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Integrating AHP and TOPSIS for Evidence-Based Supplier Evaluation in the Pharmaceutical Industry

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Abstract

ACI Pharma typically spends between \$12 and \$15 million annually on brand marketing activities, with portions of that funding used to create printed promotional materials that clearly convey scientific knowledge to relevant stakeholders and medical expert audiences. Previous iterations of supporting evidence among promotions find that these limitations significantly undermine marketing initiatives overall from effectiveness and efficiency perspectives due to a subjective evaluation of suppliers. Given that the lack of real evaluation and integration of operations has contributed to an undermined competitive performance, this study tackles these issues through the integration of the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) as a hybrid multi-criteria decision-making (MCDM) method for developing an evidence-driven supplier evaluation methodology specifically for advanced chemical industries (ACI) Pharma. The proposed AHP-TOPSIS methodology enables a transparent, consistent supplier assessment, based on multiple performance criteria, including communications, flexibility, price, quality, and delivery. The results show that supplier S2 consistently had the highest closeness coefficient (CC) or performance score, and this ranking is validated by sensitivity analysis to be stable when criterion weights vary $\pm 10\%$. Overall, ACI Pharma now has a consistent, practical, and objective way to select the best vendors for printed promotional materials, while also enhancing competitiveness and efficiency with procurement.

Keywords: Supplier Selection; AHP; TOPSIS; Supply Chain Management; MCDM; Decision Making; Multi-criteria Analysis.

1 | Introduction

In a business-to-business (B2B) environment, both organizations and their overall performance have a significant impact on strong, reliable relationships. Due to the rapid growth of economies and industries around the world, studies on internal and external processes in various business types have received a lot of attention lately. Therefore, there are a lot more options and methods available to us now for monitoring and controlling the supply chain (SC) and associated activities [1]. More than half of the overall cost of construction projects is due to material-related activities, which also significantly impact the project timeline. To optimize customer value and establish a sustainable competitive advantage, Supply Chain Management (SCM) requires a sophisticated approach. Furthermore, the significance of purchasing decisions grows in parallel with the implications of the purchase function. Since businesses have gradually become increasingly dependent on suppliers to deliver services and supply products that were previously provided in-house so that they can specialize and focus on their expertise, the supplier selection process is essential for purchasing



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activities [2]. Furthermore, businesses frequently misunderstand the supplier selection issue as a one-criterion decision-making problem, taking only cost considerations into account when making decisions, despite the fact that the selection process significantly lowers costs, increases profits, and enhances product quality. The business environment has evolved recently, and competitiveness is now influenced by many more factors than just an organization's internal operations. Therefore, it is essential to give particular consideration to important choices that might boost a business's performance, such as how to choose suppliers, as a good supplier selection will improve organizational performance [3]. However, the subjectivity of expert opinions and the possible inconsistency of paired preferences make supplier selection still difficult. In real life, decision-makers deal with ambiguous and insufficient performance data, and it can be challenging to assign accurate weights to diverse variables. Latent interdependencies across criteria can affect the result if they are not explicitly represented, and the computing load rises with the number of alternatives and criteria. Hybrid MCDM techniques, like combining TOPSIS for robust ranking with AHP to create consistent criteria weights, are being used more and more to overcome these problems.

1.1 | Supplier Selection in SCM

In the subject of SCM, selecting a supplier is essential since it has a big impact on an organization's operations, efficacy, and success. Selecting suppliers is a crucial step in making sure that goods, services, and materials go through the SC smoothly. A thorough evaluation of numerous elements, each of which has the potential to have a major influence on the SC, is part of a well-planned supplier selection strategy. When choosing a supplier, evaluating the supplier's skills and dependability is one of the most important factors. The ability of a possible supplier to fulfill their production and delivery needs must be assessed by the organization. This includes evaluating the lead times, capacity utilization, and production capabilities of the provider. A trusted supplier should be able to regularly deliver the necessary amounts of superior products or services on schedule. Inadequate performance in this area may lead to SC interruptions, longer lead times, and possible damage to client relationships [4],[5]. Another important consideration when choosing a supplier is the quality. Producing consistent and dependable final products requires ensuring the quality of incoming materials or products [6]. Businesses need to evaluate a supplier's qualifications, quality control procedures, and performance history. Problems with quality can result in faulty goods, more rework or scrap, and dissatisfied customers, all of which directly affect the SC's efficacy and efficiency. When choosing a supplier, cost is also a crucial factor. While choosing a supplier who can provide high-quality products on schedule is important, businesses also need to consider the financial implications. The profitability of a business is directly impacted by the price of goods and services from suppliers [7]. Also, geographic factors are also taken into account when choosing a supplier. Lead times, transportation costs, and the general effectiveness of the SC can all be impacted by the location of suppliers. When it comes to transportation costs and lead times, being close to suppliers can be beneficial, particularly for consumable or time-sensitive products [8]. Global SCs, on the other hand, frequently depend on suppliers from other geographical areas, which might add complexity but could be required to obtain particular resources or benefit from price differentials in other markets. Although they are often ignored, supplier connections and compatibility are quite important when choosing a supplier. Collaboration, creativity, and responsiveness can result from effective communication, shared values, and a mutually beneficial connection. Choosing a supplier is only one aspect of it; another is establishing a collaboration that promotes dependability and confidence. Strong supplier relationships can result in cooperative problem-solving, collaborative risk management, and the creation of new goods or procedures that are profitable to both sides. The primary decision-making steps in the supplier selection process are highlighted in Figure 1, which provides an organized summary of the whole process.

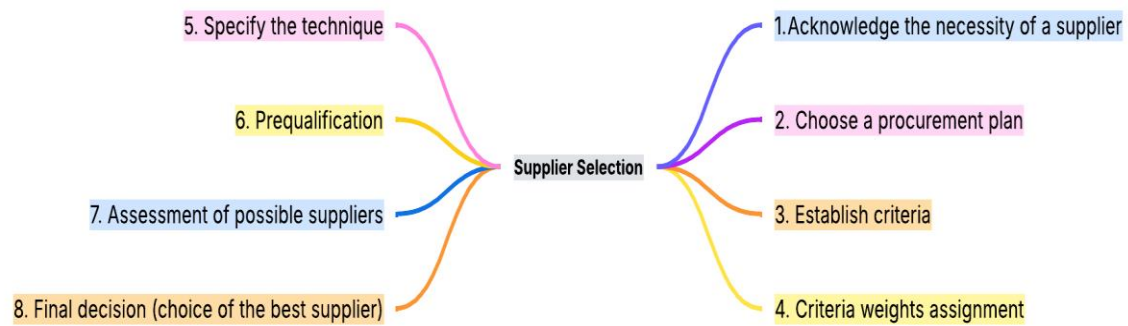


Figure 1. Supplier selection steps.

1.2 | Role of MCDM in Supplier Evaluation

As a strategic decision, supplier selection impacts the overall competitiveness, cost structure, and efficiency of SCs. Decision making in supplier selection is often poorly supported due to the inherent complexity of the decision-making process, which involves several sometimes conflicting a priori criteria (e.g., total cost, quality, delivery, reliability, sustainability). Consequently, MCDM processes have emerged as powerful methods to structure and objectively evaluate and select suppliers [9]. Decision makers can systematically analyze complex supplier selection problems through the mechanics of MCDM techniques, which both define the relevant criteria and provide relative levels of importance (weights) for a ranking of alternatives. MCDM techniques can help ease difficult trade-offs in the assessment of qualitative and quantitative measures. There has been widespread use of AHP, TOPSIS and hybrid models in both academic research and commercial applications in order to improve supplier selection performance. Through their integration of MCDM methodologies into their organizations, organizations can make consistent data driven decisions that can support strategic procurement objectives and sustainability standards. Additionally, MCDM technologies promote collaborative decisions through gathering feedback from multiple stakeholders into the evaluation process, which promotes transparency and acceptance of the chosen decision [10]. The main methods of MCDM techniques are depicted in Figure 2. MADM and Multi-Objective Decision Making (MODM) are the two primary categories into which these techniques are typically divided. Whereas MODM approaches are used in issues with infinite or huge decision spaces, which are frequently resolved through the use of mathematical programming or evolutionary algorithms, MADM approaches such as AHP, TOPSIS, and PROMETHEE are frequently employed when decision options are finite and known.



