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RESEARCH ARTICLE

Supplier selection through multicriteria analysis in a pharmacy network

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ABSTRACT

The effective management of pharmaceutical supply chains is essential for ensuring the availability of critical products, such as medicines, which are directly linked to public health. Supplier selection plays a pivotal role in maintaining a stable supply chain, requiring an evaluation framework that balances multiple, often conflicting, criteria. This paper addresses three research questions: (RQ1) How can a multicriteria decision-making framework effectively prioritize suppliers in a dynamic and competitive supply chain context? (RQ2) What are the critical factors influencing supplier evaluation in the pharmacy industry, and how can their relative importance be quantified? (RQ3) How robust is the proposed methodology when subjected to sensitivity analyses across varying criteria weights? To answer these questions, we propose a multicriteria decision-making approach for ranking suppliers within a pharmacy network to enhance decision-making and foster strategic partnerships. The study focused on five suppliers of a pharmacy network operating in the state of Paraná, Brazil. The Best-Worst Method (BWM) was used to determine the weights of the criteria and subcriteria, while the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) ranked the suppliers. The criteria related to economic efficiency and delivery reliability were given the highest weights, as they are critical to ensuring the stability of the pharmaceutical supply chain. The analysis of the suppliers showed that Supplier 3 consistently ranked first, with Supplier 1 and Supplier 2 completing the top three. Despite differences in their performance across various criteria, the results highlight the importance of using robust multicriteria frameworks to identify supplier strengths and weaknesses, mitigate supply chain risks, and support more informed and strategic decision-making processes.

Keywords: Supplier Selection; TOPSIS; BWM; Supplier selection through multicriteria analysis

1. Introduction

For many years, the procurement area's main objective was to ensure that the goods and services

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necessary to execute its activities were present to maintain the company's operational continuity. They sought more for the lowest price in these acquisitions. This area was considered an executor of bureaucratic services, not closely tied to the company's strategy. Over time, this sector gained strength and greater importance as its relevance was noted due to its significant financial impact within the organization.

Today, it is known that this sector plays a fundamental role in business management, particularly regarding the supply chain. The supply chain management sector is responsible for aligning the company's processes with the strategic planning set by Chief Executive Officers (CEO) for the organization, involving not only the relationship between suppliers and procurement but also customers, retailers, carriers, and other links in the supply chain. Pharmaceutical management, in particular, involves a complex supply chain system, both upstream and downstream, due to the large number of products and customers it must consider [1].

According to[2], the main result of strategic alignment among companies within a supply chain is establishing a solid operation in which all participants gain competitive advantages and some value generation for each of them. In the 1990s, the era of competitiveness brought about a need for companies to consolidate their relationships with suppliers to develop mature partnerships rather than mere suppliers.

Through the establishment of partnerships, the internal competence of the company is improved as companies evolve with the development of new characteristics. According to[3], strategic alliances tend to create competitive advantages for both sides of the supply chain, benefiting not only their customers—who maximize their relationship with suppliers—but also the suppliers themselves, who, by providing higher value to the customer, become an indispensable differential within the supply chain. However, despite the widespread acknowledgment of these advantages, significant gaps remain in the systematic evaluation and ranking of suppliers using robust multicriteria methods tailored to the pharmaceutical industry.

Currently, several criteria are considered for the eligibility of the best suppliers within a supply chain, not limited solely to the lowest offered price. Within the pharmaceutical sector, the search for criteria such as quality and flexibility is of fundamental importance to maintain a stable and lasting relationship between partners in the supply of medicines, as these products are directly related to customer health. Furthermore, studies have shown that using multicriteria approaches, such as TOPSIS and BWM, can significantly enhance decision-making by balancing competing priorities like cost efficiency, delivery reliability, and product quality[4-7].

In this context, this paper aims to rank suppliers of a pharmacy network using a multicriteria analysis. This approach will consider both qualitative and quantitative criteria, which companies evaluate to obtain the best partners for their operational relationships. The multicriteria analysis method is essential for analyzing and directing the criteria, aiming to define the best supplier for the pharmacy network in question. This research contributes to addressing a critical gap by integrating the BWM and TOPSIS methods to provide a comprehensive supplier ranking system, enabling organizations to make informed decisions in complex supply chain environments.

