chain.

Surprisingly, there is only one mentionable work on supplier selection of the pharmaceutical industry of Bangladesh. Pantha et al. (2020) used the Integrated Data Envelopment Analysis (DEA) and Differential Evolution (DE) Model for the API (Active Pharmaceutical Ingredient) supplier section of the pharmaceutical industry. The study considered six criteria for supplier selection: price, lead time, supplier reputation, service quality, carbon dioxide emission, and quality. Since most of the research on supplier selection in Bangladesh used conventional multi-criteria decision-making methods, and there is a scarcity of research on supplier selection in the pharmaceutical industry of Bangladesh, our study is focused on supplier selection in the pharmaceutical industry of Bangladesh using BWM and TOPSIS methods.

3. Methodology

The supplier selection problem in this study was approached using a three-phase methodology. The first phase entails determining the criteria that will be used to evaluate potential suppliers. Eight criteria were finally chosen after a thorough assessment of the literature and consultation with specialists. The BWM mrthod was then used to calculate the relative weights of those criteria in the second phase of the study. In the last phase, a questionnaire was handed to the experts to gain feedback on the potential suppliers, as they had all previously worked with those vendors on various occasions. Each supplier was given a certain number of points in each criterion based on their data, which served as the raw data for selecting the best one. TOPSIS, a common MCDM technique, was applied to rank the vendors in the end.

The overall research methodology framework is outlined in Figure 01.

3.1 Best–worst method

The Best-worst method (BWM) is a relatively new and popular MCDM technique developed by Dr. Jafar Rezaei in 2015 (Rezaei, 2015). First, this method identifies the most important and the least important decision criteria. Then, this method can generate weights for all the criteria by a systematic pairwise comparison of the remaining criteria against the best and worst decision criteria. BWM uses fewer comparison data than most other multi-criteria decision-making procedures and produces more reliable outcomes (Javad et al., 2020). This method has been used in this research to identify the optimal weights of the criteria.

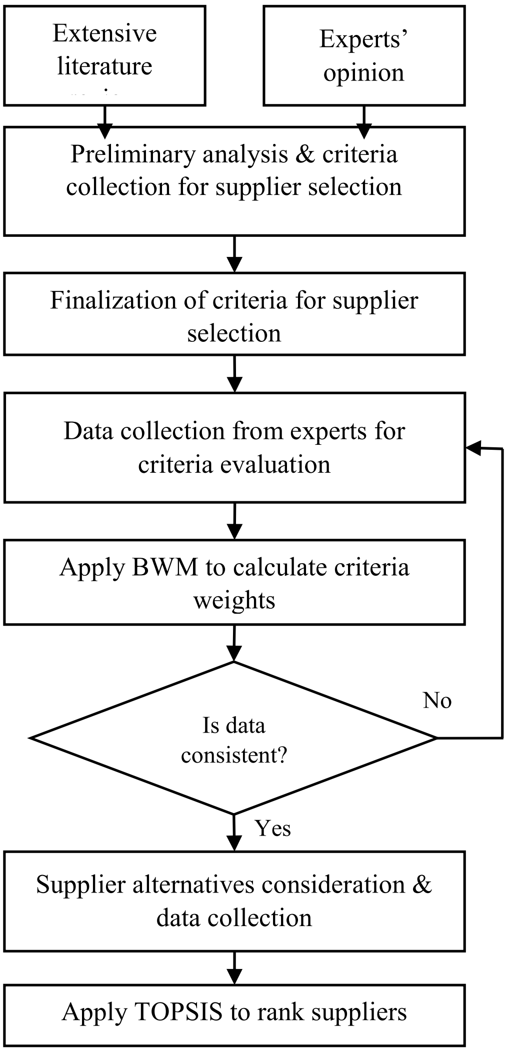

Figure 1: Research methodology framework

The methodology of this technique is briefly discussed here:

Step 1: Identification of decision criteria by the experts.

A set of n decision criteria is fixed as $\{c_1, c_2, \ldots\ldots, c_n\}$

Step 2: Experts determine the best and worst criteria found in Step 1.