Figure 2. Main methods of MCDM.

The goal of this research is to assist the management of ACI Pharma in determining the ideal supplier for printing materials, by offering an objective purchasing policy that is combined with supplier management techniques. The study outlines a framework that attempts to remedy the negative consequences of subjective supplier selection approaches that impeded success in promotional efforts, as well as market share. Furthermore, the study provides a generalized model that can be used by other organizations which are struggling with the evaluation of suppliers and the procurement decision-making process. The approach taken to achieve and validate this goal uses a hybrid MCDM approach which incorporates the AHP and the TOPSIS. In the hybrid methodology, AHP is used to ascertain the relative importance (weights) given by experts on the evaluation criteria, and TOPSIS is used to rank the alternative suppliers based on how closely they are related to the ideal solution. The implementation of this combination supports an organized, transparent and reliable selection process for suppliers and procurement strategy.

2 | Literature Review

Choosing the right suppliers is critical for the well-functioning of SCs, particularly given the complex and highly regulated business world today. Supplier selection is a multifaceted problem that must balance consideration in regard to cost, quality, delivery, sustainability, and risk in regulated industries, such as pharmaceuticals. Due to the complex nature of this decision making process, Multi-Criteria Decision-Making (MCDM) techniques that provide structured and transparent process for evaluating supplier alternatives, are gaining popularity [11]. TOPSIS and the AHP are two of the most popular MCDM methods. While AHP helps decision-makers to integrate expert opinions by decomposing the decision problem into a hierarchy of sub-problems and establishing reasonable weights of criteria based on pairwise comparisons, TOPSIS is an ideal method for capturing trade-offs across multiple dimensions, ranking options based on their distance from the negative-ideal solution and their proximity to the ideal solution. Numerous industries have used the methodology combination of AHP and TOPSIS, which is often seen as a strong hybrid model that merges

accurate weighting (AHP) with reliable ranking (TOPSIS) [12]. The AHP-TOPSIS approach has been proven effective in various practical studies. For instance, a fuzzy AHP-TOPSIS framework was developed using key performance indicators (KPIs) to assist with supplier evaluation in the post-COVID-19 environment [13]. Also, the same combined approach was utilized to select sustainable suppliers in the electronics sector, integrating economic, social, and environmental sub-criteria and showing how factors like pollution control and human rights impacted final rankings. AHP and TOPSIS have been used with SCOR performance indicators in the oil and gas industry to evaluate suppliers based on operation and sustainability criteria [14]. Despite the growing literature on hybrid MCDM models, their use in the pharmaceutical industry has remained relatively minimal. Much of the previous work has either focused on fuzzy variants of AHP and TOPSIS in hospital pharmacy settings [15] or the use of fuzzy TOPSIS and DEMATEL methodologies to examine barriers to green SC adoption [16,17]. Despite identifying fuzzy AHP frameworks for Indian pharmaceutical companies to apply in supplier selection [18], the comprehensive AHP-TOPSIS combination still has few substantive examples of implementation. While AHP-TOPSIS has been featured in numerous studies on supplier evaluations, there are only a handful of studies that focus on the selection of printing material suppliers in the pharmaceutical industry, even though these suppliers are critical to regulatory compliance and branding. Most studies that examine supplier evaluation tend to focus on logistics providers or raw materials and not on procurement related to marketing. In addition, most of the models considered in earlier studies only included quantitative measures or expert judgement into a structured decision-making process. This gap in the literature is the basis for this study, which employs a hybrid AHP-TOPSIS approach to evaluate and select printing material suppliers for the ACI Limited which is a Bangladesh-based multinational company operating 42 businesses worldwide. The decision on reliable printing suppliers is even more important as printed promotional materials are an integral part of the business's marketing efforts and branding initiatives attract significant annual budgets. This proposed model uses both expert judgement and quantitative performance data to create a valuable and structured decision-support tool that meets the strict quality, compliance, and operational requirements of the pharmacy industry.

3 | Methodology

3.1 | AHP Method and Structure

The AHP, created by Saaty, is a powerful MCDM tool that has been applied in many different domains in engineering, politics, and economics [19]. AHP compares the importance of the criteria to the goal pairwise. This pairwise comparison allows us to find the relative importance of the criteria, in relation to the goal, since relative importance varies from the goal. Whenever quantitative information is available, comparisons can be conducted conveniently using a ratio or established scale, and this will lead to perfect judgment since the inconsistent judgement will be zero [20]. Qualitative assessment can be employed for a pairwise comparison when quantitative data is not available. This qualitative pairwise comparison is referenceable to the Saaty importance scale as illustrated in Table 1. The relative importance of the alternatives based on each criterion can be evaluated using the same pairwise comparison approach.

Table 1. Saaty importance scale of factors.

Importance Level	Importance Level Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, and 8	The importance in between two neighboring judgments

The hierarchical structure of AHP, which involves breaking down a decision problem into multiple layers, is illustrated in figure 3. At the top, there is the general objective (e.g., choosing the best supplier), then the selection criteria (e.g., price, quality, delivery performance, etc.), and finally at the bottom are the alternatives (the suppliers). This step-wise, structured comparison of criteria and alternatives provides a more rational and transparent decision-making process.

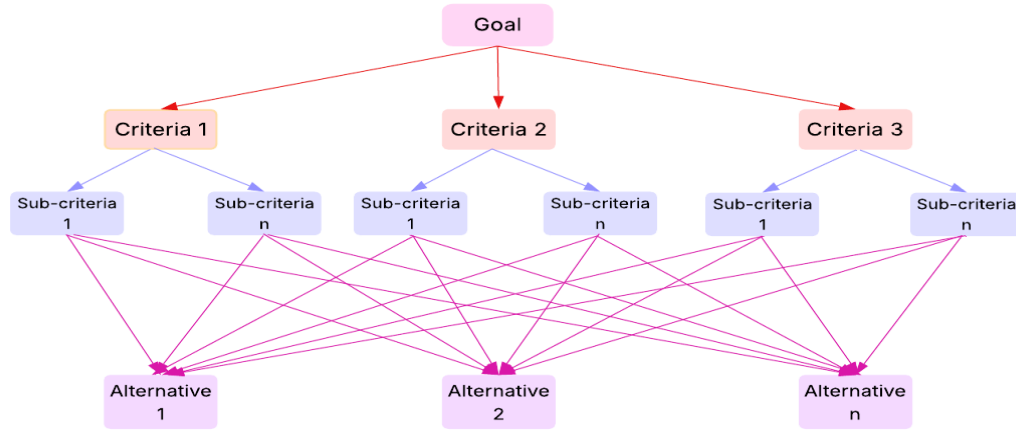


Figure 3. Analytical Hierarchy Process (AHP).

The first step is to define the evaluated criteria. In order to retrieve the criteria priority value (CPV), a pairwise comparison matrix A of size $n \times n$ is formed, where n is the number of criteria and element of the matrix a_{ij} . Saaty importance scale will be used. The scores present importance of each alternative. The pairwise comparison should be carefully performed, using very small or very large preference indicative scale.

$$A = \begin{pmatrix} a_{11} & \dots & a_{1j} \\ \vdots & \ddots & \vdots \\ a_{i1} & \dots & a_{ij} \end{pmatrix}$$

Where $a_{ij} = 1$ for all $i = j$

To determine the numerical weights ($W_1, W_2, \dots, W_3$) of the options, the second step is computing the priority vector of criteria, where $\sum_{i=1}^n W_i = 1$.