Ranking suppliers is essential as it brings to light the strengths and weaknesses of each one within the evaluated criteria and subcriteria to define which one best fits the needs of the company in question. It is worth noting that the pharmacy network where the present study was conducted has had a consolidated relationship with its suppliers for over ten years. Nevertheless, it is important to highlight the suppliers' strengths and areas for improvement since adjustments can be made to optimize this relationship.

According to[8]**,** the multicriteria analysis method has become an essential tool in the current world for developing relationships among supply chain partners. According to[9]**,** seeking the best suppliers often involves conflicting attributes since lower prices are only sometimes linked to high product quality. Therefore, the multicriteria analysis aims to weigh these conflicts, assist the company in the decision-making process, and suggest who the best partners would be based on the evaluation of the criteria.

According to[7], the constant changes in the market imply that the distributor is sometimes less efficient than its demand. As a result, a competitor may supply the demand more effectively, i.e., being faster and having lower costs than the current distributor. This shows the need for a multicriteria ranking system, as it would enable the analysis of the most important criteria for a particular company to find its ideal distributor. In this study, the BWM method was selected due to its ability to simplify pairwise comparisons while ensuring consistency in judgments, making it particularly suitable for complex supply chain scenarios[6].

Choosing an appropriate supplier can help reduce purchasing costs and improve competitiveness, while working with an unsuitable supplier for the business can lead to high financial and operational risks. By selecting the best supplier, the company can establish a strategic and collaborative partnership with its suppliers. Therefore, to achieve advanced corporate goals in a competitive market, corporations must select the most suitable supplier and establish a profitable and strategic partnership with them[10].

According to[11], the most critical purposes of supply chain management are satisfying customer demand, decreasing total connection costs, and increasing the quality of produced products. To achieve this goal, all supply chains should work and cooperate in an integrated manner. In other words, an integrated supply chain operation results in organizational efficiency costs.

Sometimes, the criteria for the eligibility of a supplier are dynamic, as momentary delivery priorities of the product can occasionally outweigh the need for the lowest price. According to[12], criteria such as Lead Time, just-in-time capacity, delivery, quality, geographical location, packaging ability, e-commerce capacity, and customer response are among some of the main criteria for supplier selection. These dynamic criteria highlight the necessity for flexible and adaptable decision-making frameworks, which this study aims to address through the integrated application of BWM and TOPSIS.

To guide this study, the following research questions were posed:

RQ1: How can a multicriteria decision-making framework effectively prioritize suppliers in a dynamic and competitive supply chain context?

RQ2: What are the critical factors influencing supplier evaluation in the pharmacy industry, and how can their relative importance be quantified?

RQ3: How robust is the proposed methodology when subjected to sensitivity analyses across varying criteria weights?

2. Literature review

2.1. Supplier selection

Amidst the intensifying competition in the manufacturing sector, the need for a well-thought-out approach to selecting collaborative partners for economic development has become increasingly evident. The efficient oversight of a company's day-to-day operations is a central concern for top-level management. In the realm of manufacturing and logistics, one of the pivotal decisions revolves around the choice of a significant supplier. Opting for a reputable and dependable supplier has become one of the essential and coveted factors contributing to many enterprises' success. The procurement department plays a crucial role in ensuring the cost of raw materials is minimized through a judicious supplier selection, thereby enhancing the company's competitive edge without compromising product quality. Cultivating supplier relationships within a business environment supports the sustainable management of the enterprise[13].

Multicriteria decision-making (MCDM) methods are essential tools for supplier selection. These methods support managers in decision-making processes and supplier selection procedures by adopting approaches that enhance environmental and social impacts while increasing the overall efficiency of procurement operations.

Supplier selection is a dynamic process that necessitates the consideration of multiple conflicting criteria. Traditional approaches, such as those proposed by[14], provide a foundational understanding of supplier evaluation. However, these methods often lack the robustness required to address uncertainties and disruptions inherent in modern supply chains. Recent advancements in fuzzy control systems and robust methodologies have introduced powerful tools to address these limitations, offering more effective solutions for managing the complexities of contemporary supplier selection processes.