In this stage, experts identify the best and worst criteria for making the decision according to their opinion in general. No comparison is made at this stage.

Step 3: The best criterion is compared to all the other criteria by the experts.

An expert determines the preference of the best criterion over all the other criteria using a number between 1 and 9, where 1 indicates an equal preference between the criteria and 9 is an extreme preference. The constructed best-to-others vector is as follows:

$$A_B = (a_{B1,}a_{B2,} \ldots\ldots, a_{Bn}) \quad (1)$$

Where a_{Bj} indicates the preference value of the best criterion B over criterion j.

Step 4: Then the experts compare all criteria to the worst one.

An expert determines the preference of all the other criteria over the worst one using a number between 1 and 9, where 1 indicates an equal preference between the criteria and 9 being an extreme preference. The constructed others-to-worst vector is as follows:

$$A_W = (a_{1W,}a_{2W,} \ldots\ldots, a_{nW}) \quad (2)$$

Where a_{jW} indicates the preference value of criterion j over the worst criterion W.

Step 5: Calculate the optimal weights $(w_1^{*}, w_2^{*}, \ldots\ldots, w_n^{*})$

The maximum absolute differences for all j are minimized over the following set:

$$\{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}$$

The following min-max model can be formulated:

$$Min\ max\ \{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}$$

Subject to,

$$\sum_j W_j = 1,$$

$$W_j \geq 0\ for\ all\ j \quad (3)$$

Model 3 may be transformed into a linear programming problem as follows:

$$\min \xi^L,$$

Subject to,

$$|w_B - a_{Bj}w_j| \leq \xi^L\ for\ all\ j,$$

$$|w_j - a_{jW}w_W| \leq \ \xi L\ for\ all\ j,$$

$$\sum_j W_j = 1,$$

$$W_j \geq 0\ for\ all\ j \quad (4)$$

The optimal weights of all the criteria $w_1^{*}, w_2^{*}, \ldots\ldots, w_n^{*}$ and the optimal value of ξ^L are achieved by solving this linear programming problem. Higher consistency is denoted by a lower ξ^L value and vice versa.

3.2 TOPSIS method

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a quantitative multi-criteria decision-making procedure that applies a complete set of information on criteria (Mehralian et al., 2016). TOPSIS is a very useful method for solving practical problems as it can provide the optimal solution or ranking of the alternatives. Besides, the calculation is not too complicated and it does not require a high level of skill and knowledge, yet it can provide a very practical and optimal solution. The TOPSIS technique searches for the given alternatives and finds the one that is closest to the ideal solution but farthest from the anti-ideal solution at the same time (Hwang et al., 1993). That's why it is one of the most widely used MCDM techniques, and in this paper, the final ranking of the suppliers was also calculated by this method.

The methodology of this technique is briefly discussed here:

Step 1: Calculate the normalized matrix.

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} {x_{ij}}^2}} \tag{5}$$

Step 2: Calculate the weighted normalized matrix.

$$n_{ij} = w_j \boxtimes n_{ij} \tag{6}$$

Step 3: Calculate the ideal best and ideal worst value.

Ideal best value:

For beneficial criteria,

$$V_j^+ = \left(n_{i1}^+, n_{i2}^+, \ldots\ldots, n_{ip}^+\right), n_{ij}^+ = \max_{1 \le i \le n}\left(n_{ij}\right) \tag{7}$$
$$where\ j = 1,2, \ldots\ldots, p$$

For non-beneficial criteria,

$$V_j^+ = \left(n_{i1}^+, n_{i2}^+, \ldots\ldots, n_{ip}^+\right), n_{ij}^+ = \min_{1 \le i \le n}\left(n_{ij}\right) \tag{8}$$
$$where\ j = 1,2, \ldots\ldots, p$$

Ideal worst value:

For beneficial criteria,

$$V_j^- = \left(n_{i1}^-, n_{i2}^-, \ldots\ldots, n_{ip}^-\right), n_{ij}^- = \min_{1 \le i \le n}\left(n_{ij}\right) \tag{9}$$
$$where\ j = 1,2, \ldots\ldots, p$$