Observe that if $A \times W = n \times W$, then A is consistent. We consider this equation to be an Eigenvalue problem. According to Saaty, it is fair to assume that the greatest Eigenvalue is larger than or equal to n ($\lambda_{\max} \geq n$). The more consistent A is, the closer $\lambda_{\max}$ is to n . The total of the items in the column vector AW is equal to $\lambda_{\max}$. AHP determines the consistency ratio (CR) as:

$$CR = \frac{\text{Consistency index (CI)}}{\text{Random consistency of A (RI)}}$$

Where

$$CI = (\lambda_{\max} - n) / (n - 1)$$

Table 2 provides the random index (RI) value for criteria 1 through 10 [21] and

$$RI = 1.98(n - 2) / n$$

Table 2. The RI value for attributes from 1 to 10.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

A level of inconsistency is considered acceptable if CR is less than 0.10. Otherwise, the judgment on the values of aij must be revised by the decision maker.

With the hierarchical criteria/alternatives containing complicated issues, AHP allows the decision makers to make them easier to understand and compare. It also provides a rational approach for pairwise comparisons of criteria and alternatives, ensuring transparency and minimizing biases. AHP includes both qualitative and quantitative elements which allows the alternatives to be more thoroughly evaluated. On the other hand, the decision problem may be simplified if AHP does not fully represent the dependencies and interactions among the criteria. Calculating the AHP weights may take some time and effort to acquire proper and legitimate results [22].

3.2 | TOPSIS Method Overview

The basic idea behind TOPSIS is that the optimal solution is the one that is the closest to the positive-ideal solution (PIS) and the furthest from the negative-ideal one (NIS). An overall index that is determined by the distances from the ideal solutions is used to rate the alternatives [23], [24]. Although the negative ideal solution is simply the opposite of the prior one, the objective of the PIS is to maximize the profit criterion and to minimize the cost criteria. The NIS is comprised of all of the worst possible values for the criteria, while the PIS is comprised of all of the good possible values for the criteria. The TOPSIS method generates a decision matrix and a normalized decision matrix by using the actual scores which is recorded for the alternatives by the criteria. Both PIS and NISs are calculated based on the ratings of each criterion. The preferred order of the alternatives can be established by assessing their distance coefficients [25]. The following is a summary of the TOPSIS method's steps.

Step 1: Decision matrix creation.

Consider $A = [aij]$ is the initial decision matrix where:

aij is the alternative X_i performance value according to C_j criteria,

i denotes the alternatives number from 1 to m , and

j denotes the criteria number from 1 to n .

Step 2: Decision matrix normalization.

The aim is to eliminate biases resulting from different units or different scales of measurement across criteria to permit fair comparisons of all alternatives. At this step, the original decision matrix is transformed using vector normalization, resulting in a dimensionless matrix. Each element is divided by the square root of the sum of the squares of all values for that criterion. The normalized value rij can be calculated as:

$$rij = \frac{aij}{\sqrt{\sum_{i=1}^m aij^2}}$$

The normalized matrix $R = [rij]$ is the result of this step.

Step 3: Weighted normalized decision matrix construction.

The weights assigned to each criterion w_j are then multiplied by the normalized matrix as follows:

$$vij = w_j * rij$$

Where $\sum_{j=1}^n w_j = 1$, and

vij denoted the weighted normalized value of alternative i under criterion j .

The weighted normalized matrix $V = [vij]$ is the result of this step.

Step 4: Identify the ideal solutions, both positive X^+ and X^- negative.

Step 5: Calculate measures of separation.

The Euclidean distance of each alternative from the PIS (S_i^+) and from the NIS (S_i^-) can be computed as:

$$S_i^+ = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^+)^2}$$

$$S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2}$$

Step 6: The relative closeness to the ideal solution computations.

$$Ci = \frac{S_i^-}{S_i^+ + S_i^-}$$

Where Ci is the relative closeness of each alternative and $0 \leq Ci \leq 1$.

An alternative that is closer to the perfect solution is indicated by a higher Ci rating.

Step 7: Rank all alternatives.

Based on the values of Ci , the choices are arranged in decreasing order, with the best option being indicated by the highest Ci .

TOPSIS is a straightforward and user-friendly method for analysis of options conceptually based on their relative proximity to the best and furthest from the worst solution. It represents a clear and simple ranking of alternatives that is easy to communicate and make decisions; it also allows for positive and negative assessment of criteria, leading to tradeoffs and conflicting objectives. Furthermore, given that TOPSIS assumes a linear relationship between criteria, it risks failure to recognize complex interactions or non-linear relationships. Due to its reliance on selecting the best and worst solutions to rank its outcomes, the ranking can be overtly influenced and subjectively interpreted. Additionally, its use in circumstances involving uncertain or ambiguous information is highly limited, as it ignores vagueness or uncertainty in the available decision information.

3.3 | Suggested AHP-TOPSIS Framework

The comprehensive process of the proposed integrated AHP-TOPSIS decision-making framework for evaluating and ranking potential printing material suppliers for ACI Pharma is shown in Figure 4. This hybrid approach benefits from the strengths of both methods: TOPSIS provides a relatively simple means of ranking alternatives based on their relative distance from both the ideal best and anti-ideal worst solutions, while AHP provides a way to structure the decision problem and determine the weighted importance of evaluation criteria based on expert input. The method begins with specifying a hierarchical model that provides detailed descriptions of the evaluation criteria, alternative suppliers, and decision objective. Domain experts use the AHP method to comparatively determine the pairwise comparisons of the criteria according to the relative importance of the criteria. Using those comparisons, normalized weights which provide an indication of the relative importance of each dimension, are determined. A CR can be calculated to help verify the reliability of expert judgments, we ensure the matrix makes sense (i.e., $CR < 0.1$). Once consistency is achieved, the calculated weights can be factored into the TOPSIS analysis. The TOPSIS phase begins with the construction of a decision matrix that identifies and captures the performance of each supplier in terms of the selected criteria. The decision matrix has been standardized to begin with, in order to reduce the effect of differing measurement units, across criterion. A weighted normalized decision matrix is then constructed by multiplying the normalized value by the weights determined through the AHP. The PIS and NIS represent the highest and worst potential performance values. After the distance of each supplier to the PIS and NIS is

calculated, a proximity index has been generated that indicates how close an alternative is from the ideal solution. In order to help decision-makers find the best printing material provider, suppliers are finally placed in descending order based on CCs. As seen graphically in the figure, this integrated AHP-TOPSIS structure guarantees that both objective performance statistics and subjective expert knowledge are carefully taken into consideration. The end result is a transparent, dependable, and consistent decision-making process that is in line with the stringent operational and compliance requirements of the pharmaceutical industry as well as ACI Pharma's strategic priorities.