Lo et al.[15] states that evaluating a supplier depends on the acquired product, its nature, complexity, and criticality. For this purpose, [16]propose a supplier evaluation and selection model consisting of 7 activities: identify the need for selecting a new supplier, identify key supply needs, determine acquisition strategies and relationship type, identify potential sources of supply, limit potential suppliers, determine the method of evaluation and selection, define the supplier and, finally, acquisition.

According to[17], supplier selection is a complex process in which economic criteria (e.g., product price) should be considered, and aspects such as the company's history and proposals for short-, medium-, and long-term partnerships. These factors are subject to change over time. Therefore, it is essential to determine the most significant evaluation criteria. The author proposed to group these criteria as Product (price, lead time, quantity, quality), Relationship with the company (one-time purchase - simple; long-term partnership - business alliance), and Company history (performance, warranty, costs, reliability). To ensure a reliable process, the interconnection between the various criteria and sub-criteria that compose the company's interests must be considered to characterize the suppliers properly.

According to[18], supplier selection is part of the purchasing strategy, requiring a multidimensional approach. The author suggests that criteria must be used to evaluate and select diverse suppliers. In a multidimensional model, a better understanding of the factors determining performance capacity, management philosophy, and the organization's competitiveness within the market should be pursued, as described in the following section.

2.2. Criteria in supplier selection

It is important to define the criteria to be used in supplier selection, as well as the methodology for comparing the organization's potential partners.[14] considers 23 criteria that define a good partner for the organization, including quality; delivery; performance history; warranties/complaint policies; production installation/capacity; price; technical capability; financial position; procedural compliance; communication systems; reputation/industry standing; willingness to do business; management/organization; operational controls; repair services; attitude, impression; packaging capability; labor relations record; past business volume; geographical location; training materials, and reciprocal arrangements.

According to[19], the lowest cost in price does not always represent the entire value chain upon which the company should base its partner decisions. Thus, a supplier should be evaluated based on the total cost, not just the acquisition cost. There are various types of costs to consider, including cost of quality, cost of delivery assurance, cost of response time, cost of replacement batches, cost of lack of improvement, and cost of technological obsolescence.

Table 1 presents the ranking of the attributes selected by[14], classified according to attributes of extreme importance, considerable importance, moderate importance, and slight importance. Despite this study being conducted in the 1960s, it was found that these criteria are still predominantly used in the industry even after changes in its process dynamics[20].

Table 1. Ranking of Attributes According to[14].

Rank	Criteria	Average rating	Evaluation
1	Quality	3,508	Extreme importance
2	Delivery	3,417	Extreme importance
3	Performance History	2,998	Extreme importance
4	Warranties and complaint policies	2,849	Extreme importance
5	Production facilities and capacity	2,775	Considerable importance
6	Price	2,758	Considerable importance
7	Technical capability	2,545	Considerable importance
8	Financial position	2,514	Considerable importance
9	Procedural compliance	2,488	Considerable importance
10	Communication systems	2,426	Considerable importance
11	Reputation and industry standing	2,412	Considerable importance
12	Willingness to do business	2,256	Considerable importance
13	Management and organization	2,216	Considerable importance
14	Operational controls	2,211	Considerable importance
15	Repair services	2,187	Considerable importance
16	Attitude	2,12	Moderate importance
17	Impression	2,054	Moderate importance
18	Packaging capability	2,009	Moderate importance
19	Labor relations record	2,003	Moderate importance
20	Geographical location	1,872	Moderate importance
21	Past business	1,597	Moderate importance
22	Training materials	1,537	Moderate importance
23	Reciprocal arrangements	0,61	Little importance

Source: *Adapted from* [14].

According to[21], in addition to the 23 criteria addressed by[14], another 21 criteria are mentioned in the literature on the subject. These include after-sales service; technical support; customer order response; e-commerce capability; just-in-time manufacturing; ease of use; maintenance; environmentally friendly products; product appearance; technology catalog; reliability; flexibility; payment terms; productivity; applicable manufacturing concept; manufacturing challenges; driving power; lead times combination; employee capacity; solution-oriented approach; global factors, and environmental risk.