For non-beneficial criteria,

$$V_j^- = \left(n_{i1}^-, n_{i2}^-, \ldots\ldots, n_{ip}^-\right), n_{ij}^- = \max_{1 \le i \le n}\left(n_{ij}\right) \tag{10}$$
$$where\ j = 1,2, \ldots\ldots, p$$

Step 4: Calculate the difference from each response from ideal best value and ideal worst value.

$$S_i^+ = \sqrt{\sum_{j=1}^{p} \left({n_{ij}}^+ - n_{ij}\right)^2} \tag{11}$$

$$S_i^- = \sqrt{\sum_{j=1}^{p} \left({n_{ij}}^- - n_{ij}\right)^2} \tag{12}$$

Step 5: Calculate the performance score for each alternative.

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \tag{13}$$

Step 6: Rank the alternatives in increasing order according to the performance score P_i obtained in step 5.

4. Data Collection and Analysis

4.1 A case study

The research was conducted at one of the renowned pharmaceutical companies that specialize in researching, developing, manufacturing, and marketing pharmaceutical-led healthcare products in Bangladesh. This research used API (Active Pharmaceutical Ingredient) purchasing data collected from them. In addition, the qualitative data was collected from five experts in their procurement division with a minimum experience of seven years who were familiar with the potential suppliers.

4.2 Criteria evaluation

A substantial literature review and the experts' opinions were the basis of the selection of all criteria for this study. Scientific journals were initially searched using many key terms, such as "supplier selection," "suppliers for pharmaceuticals," etc., in order to locate the appropriate criteria. Only Science Direct publications from the Google Scholar databases were examined for searching different criteria, and only research completed after 2010 was taken into account. Previous pieces of literatures provided lots of criteria that were used for various supplier selection problem in various industries. All these criteria were collected at first and were handed out as a questionnaire to the experts working in the procurement division of the case company. They were instructed to shortlist the most important ones that they generally use for supplier selection for the case company. At last, 8 criteria were finalized by the experts that were the basis of this research. These criteria (C_n) are as follows:

1. Quality and Process Control, C_1: This criterion includes the quality of API, how the suppliers control their API production and what statistical process control techniques they use, inspection methods, consistency of their product, failure prevention measures taken etc.

2. Pricing, C_2: The pricing criterion is comprised of the product cost and shipping charges.
3. Delivery, C_3: Delivery indicates the lead time from ordering to receiving the product.
4. Inventory, C_4: Inventory is required for meeting the uncertain demand capabilities. This criterion includes the inventory capacity, tracking, management system, safety protocols maintenance, computer records etc.
5. Facility Environment, C_5: Environmental management plan, hygiene maintenance in production floor, proper PPE (Personal Protective Equipment) usage, protective packaging, degree of regulatory requirements met, availability of adequate equipment, safety procedures, facility control process etc. are in this criterion.
6. Customer Service, C_6: This criterion is comprised of sufficient documentation, complaint handling process, technical assistance, proactiveness and fast response, commitment, in-time communication, EDI (Electronic Data Interchange) capability, reordering system, confidentiality maintenance etc.
7. Continuous Improvement, C_7: The R&D (Research & Development) sector of the supplier Company, skill development program taken, training, awareness of industry trends and new technologies etc. are in this criterion.
8. Financial Condition, C_8: This criterion includes long-term stability of the supplier company, size of the organization, reputation, credit standing, market share, experience in the market, diverse markets etc.

4.3 BWM application & criteria ranking

The experts were given a set of structured questionnaires. The experts were asked to weigh in on determining the best and worst criteria (Table 1), as well as pairwise comparisons of the best to the other criteria (Table 2) and the worst to the other criteria (Table 3) on a 1–9 scale. The experts are denoted by E_n hereafter.