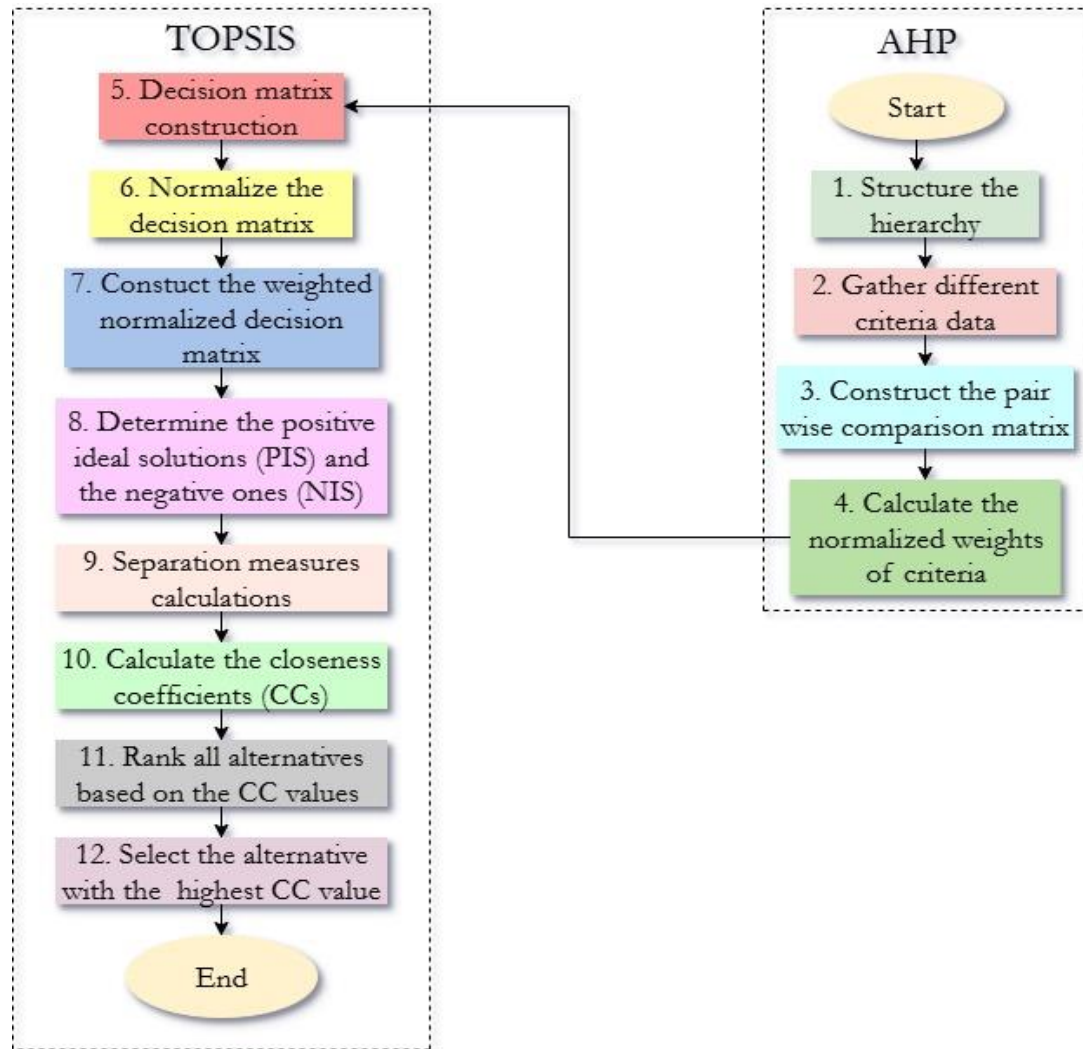


Figure 4. Proposed AHP-TOPSIS framework for supplier evaluation at ACI pharma.

4 | Case Study

4.1 | Problem Definition

Bangladesh's pharmaceuticals sector plays a vital role for shareholders on the national economic development and global health security role when they export pharmaceutical products to more than 100 countries [26]. One of the main contributors to this sector is ACI Limited - a multinational set across the world with 42 business units and headquartered in Bangladesh. ACI has been in business for over 25 years in Bangladesh and one of the major business units, ACI Pharma exports its products to 30 countries on four continents and assists in global health programs by providing quality and innovative medicines [27]. ACI Pharma is considered one of the largest pharmaceutical companies in Bangladesh with a market share of around 3% to 4% in the local market [28], [29]. Prescriptions direct what people purchase, and physicians are the primary

drivers of consumer behavior in the highly competitive pharmaceutical industry. Consequently, to engage physicians, pharmaceutical companies in Bangladesh primarily utilize promotional strategies like samples of medicine, free gifts, and in particular, print products [30]. Potential print products are showcards, call cards, drop cards, spiral pads, calendars, posters, banners, and scientific publications. The mentioned print products also play an essential role in conveying complete information about how to use drugs.

The SC department of ACI Pharma that is currently working with 25 partners is responsible for procuring these promotional items. In procurement as a component of a SC, it plays a central role to marketing performance and administrative efficiency [31]. Good relationships with suppliers are important in providing procurement processes that are timely and of acceptable quality. Purchased products can be classified by taxonomy methods as routine, leverage, bottleneck, or critical based on inspired motivations such as strategic importance, volume of purchase, supply risk, and availability [32]. For leverage products that have a lower level of supply risk and higher strategic importance, supplier selection and negotiation remain critical to accomplishing organizational efficiency and value from procured items.

ACI Pharma's existing supplier selection process is largely subjective, regardless of the importance of printed promotional materials. It has resulted from suppliers making attempts to take profits once contracts have been signed. This leads to a high frequency of breaches against contractual obligations related to pricing, delivery, and quality. Even with ACI Pharma spending \$12-\$15 million a year on branding, it experienced a disruption in promotional activities, causing a loss of market share and significant amounts of money. Management has come to the realization that selecting a supplier requires an objective and systematic process of decision-making. Unfortunately, implementing such a process is difficult due to the complexity and number of dimensions, both quantitative and qualitative [1].

This study proposes a structured hybrid MCDM model consisting of the TOPSIS and the AHP to address this problem. This hybrid model provides a systematic and transparent evaluation of potential suppliers using various performance criteria. TOPSIS derives supplier options' relative closeness to an ideal solution, and AHP informs the development of the relative weights for assessment criteria.

The data that the study relied upon was taken from ACI Pharma. The study established five criteria for the supplier selection dilemma: price, quality, delivery, flexibility, and communication. These criteria were developed through two hours of a focus group discussion (FGD) with eight key decision-makers from the organization, and through a comprehensive review of existing literature. The participants were the Head of SCM, Director of Marketing Operations, Manager of Chain Management, Manager of Procurement, Marketing Manager, and senior management from the Quality Control, Quotation Raising, and Logistics and Planning departments. Four of the five supplier selection criteria mentioned above are qualitative and are measured using a 5-point Likert scale. The cost is quantitative in nature and is measured in terms of the local currency, TAKA.

According to Table 3, the values represent how relative an attribute is to another attribute based on the five attributes selected and the scaling method. The relative significance level for the attributes has chosen from the literature review and follow-up focus group discussion that consisted of head of SCM, director of marketing operations, SCM manager, procurement manager, and marketing manager. They participated in a two hour focus group discussion.

Table 3. Five selected criteria pair-wise comparison values.

Criteria	Cost (C1)	Quality (C2)	Delivery(C3)	Flexibility(C4)	Communication(C5)
Cost (C1)	1	0.143	0.200	0.333	0.500
Quality (C2)	7	1	3	3	2
Delivery(C3)	5	0.333	1	4	4
Flexibility(C4)	3	0.333	0.250	1	2
Communication(C5)	2	0.500	0.250	0.500	1

Based on the table above, all diagonal elements must equal a value of 1 denoting that the attributes are of equal importance. The comparison of quality to quality is 1, delivery to delivery is 1, cost to cost is 1, etc... The values of the off-diagonal elements have to be less than or equal to one. Quality and cost ratio is $a_{21} = 7$, quality is very strongly important than cost, so cost and quality ratio is $a_{12} = 1/a_{21} = 1/7 = 0.143$. Also, delivery and cost ratio is $a_{31} = 5$, delivery is strongly important than cost, so cost and delivery ratio is $a_{13} = 1/a_{31} = 1/5 = 0.200$. The pairwise comparison criteria values' normalized weight vector w is

$$W = \begin{pmatrix} wa1 \\ wa2 \\ wa3 \\ wa4 \\ wa5 \end{pmatrix} = \begin{pmatrix} 0.049 \\ 0.420 \\ 0.300 \\ 0.129 \\ 0.102 \end{pmatrix}$$

Quality attribute has the highest rating value of 0.420 and delivery attribute rates at 0.300, followed by flexibility attribute rated at 0.129, communication attributes rating of 0.102, and the lowest cost rated 0.049. The calculation of the weighting is correct, shown by the total of the normalized weight vector is equal to 1.

Over the last six months, July to December 2022, ACI Pharma bought printing supplies from 25 suppliers. Anyway, 90.8% of materials were provided by the top 10 suppliers, and hence the research first examines 10 suppliers as options before selecting the best one. Table 4 shows ACI Pharma's top ten printing materials suppliers.

Table 4. ACI Pharma's top ten printing materials suppliers.