Based on the studies by[21] and[14] regarding the most important criteria in supplier selection, 41 criteria were identified. **Table 2** presents the characterization of the identified criteria in each study from the literature review.

Table 2. Characterization of Studies and Used Criteria.

Selection Criteria	Identification of criteria identified in the study.
Price	[14, 22-37]
Quality	[14, 22-24, 26-28, 30-34, 36, 37, 39]
Delivery	[14, 22-24, 26-28, 30-32, 34-39]
Warranties and complaints	[14, 23]
After-sales services	[14, 23, 25, 27, 30, 32, 39]
Technical support	[23, 25, 26]
Training materials	[14, 23, 27]
Attitude	[14, 25, 27]
Performance History	[14, 27]
Financial position	[14, 23, 27, 39]
Geographical location	[14, 22, 24, 27]
Organization and management	[14, 24, 27, 30, 34]
Labor relations	[14, 27, 32]
Communication systems	[14, 27, 37]
Customer order response	[23, 26, 30, 40]
E-commerce capability	[28, 29, 36]
Just-in-Time capability	[26, 28]
Technical capability	[14, 22, 27, 28, 33, 36, 37]
Production facilities	[14, 27, 32, 35]
Packaging capability	[14, 27]
Operational controls	[14, 27]
Ease of use	[23, 25]
Maintenance	[23, 25]
Past business volume	[14, 22, 23, 27]
Reputation and industry standing	[14, 22, 23, 25, 27, 36, 38]
Reciprocal arrangements	[14, 22, 24, 27]
Impression	[14, 23, 25, 27]
Environmental products	[28, 32, 36, 39]
Product Appearance	[29]
Technological catalog	[29]
Reliability	[38, 40]
Flexibility	[36, 38]
Payment terms	[36, 38]
Productivity	[32, 33]
Applicable manufacturing concept	[32]

Table 2. (*Continued*)

Selection Criteria	Identification of criteria identified in the study.
Manufacturing challenges	[32]
Driving power	[32]
Lead time	[37]
Employee capacity	[37]
Solution-oriented approach	[37]
Global factors	[39]
Environmental risk	[36]

2.3. Decision-making in supplier selection

According to[41], multicriteria methods assist in decision-making by allowing the approach of complex problems where usual intuitive-empirical procedures would not be able to solve and by providing greater clarity and transparency to the decision-making process compared to intuitive-empirical or single-criteria methods. [42] states that the advantage of using multicriteria methods is that there are generally no decisions that are simultaneously optimal under all analysis points, leading to the selection of the best possible option - considering the company's interests.

Multicriteria decision-making methods emerged as support tools, seen as effective mathematical instruments for solving problems with conflicting criteria[42]. For[43], the relationships between "Companies and suppliers" have changed over the years as companies realize they do not have total control over the production and logistics chain. Supply may only sometimes be carried out when companies need it, and this entire process needs to be well-orchestrated to avoid disruptions, losses, or production damages. The author further asserts that companies have started to relate to suppliers more, integrating them into their strategies rather than just operations, revealing the need for a relationship as true partners rather than mere suppliers.

The mathematical robustness of fuzzy systems is explored further in[44], which discusses applications of fuzzy differential equations and focuses on the stabilization of chaotic nonlinear systems. These studies provide a theoretical foundation for the application of fuzzy logic within the BWM and TOPSIS frameworks used in this research[45].

The study of fuzzy control models for nonlinear supply chain systems with delivery lead times focuses on designing robust mechanisms to manage uncertainties in demand, production, and system dynamics. [46] proposed a Takagi-Sugeno (TS) fuzzy control system to stabilize nonlinear supply chains while addressing the complexities introduced by delivery lead times. Their model employs a robust fuzzy control strategy using maximum overlapping rule groups to mitigate disruptions caused by stochastic customer demands and switching between subsystems. This approach ensures system stability while reducing fluctuations, as evidenced by simulations in a two-stage supply chain[47].