Table 1: Selection of best and worst criteria

Notation	Criteria	Marked as best	Marked as worst
C1	Quality and Process Control	E3	
C2	Pricing	E1, E2, E4	
C3	Delivery		
C4	Inventory		
C5	Facility Environment		E4
C6	Customer Service	E5	
C7	Continuous Improvement		E1, E5
C8	Financial Condition		E2, E3

Table 2: Evaluation of best-to-other criteri a

Expert	Best criteria	C1	C2	C3	C4	C5	C6	C7	C8
E1	C2	3	1	4	6	7	2	9	8
E2	C2	2	1	3	5	8	4	7	9
E3	C1	1	7	5	8	3	5	3	9
E4	C2	4	1	3	6	9	3	7	7
E5	C6	2	3	3	6	8	1	9	8

These three tables (Table 1, 2, 3) are the primary data to conduct a BWM analysis.

The relative weights of the criteria were identified by applying the BWM method to the data received from the experts. Based on the data each expert provided, a set of weights were assigned to all the criteria by solving the linear equations generated from Table 2 and Table 3. These 5 sets of weights obtained were aggregated using the geometric mean to find the optimal weight of the criteria (Table 4) and the criteria are ranked in Table 5.

The BWM calculation shows that C_2, C_1 and C_6 are the major criteria in supplier selection according to the experts. The ξ^L values for all experts' opinions range from 0 to 0.1 which indicates valid data which are consistent enough to give an accurate result.

Table 3: Evaluation of worst-to-other criteria

	Experts				
	E1	E2	E3	E4	E5
	C7	C8	C8	C5	C7
C1	7	7	9	5	7
C2	9	9	5	9	7
C3	5	8	6	8	6
C4	3	2	3	5	4
C5	2	3	8	1	5
C6	7	6	5	7	9
C7	1	5	7	3	1
C8	3	1	1	2	3

Table 4: Final weights of the criteria

Expert	ξ^L	Weights of the criteria							
		C1	C2	C3	C4	C5	C6	C7	C8
E1	0.0720	0.1379	0.3419	0.1035	0.0690	0.0591	0.2069	0.0300	0.0517
E2	0.0827	0.2068	0.3309	0.1379	0.0827	0.0517	0.1034	0.0591	0.0276
E3	0.0909	0.3634	0.0649	0.0909	0.0568	0.1514	0.0909	0.1514	0.0303
E4	0.0895	0.1118	0.3578	0.1491	0.0745	0.0298	0.1491	0.0639	0.0639
E5	0.0834	0.2045	0.1363	0.1363	0.0682	0.0511	0.3256	0.0269	0.0511
Average	0.0837	0.2049	0.2464	0.1235	0.0702	0.0686	0.1752	0.0663	0.0449

Table 5: Final ranking of criteria

Notation	Criteria	Weight	Rank
C1	Quality and Process Control	0.20488	2
C2	Pricing	0.24636	1
C3	Delivery	0.12354	4
C4	Inventory	0.07024	5
C5	Facility Environment	0.06862	6
C6	Customer Service	0.17518	3
C7	Continuous Improvement	0.06626	7
C8	Financial Condition	0.04492	8