Name	Notation	Material Value Supplied (%)
Lutfur Enterprise	S1	17.1
Spark Printers	S2	16.8
Quality Printing & Packaging	S3	11.2
Rupa Printing & Packaging	S4	9.0
Marvelous Printers Ltd.	S5	8.3
Abir Enterprise	S6	7.4
Graph Tech Printing and Packaging	S7	6.2
Siddique Printers	S8	6.1
Intimacy Printers	S9	5.1
Dot Line Printers	S10	3.6

The 15 senior executives of ACI Pharma involved in obtaining quotes, communicating with suppliers, passing designs off to suppliers, verifying machine proof, and guaranteeing the delivery of materials, have uniformly and independently evaluated these 10 suppliers using a standardized rating tool. The four qualitative criteria of suppliers which are quality, delivery, flexibility, and communication are measured on the questionnaire using a 5-point Likert scale. The best quality for each qualitative aspect denotes they are the most satisfied. In the study mentioned here, the points were 5, 4, 3, 2 and 1 for the very good, good, medium, poor and very poor options, provided by the participants and the scaling format. Later, after the assessment was completed, the study established an average score for each supplier against each aspect of supply. Cost is another criterion, and in that case, the lower the number, the greater the pleasure. While the company offers multiple product lines, they print showcards more than all other materials combined 62.3%, books 19.5% are second, and pads 8.2% are only third. Also, all suppliers provide these three materials. The research took the average cost of the 1000 cards, 1000 pieces of literature, and 1000 pads as all suppliers provided to the company into the cost criterion. The suppliers' average score by attribute is shown in Table 5.

Table 5. Suppliers' average score by criteria.

Supplier	C1	C2	C3	C4	C5
S1	52422	3.800	3.600	3.400	3.533
S2	44673	3.867	3.867	3.733	4.067
S3	25460	3.000	3.000	3.133	3.267
S4	43811	3.133	3.000	3.000	3.000
S5	43789	3.733	3.733	3.400	3.800
S6	17926	3.467	3.267	3.067	2.933
S7	36927	3.533	3.333	3.333	3.467
S8	24702	2.733	2.800	2.600	2.667
S9	37749	3.533	3.000	3.000	3.333
S10	22975	3.400	3.000	3.000	3.333

5 | Results and Discussion

The AHP-TOPSIS hybrid MCDM methodology was developed and implemented using the Python programming language to address the supplier selection problem at the ACI Pharma. The implementation was accomplished in a cloud computing platform called Google Colab, which is an interactive platform that lets the Python code executed in real-time. Google Colab was selected as it is an optimal platform for academic and operational research due to its ease of use, flexibility and extensive willingness to provide support for scientific computation.

To determine the relative weight of the SC supplier assessment criteria, the AHP was applied. These criteria were developed following analysis of literature and a FGD with eight key decision-makers from ACI Pharma include marketing managers, SC personnel, and procurement managers. The criteria weights were calculated using pairwise comparisons and the reliability of the expert opinions was verified by consistency checks. After weights were established, the shortlist of suppliers was evaluated and ranked using the TOPSIS method. We first normalized the decision matrix. Then we created a weighted normalized decision matrix using the weights established through the AHP process. This allowed us to find the supplier closest to the ideal solution, and farthest from the negative-ideal solution, based on the well-defined performance criteria. Python scripts were created to fully automate the entire process from data input and criteria weighting to supplier ranking. The methodology provided a data-driven, transparent, and repeatable supplier evaluation process. The results of this methodology will be presented later, including: a full ranking of the suppliers, individual performance rating, a normalized decision matrix, and the calculated criteria weightings.

This systematic methodology provides ACI Pharma with a formalized basis for a transparent supplier evaluation process and transparency into optimal sourcing decisions. Ten suppliers from S1 to S10 are compared according to five criteria: price, quality, delivery, flexibility, and communication. The raw data values were normalized on a scale from 0 to 1, thus allowing for raw data comparisons across the range of criteria. This normalizing process allows for an unbiased evaluation of supplier performance, without the impact of disparate units and scales. The normalized matrix $\hat{A}$ is found by the study as follows after normalization:

$$\hat{A} = \begin{pmatrix} 0.177648 & 0.349584 & 0.347261 & 0.338068 & 0.332226 \\ 0.208463 & 0.355748 & 0.373017 & 0.371179 & 0.382440 \\ 0.365777 & 0.275987 & 0.289385 & 0.311520 & 0.307212 \\ 0.212565 & 0.288223 & 0.289385 & 0.298295 & 0.282105 \\ 0.212672 & 0.343420 & 0.360091 & 0.338068 & 0.357333 \\ 0.519507 & 0.318949 & 0.315140 & 0.304957 & 0.275805 \\ 0.252192 & 0.325021 & 0.321506 & 0.331406 & 0.326019 \\ 0.377001 & 0.251425 & 0.270092 & 0.258522 & 0.250791 \\ 0.246700 & 0.325021 & 0.289385 & 0.298295 & 0.313419 \\ 0.405340 & 0.312786 & 0.289385 & 0.298295 & 0.313419 \end{pmatrix}$$

Large variability among suppliers have been displayed with matrix analysis. For example, supplier S6 is notable for this criterion, while it has the highest normalized score for the cost criterion C1 (0.5195). Again, this may mean that S6 has the highest cost or the highest cost efficiency, depending on the role of cost as a benefit or cost criterion. This should be considered in the context of the study. But overall, Supplier S2 appears to be a solid candidate because of its strong performance across several factors (Quality = 0.3557, Delivery = 0.3730, Flexibility = 0.3712, Communication = 0.3824) and balanced performance across them. In contrast, Supplier S8's performance scores on Quality (0.2514) and Communication (0.2508) are relatively poor which might be an area of weakness that would affect its suitability.

A key step in the proposed AHP-TOPSIS hybrid technique is constructing the normalized weighted decision matrix, which will now evolve from this normalized decision matrix. According to the experts' opinions, AHP was used first to determine the relative importance of the five assessment criteria. The normalized weighted decision matrix will be developed by multiplying these weights by the associated values in the normalized decision matrix. The weighted normalized decision matrix is as seen in Figure 5. This matrix grants a separate account of both the relative importance of each criterion and the performance of each supplier.

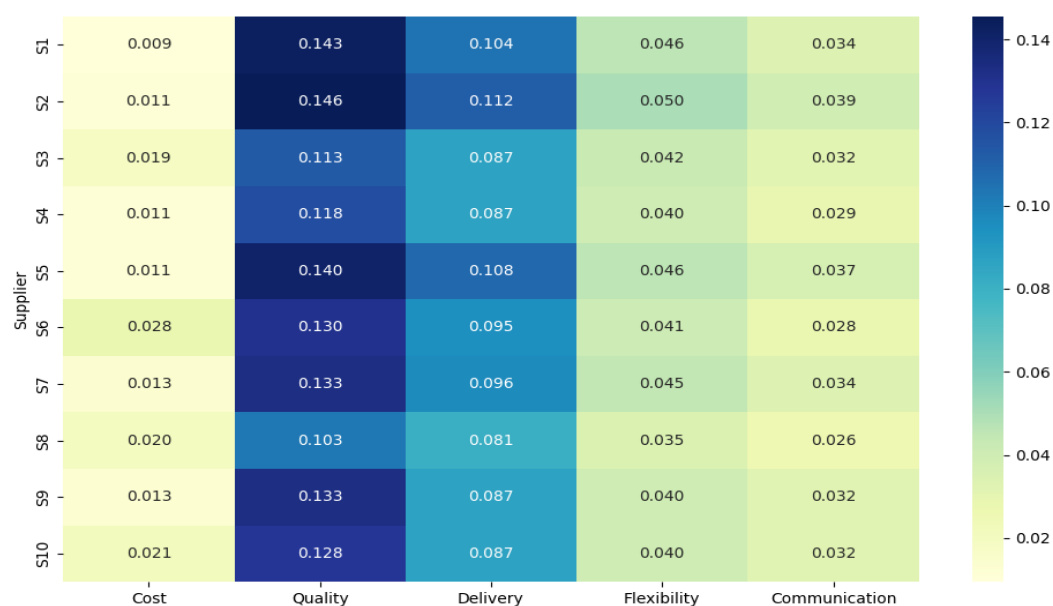


Figure 5. Weighted normalized decision matrix (AHP-TOPSIS).