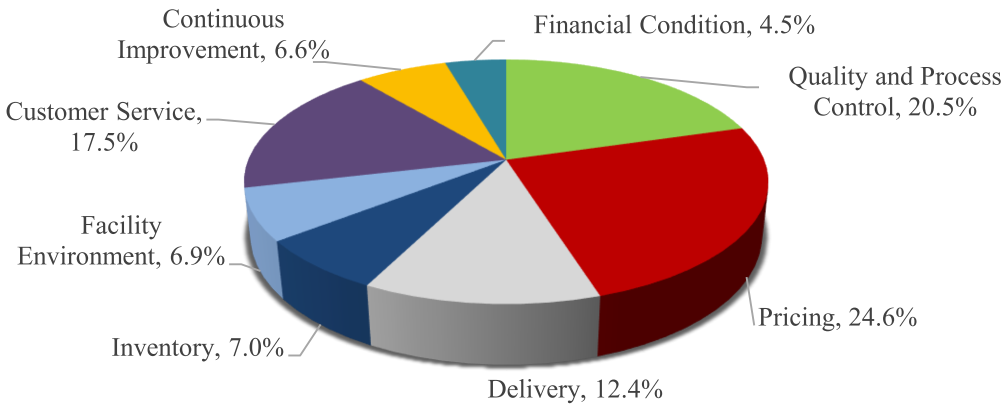

Figure 2: Relative Weight% of the criteria

4.4 TOPSIS calculation & supplier ranking

For ranking the suppliers according to their performances in each criterion, experts were given another set of questionnaires to give their personal judgment against the qualitative criteria. C_1, C_4, C_5, C_6, C_7 and C_8 are the qualitative criteria here whereas C_2 and C_3 are the quantitative criteria. Each expert was asked to give the suppliers a numeric point on a scale of 1-10 (1 being extremely poor, 10 being extremely good, and the rest in between) based on their experience over working with the suppliers on previous occasions. Then the points obtained from the 5 experts on a single criterion were summed up and considered as obtained scores in that criterion out of 50. After obtaining quotations from vendors and conducting a commercial negotiation with them, the objective criteria values were determined. Seven out of eleven providers were shortlisted after a brief technical and commercial observation and are being considered in this study based on their potential, and they will be referred to as SP_n henceforth.

Individual suppliers' total scores in all criteria are presented as raw data in Table 6, which is used for TOPSIS calculation.

Table 6: Raw data of suppliers

Supplier	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
SP_1	34	18300	60	29	31	31	30	28
SP_2	37	17500	60	35	31	38	32	33
SP_3	31	16700	105	33	36	34	26	29
SP_4	46	20500	90	40	43	44	44	41
SP_5	33	17000	60	35	37	32	30	32
SP_6	45	22000	120	39	44	41	41	43
SP_7	28	16500	45	25	28	29	21	26

The data was normalized (Table 7) and then the ideal best values, V_j^+ and ideal worst values, V_j^- are obtained (Table 8). Here, C_1, C_4, C_5, C_6, C_7, and C_8 are all beneficial criteria (the higher the value, the better) whereas C_2 and C_3 are non-beneficial criteria (lower value better). By following the TOPSIS method, performance score, P_i for each supplier was identified (Table 9) and according to their performance scores, all the seven suppliers are ranked.

Table 7: Normalized decision matrix

Supplier	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
SP_1	0.4616	0.5011	0.4558	0.4427	0.4593	0.4306	0.4574	0.4305
SP_2	0.5023	0.4792	0.4558	0.5343	0.4593	0.5279	0.4879	0.5074
SP_3	0.4209	0.4573	0.7977	0.5038	0.5334	0.4723	0.3965	0.4459
SP_4	0.6245	0.5614	0.6838	0.6106	0.6371	0.6112	0.6709	0.6304
SP_5	0.448	0.4655	0.4558	0.5343	0.5482	0.4445	0.4574	0.492
SP_6	0.611	0.6024	0.9117	0.5954	0.6519	0.5696	0.6252	0.6611
SP_7	0.3802	0.4518	0.3419	0.3816	0.4149	0.4029	0.3202	0.3998

Table 8: Calculation of ideal values

Supplier	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
SP_1	0.0946	0.1235	0.0563	0.0311	0.0315	0.0754	0.0303	0.0193
SP_2	0.1029	0.1181	0.0563	0.0375	0.0315	0.0925	0.0323	0.0228
SP_3	0.0862	0.1127	0.0985	0.0354	0.0366	0.0827	0.0263	0.02
SP_4	0.1279	0.1383	0.0845	0.0429	0.0437	0.1071	0.0445	0.0283
SP_5	0.0918	0.1147	0.0563	0.0375	0.0376	0.0779	0.0303	0.0221
SP_6	0.1252	0.1484	0.1126	0.0418	0.0447	0.0998	0.0414	0.0297
SP_7	0.0779	0.1113	0.0422	0.0268	0.0285	0.0706	0.0212	0.018
V_j^+	0.1279	0.1113	0.0422	0.0429	0.0447	0.1071	0.0445	0.0297
V_j^-	0.0779	0.1484	0.1126	0.0268	0.0285	0.0706	0.0212	0.018