Finally, the suppliers' ranking will be determined by applying the TOPSIS method with the weighted decision making matrix to produce a CC. Using this weighted matrix, PIS and NIS for each criterion was then determined as seen in Table 6. For each criterion, the PIS represents the most positive value across all suppliers, while the NIS represents the most negative. For instance, for the Cost criterion has the lowest PIS value (C1 = 0.0275), which indicates there is a preference for lower prices. On the contrary, Quality had the largest (C2 = 0.1455), implying that it is a priority over Cost was to reduce prices. The Euclidean distances of each supplier from the PIS and NIS are calculated and used as a scale using these ideal and anti-ideal values. TOPSIS utilized this distance and converted them into proximity coefficients for each supplier which is the basis of the final supplier rankings.

Table 6. TOPSIS ideal and anti-ideal solutions.

Criteria	PIS	NIS
C1	0.027534	0.009415
C2	0.145501	0.102833
C3	0.111905	0.081028
C4	0.050109	0.034901
C5	0.039391	0.025832

The final stage of the AHP-TOPSIS methodology is to determine the CC for each supplier based on its relative position in relation to the PIS (S_i^+) and NIS (S_i^-). The CC quantitatively demonstrates a supplier's distance from the ideal performance case, and a larger closing coefficient will indicate greater desirability.

Using AHP-TOPSIS, Table 7 illustrates the assessment of ten suppliers. The weights of five decision criteria were determined using the AHP method, allowing systematic and uniform prioritization. After applying the AHP weights to the normalized decision matrix, the modalities for calculating the distances to the ideal (S_i^+) and anti-ideal (S_i^-) solution provided the CC for each supplier. The table also illustrates the relative contribution of each of the criteria to the overall weighted score, therefore providing information on what criteria had more influence over each supplier's performance. Ultimately, the most favorable supplier based on the CC values is S2, with superior performance against the highly weighted criteria of quality and delivery. Therefore, suppliers S8 and S3 had lower performance overall, based on their weaker contributions to these criteria. In addition, a stacked bar chart displaying the weighted criteria composition for the suppliers based on the AHP-TOPSIS evaluation presents the findings in Figure 6. Each bar represents a supplier, with segments illustrating the different criteria percentages contributing to their overall weighted score. This graphic illustrates the central factors contributing to each supplier's performance and presents a simple representation of their unique strengths. It also shows that those suppliers with smaller segments in high-weighted criteria had relatively poorer overall performance. In contrast, S2 had continuing sizeable contributions in the most significant criteria, thus explaining its top CC rank.

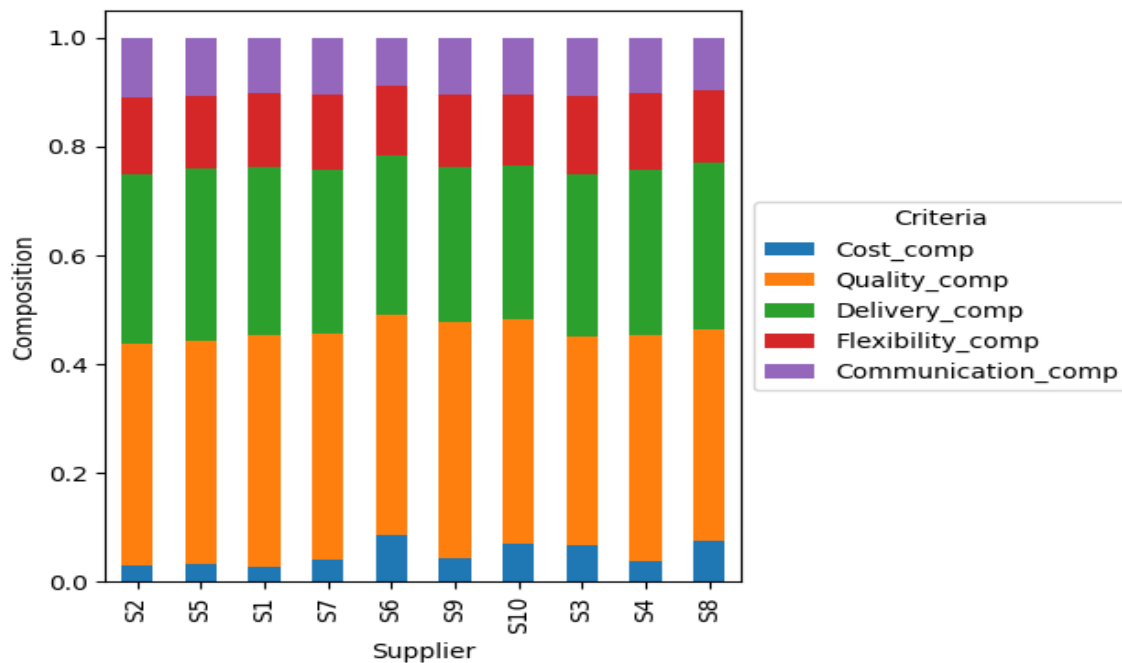
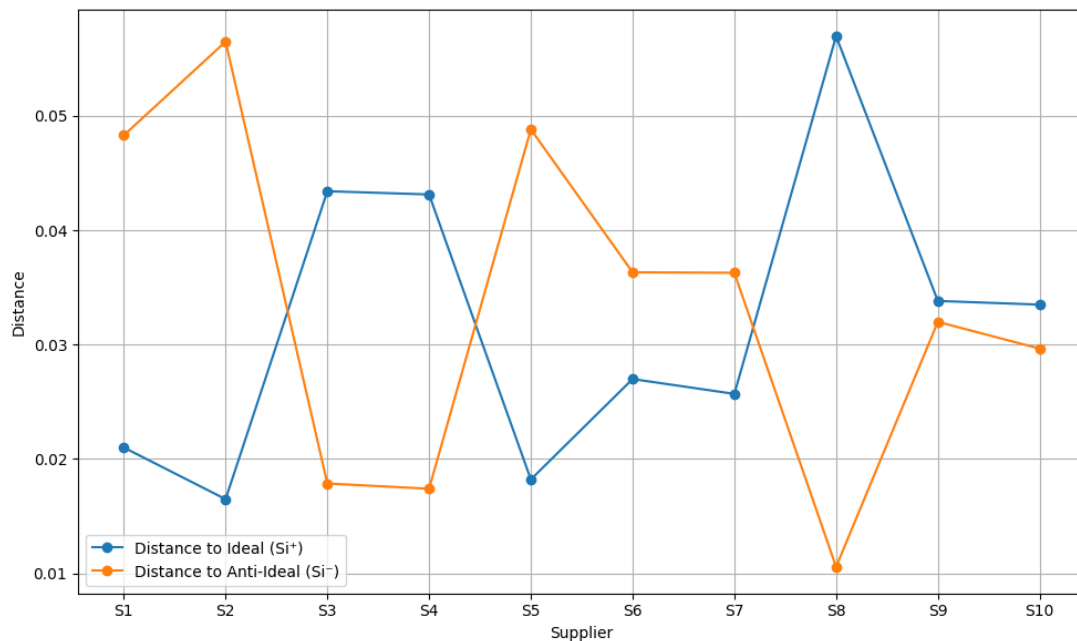


Figure 6. Criteria Composition per supplier (weighted).

Table 7. Final TOPSIS ranking by supplier with composition of criteria.

Supplier	S_i^+	S_i^-	CC	Cost composition	Quality composition	Delivery composition	Flexibility composition	Communication composition	Rank
S2	0.016485	0.056496	0.774117	0.0309	0.4065	0.3126	0.1400	0.1100	1
S5	0.018210	0.048825	0.728357	0.0329	0.4105	0.3157	0.1334	0.1076	2
S1	0.021002	0.048306	0.696978	0.0280	0.4250	0.3097	0.1357	0.1017	3
S7	0.025692	0.036283	0.585448	0.0416	0.4140	0.3004	0.1393	0.1046	4
S6	0.026992	0.036326	0.573711	0.0855	0.5040	0.2935	0.1278	0.0882	5
S9	0.033821	0.031991	0.486097	0.0428	0.4353	0.2843	0.1319	0.1057	6
S10	0.033499	0.029655	0.469562	0.0696	0.4143	0.2812	0.1304	0.1045	7
S3	0.043416	0.017855	0.291409	0.0662	0.3855	0.2965	0.1436	0.1081	8
S4	0.043133	0.017397	0.287415	0.0395	0.4132	0.3043	0.1412	0.1018	9
S8	0.056975	0.010566	0.156433	0.0755	0.3887	0.3063	0.1319	0.0976	10

According to Figure 7 below, the distances of each supplier to the PIS (S_i^+) and to the NIS (S_i^-) is depicted. The suppliers (S1 to S10) are shown on the x-axis, and the calculated distances on the y-axis. The distance from S_i^+ is shown by the blue line, while the distance from S_i^- is indicated by the orange line. In this plot we consider suppliers with lower values for S_i^+ and higher values for S_i^- as preferred options. For example, supplier S2 demonstrates its high rank by providing the shortest distance to the ideal solution and one of the longest distances to the anti-ideal. Supplier S8 has the lowest S_i^- and the highest S_i^+ confirming its rank of lowest and placing it close to the worst performance.