Table 9: Final ranking of suppliers

Supplier	S_i^+	S_i^-	P_i	Rank
Supplier 1	0.0555	0.0648	0.5387	4
Supplier 2	0.0385	0.0739	0.6575	1
Supplier 3	0.0778	0.0431	0.3565	7
Supplier 4	0.0502	0.0766	0.6041	2
Supplier 5	0.052	0.0696	0.5724	3
Supplier 6	0.08	0.0642	0.4452	6
Supplier 7	0.0709	0.0796	0.5289	5

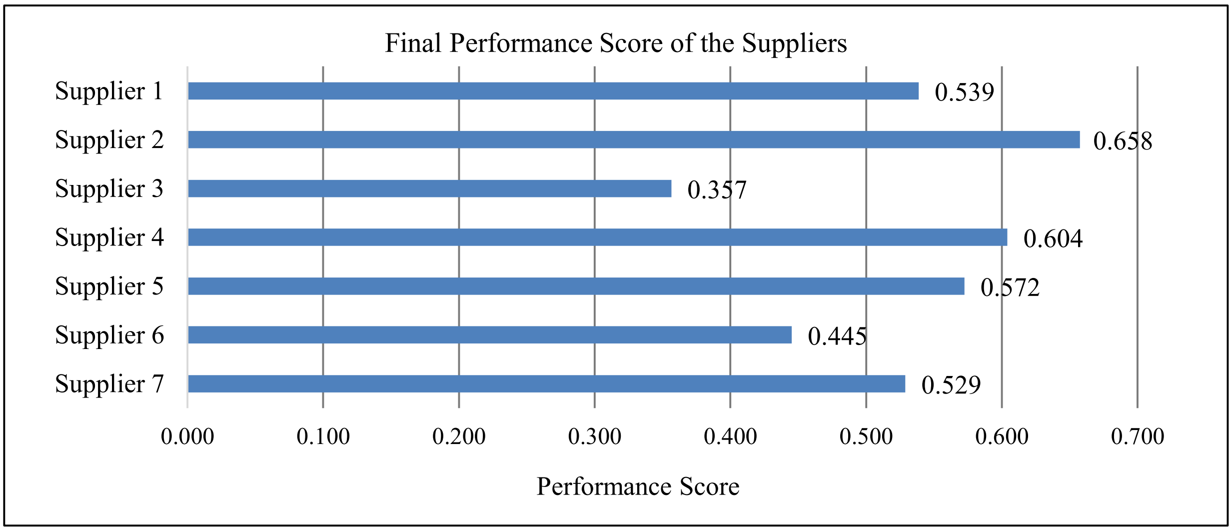

Figure 3: Final Performance Score of the suppliers

5. Results and discussion

In this article, eight criteria for supplier selection were assessed and weighted by the BWM method after gathering subjective importance information from five experts. Then, using TOPSIS, seven potential suppliers were evaluated based on how well they performed against these eight criteria. Finally, using these two MCDM methodologies, the suppliers were ranked to determine the best source for procuring a certain API for the pharmaceutical firm where the case study was conducted.

The criteria were initially selected after a careful assessment of the literature and consultation with specialists. The experts then expressed their opinions on the relative relevance of the various factors, with the majority of them deeming the pricing criteria to be the most important, whereas the continual improvement tendency and the suppliers' financial state to be the least important. Because the experts' choices differed, their subjective assessments differed greatly, resulting in five different weights for each criterion. As a result, the values generated by BWM were averaged to produce the final weights of the criteria. Pricing received the most weight in this computation, followed by quality and process control, customer service, delivery, and so on. It's worth noting that pricing, quality and process control, and customer service together accounted for over 62 percent of the total weight, indicating that they had a significant impact on the final supplier ranking.

Moreover, the data for the suppliers came from expert opinions and supplier quotations, which were used as the acquired scores in all criteria. The TOPSIS approach was used to determine the performance score of all providers, which resulted in the final ranking. Among the suppliers, supplier-04 and supplier-06 have the highest scores in all beneficial criteria. But they have relatively lower scores on non-beneficial criteria. Higher pricing and longer delivery times made them fall behind supplier-02, who had above-average and standard scores in all criteria. Furthermore, though most of the suppliers have good scores on pricing and delivery criteria, their overall performance can't surpass that of Supplier 2 due to their lower performances in the above-mentioned three highest weighted criteria (pricing, quality and process control, and customer service). Thus, the final ranking suggests supplier-02 should be chosen to achieve the best outcomes from the vendors.