**Figure 7.** Distance to ideal and anti-ideal for each supplier.

This graph thoughtfully and effectively visualizes the relative positioning of all suppliers with respect to both the perfect and anti-ideal alternatives. This demonstrates the power of the AHP-TOPSIS methodology in distinguishing between viable alternatives on a multi-criteria evaluation scale by effectively contrasting high performing vendors and low performing vendors.

Figure 8 also depicts a bar chart showing the CC of all the suppliers evaluated in the AHP-TOPSIS analysis. The horizontal axis contains suppliers labelled S1 to S10; the suppliers are arranged by performance in descending order. The vertical axis indicates the CC values from 0 to 1.

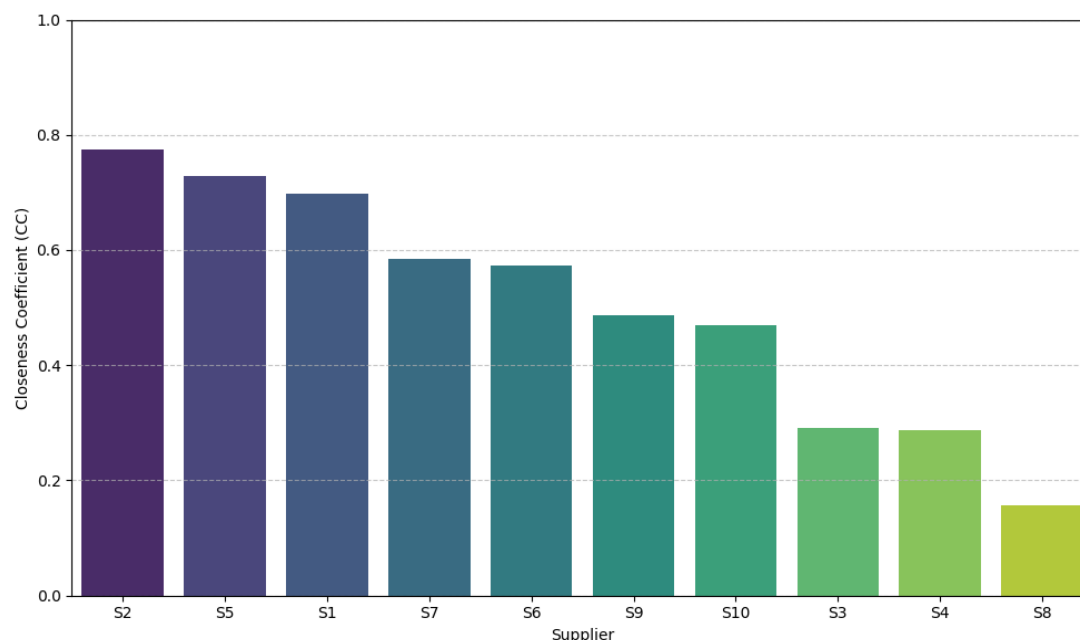


Figure 8. CC per supplier (TOPSIS).

Using this visual representation, decision-makers can rapidly identify the best and worst options on the basis of the comprehensive assessment of all considered criteria, recently presented on the graph outlining the aggregate of all criteria, leading to a transparent and easy comparison among suppliers' relative desirability. It is largely successful in demonstrating the drastic difference in performance between the top and bottom suppliers, leading to having high confidence and evidence-based supplier decisions.

Radar charts, or spider charts or web charts, are commonly used in MCDM research where researchers need to visually present the alternatives as a whole across multiple dimensions at the same time. Unlike more traditional tabular data, radar charts allow performance indicators to be compared on a two-dimensional plane and provide the opportunity to present multiple criteria in ways that facilitate systematic assessment. Supplier evaluation is a classic design context where many different criteria must be evaluated in combination across alternative different supplier options [33-35]. In this study, we use radar charts to show the relative performance of 10 suppliers against a series of evaluation criteria, including cost, quality, delivery, flexibility, and communication. Each axis on the radar chart represents a criterion, and plotted values represent each supplier's normalized performance value across all alternatives. The polygon that encloses the area outlines the overall performance profile for each supplier, allows for ease of visual interpretation and enables decision-makers to visually pick out strengths and weaknesses. In order to improve clarity and comparability, ten radar charts can be created- one for each supplier- to illustrate the respective performance patterns individually without plot overlay. This simplification process provides a number of benefits. Removing overlap makes observation cleaner and avoids reading through complexity typically seen with overlays of multiple suppliers. Moreover, distinct supplier characteristics remain distinct. It may serve the reader better to see each supplier's profile in isolation. Figure 9 presented the radar charts. Each chart is for a different supplier, and allows us to avoid the clutter and overlap of the visuals, while clearly showing strengths and weaknesses. It is clear from the visualization that S2 successfully outperformed the others suppliers and achieved the highest CC with a rating value of 0.774 and achieved rank 1. This supplier achieved reasonable levels of cost, flexibility, and communication and perpetually achieved the best ratings for quality and delivery. The supplier S8 underperformed the other suppliers greatly indicating development and improvement areas, especially regarding cost and communication. The other suppliers showed relative levels of strengths; S5, for instance, demonstrated a strong quality and delivery scores with a CC value of 0.728. In summary, the radar-charts provide a detailed, multi-criteria evaluation of suppliers, which shows their relative pros and cons graphically

and allows for easy identification of the suppliers which performed best in categories, for identifying superior suppliers for strategic sourcing decisions.