Many research studies, for instance, Forghani et al., (2018), Emec et al., (2019), Ganguly et al., (2019), Goh et al., (2020), and Forghani et al., (2022) have also identified price, quality, and customer service as critical factors for supplier selection in the pharmaceutical industry.

5. Conclusion

One of the most determining actions that firms must incorporate into their fundamental strategic decisions is supplier evaluation and selection. The performance of manufacturing enterprises' supply chain is directly influenced by supplier evaluation and selection. As a result, industrial companies must evaluate, choose, and manage these suppliers quickly to maximize the supply chain's surplus. This is especially essential for a Bangladesh-based pharmaceutical company that relies heavily on international suppliers. The study addressed the problem of procuring compounds from overseas suppliers and developed a new selection model based on the BWM and TOPSIS methods to resolve the pharmaceutical industry's supplier selection dilemma. When it comes to supplier selection, supply chain managers can certainly benefit from using this tactical approach. In this research, the most 8 criteria for supplier selection in the pharmaceuticals industry were identified. A case company were selected then for the data collection, based on which, 7 suppliers were evaluated. Pricing, Quality and Process Control and Customer Service were obtained as the three most important criteria for pharmaceutical supplier selection from BWM method. At last, the suppliers were ranked by their cumulative performance on all criteria by TOPSIS calculation. The significance of the article is that it presents a very simple, yet robust solution to the managers for supplier selection problem that can also be adopted in different industries as well.

However, the study presents several relevant points that may warrant further research. The model can also be used in other industries such as automobiles, electronics, RMG, furniture, cement, and chemicals. But, the criteria for selecting potential suppliers will differ depending on the type of company and its preferences. Nevertheless, fuzzy can be integrated with TOPSIS to increase the model's accuracy. Finally, all criteria for selecting suppliers should be reviewed and reevaluated on a recurring basis. It will assist the firm in adapting to dynamic markets and moving toward more sustainable sourcing.

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Appendix

Appendix - 1: Questionnaire for BWM

From the following table, please indicate which one is the most important and the least important criterion for supplier selection in the pharmaceuticals industry

Notation	Criteria	Select the best criterion	Select the worst criterion
C_1	Quality and Process Control		
C_2	Pricing		
C_3	Delivery		
C_4	Inventory		
C_5	Facility Environment		
C_6	Customer Service		
C_7	Continuous Improvement		
C_8	Financial Condition		

According to the best criterion you selected, please mark all the other criteria based on a scale of 1-9 (1 being equally important, 9 being the absolutely least important, and the rest in between)

Notation	Criteria	Marking on a scale of (1-9)
C_1	Quality and Process Control	
C_2	Pricing	
C_3	Delivery	
C_4	Inventory	
C_5	Facility Environment	
C_6	Customer Service	
C_7	Continuous Improvement	
C_8	Financial Condition	

According to the worst criterion you selected, please mark all the other criteria based on a scale of 1-9 (1 being equally important, 9 being the absolutely most important, and the rest in between)

Notation	Criteria	Marking on a scale of (1-9)
C_1	Quality and Process Control	
C_2	Pricing	
C_3	Delivery	
C_4	Inventory	
C_5	Facility Environment	
C_6	Customer Service	
C_7	Continuous Improvement	
C_8	Financial Condition	

Appendix - 2: Questionnaire for TOPSIS

Please mark the suppliers on their previous performances on the following criteria on a scale of 1-10 (1 being very poor, 10 being absolutely great, and the rest in between)

	Quality and Process Control	Inventory	Facility Environment	Customer Service	Continuous Improvement	Financial Condition
Supplier-01						
Supplier-02						
Supplier-03						
Supplier-04						
Supplier-05						
Supplier-06						
Supplier-07						