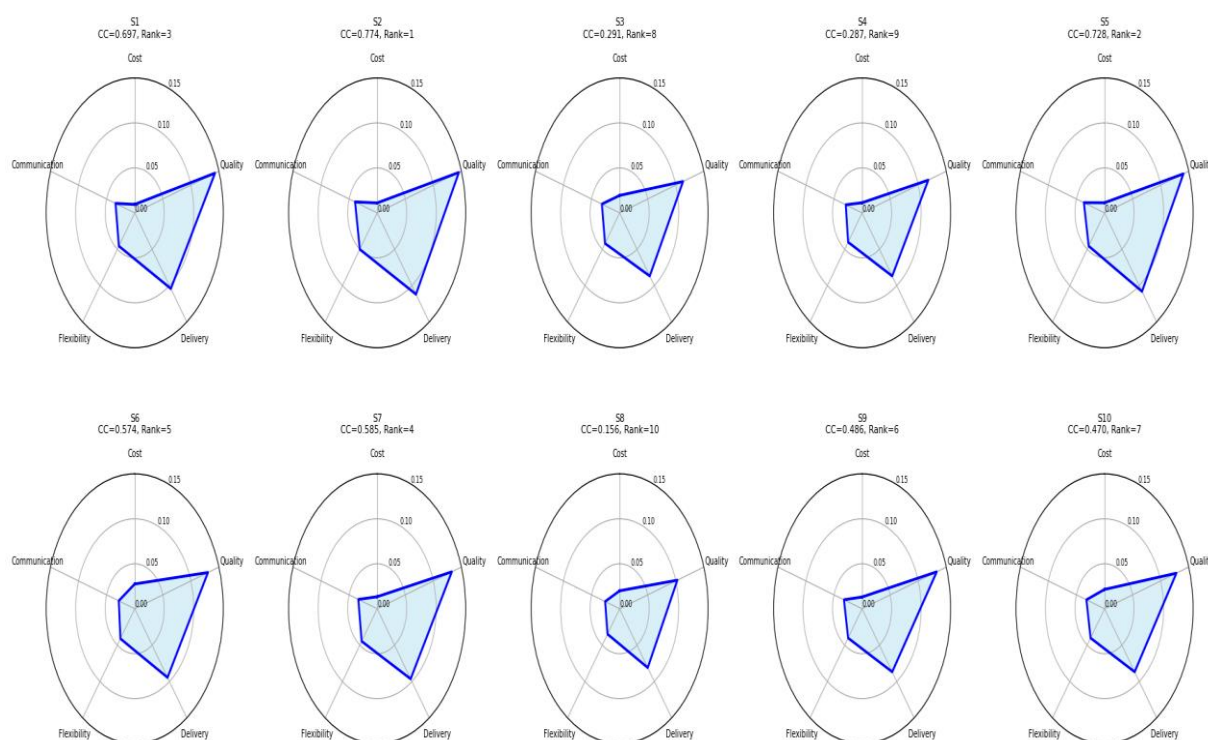


Figure 9. Ten suppliers' performance profiles radar charts taking into account five evaluation criteria: communication, quality, cost, delivery, and flexibility.

6 | Conclusions and Future works

This study utilized a hybrid AHP-TOPSIS model to conduct a comprehensive rating of ten suppliers for ACI Pharma. The aim of the study was to identify weaknesses in ACI Pharma's supplier selection process for printed promotional materials, which are necessary for communicating scientific discoveries to stakeholders and healthcare practitioners. The dataset was obtained from supplier performance data as well as ACI Pharma's procurement history, with five core decision criteria: cost, quality, delivery, flexibility, and communication. First, we derived consistent and objective weights for these criteria, using the AHP, reflecting the relative importance of the criteria under ACI Pharma's operational and strategic context. Then, using the TOPSIS model we calculated the proximity CC for each supplier as a function of the distance to the ideal (S_i^+) and anti-ideal (S_i^-) solutions. The results indicated that suppliers S3 and S8 performed poorly in terms of the most important criteria, quality and delivery, while S2 had the best CC and overall performance.

A sensitivity analysis was conducted to ensure the stability and reliability of the supplier ranking created using the AHP-TOPSIS approach. It examines the effect of small alterations in the criterion weights $\pm 10\%$ on each supplier's cumulative performance scores which is the CC. Sensitivity analysis is important to a MCDM process in determining if the ranking of suppliers is stable or subject to extreme dependence on the specific weightage of the criteria in the decision. The CC values for each supplier based on the original weight are directly comparable to a 10% increase or decrease in each criterion weight in Figure 10, enabling clear comparison of how changes to specific criteria impact the rankings of the suppliers as a whole. For example, some suppliers may have a small change in CC, while others seem highly vulnerable to certain criteria which might indicate a weakness in their evaluation.



Figure 10. Sensitivity analysis of suppliers' CC for $\pm 10\%$ weight changes in each criterion.

When each and every criterion weight is increased or decreased by 10%, Figure 11 indicates the trend of CC for each supplier. A steeper slope means higher sensitivity, and a flatter line means less sensitivity. Decision-makers can assess how each supplier's ranking was steady or unstable in this way.

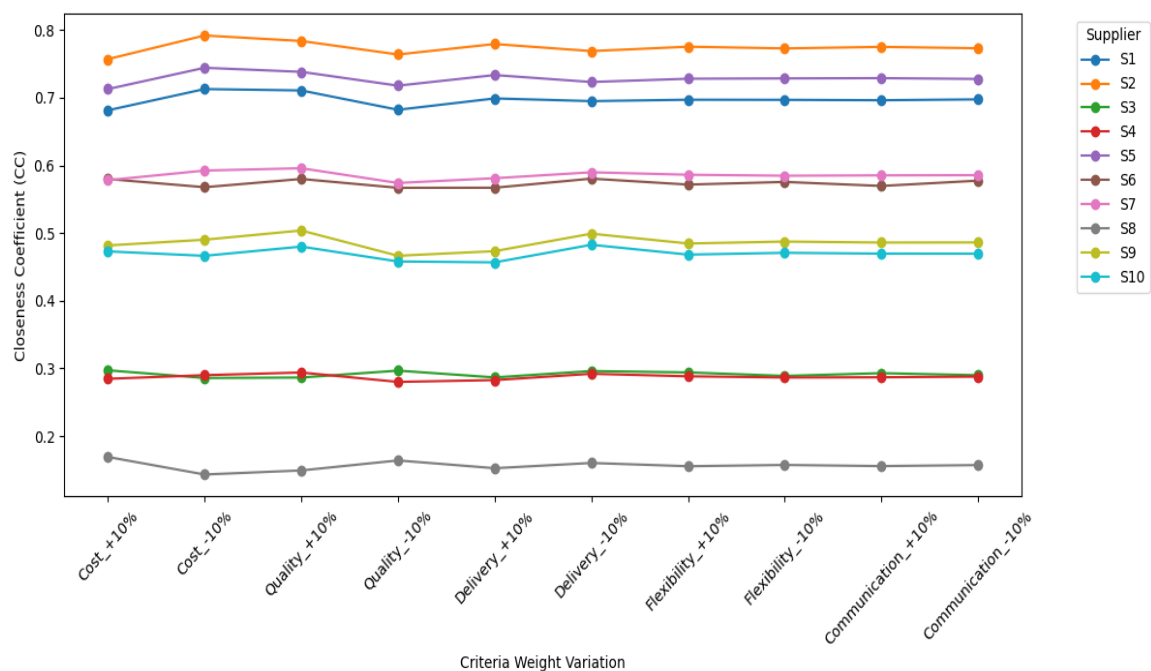


Figure 11. Sensitivity analysis of CC per suppliers to $\pm 10\%$ weight changes.

From the analysis, it is clear that S2 is the most reliable and robust because S2 continuously had the highest CC in all scenarios. S2 is the best choice for ACI Pharma for accessible printed promotional materials based on the fact that S2 retained the same rating even when the weights of critical criteria, such as quality or delivery, were altered by $\pm 10\%$. While sensitivity analysis showed varying degrees of sensitivity for the other

suppliers none of the suppliers outperformed S2 in any of the scenarios explored. In addition to verifying the original ranking of suppliers, sensitivity analysis gives procurement managers confidence that the decision to do business with S2 is robust to small amounts of uncertainty in the weighting of criteria. It gives managers confidence that decisions supported by data and are able to withstand slight adjustments to the relative weights for the criteria valuation.

The results were made more accessible with the use of visualizations: stacked bar charts determined how the individual criteria contributed proportionately to the weighted score, radar charts compared each supplier's strengths and weaknesses, and heat maps identified specific weighted scores. Furthermore, the sensitivity analysis confirmed the robustness of the AHP-TOPSIS approach, in that small changes in significant criteria weights- including quality, did not produce substantial differences in rankings.

In closing, the proposed methodology provides ACI Pharma with a systematic, transparent and repeatable mechanism to assess and select suppliers, leading to educated decisions, greater efficiency and enhanced competitiveness in procuring printed promotional materials.

For Future research, further attributes such as sustainability, supplier innovation, risk management, and compliance with regulations, among others, can be included within the ACI Pharma supplier assessment framework to enhance the previous supplier performance review. If more suppliers are added to the information and segmenting or clustering algorithms are applied, opportunities may be available to identify strategic groups of suppliers and reveal performance trends. Furthermore, including a dynamic visualization option such as Plotly would improve the flexibility of generating decisions from visualizations by allowing participants to interactively amend the criterion weights and examine alternative scenarios. Finally, AHP-TOPSIS's generalizability and reliability opportunity may be substantiated by comparative analysis or research with dynamic multi-criteria decision-making approaches such as VIKOR, PROMETHEE, and ELECTRE.

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Data Availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there is no conflict of interest in the research.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Author Contributions

All authors contributed equally to this work.

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