For[48] advanced the study of uncertain supply chain networks by developing a framework that emphasizes cost-effectiveness and resilience through robust and fuzzy modeling approaches. This framework demonstrated significant capability in mitigating the impacts of lead time uncertainties while optimizing total operational costs. Similarly, [49] investigated the transient and steady-state responses of supply chains to lead time disturbances. Their findings highlighted the potential inefficiencies and oscillatory behaviors arising from abrupt changes in lead times, underscoring the critical importance of meticulously planned lead time adjustments[49].

Recent advancements in fuzzy logic and control models have further validated their efficacy in enhancing the robustness of supply chain operations. [50]expanded the concept of robust control by introducing a fuzzy control framework specifically designed for nonlinear systems. Their approach demonstrated a remarkable capacity to accommodate dynamic uncertainties in customer demand and supply processes. The study underscored the vital role of adaptive control systems in sustaining supply chain resilience and ensuring operational efficiency.

Diao and Zhang[51] propose an innovative approach to optimizing management strategies for small and medium-sized enterprises (SMEs) using a decision tree model. Their study emphasizes the capacity of decision trees to analyze complex datasets and uncover key patterns that influence business performance. By applying this method, the authors identify optimal management practices tailored to the specific challenges faced by SMEs, such as resource constraints and market variability. The model effectively integrates quantitative data analysis with actionable insights, enabling SMEs to enhance decision-making processes and operational efficiency. This research provides a valuable tool for SMEs to navigate dynamic business environments and achieve sustainable growth.

Zhang et al. [52] conducted a study grounded in fuzzy logic principles and robust control techniques to offer practical solutions to modern supply chain challenges, emphasizing adaptability and resilience. The findings are particularly relevant in contexts where environmental and operational complexities—such as product recycling and remanufacturing—exacerbate supply chain vulnerabilities. The study not only highlights the theoretical advantages of integrating fuzzy control methods but also demonstrates their practical applicability, outlining a clear pathway for implementing advanced control strategies to improve supply chain performance.

Sahoo et al.[53] present an innovative approach to supplier selection in supply chain management using a binary-coded genetic algorithm aimed at achieving Pareto optimization. The study underscores the complexity of supplier selection, which involves multiple conflicting criteria such as cost, quality, lead time, and sustainability. To address these challenges, the authors employ an optimized genetic algorithm that efficiently explores solutions within the multi-objective search space, providing practical tools for enhancing supplier selection processes.

Kizielewicz and Sałabun[54] introduce the SITW (Selected Impact-Based Target Weighting) method, an innovative approach designed to redefine criterion weights in complex multi-criteria decision analysis problems. The study emphasizes the importance of evaluating the weights assigned to criteria in decision-making analyses, which is critical for ensuring the consistency and relevance of choices in practical scenarios. Their research contributes a robust methodological framework to enhance decision-making accuracy and reliability.

In this study, the TOPSIS and BWM methods were used together to achieve the best results among the chosen criteria for partner selection. The BWM method was used for weight determination, and the TOPSIS method was used to rank partner alternatives. The following sections explain the ideas, concepts, logic, and mathematical model.

The Best-Worst Method (BWM) has emerged as a highly effective approach in multicriteria decision-making, particularly due to its efficiency and reliability compared to traditional matrix-based methods. Unlike approaches that rely on exhaustive pairwise comparisons, BWM employs a vector-based structure, significantly reducing the number of comparisons required and minimizing potential inconsistencies in judgments. This reduction not only enhances computational efficiency but also ensures greater precision in deriving the relative importance of criteria.

In this study, the BWM is applied to rank suppliers by determining the relative weights of criteria critical to the supplier selection process. By leveraging BWM's robust methodology, the study ensures a consistent and transparent framework for assigning priority to criteria, which forms the foundation for effective decision-making. The criteria weights derived from BWM are then utilized in conjunction with the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), creating a hybrid evaluation framework.

TOPSIS is a widely recognized multicriteria decision-making method that ranks alternatives by calculating their relative closeness to an ideal solution. This ideal solution represents the hypothetical best performance across all criteria, while the negative ideal solution represents the worst performance. TOPSIS evaluates each alternative by considering its Euclidean distance from both the ideal and negative ideal solutions, ultimately ranking alternatives based on their closeness to the ideal. This method is particularly effective in scenarios where decision-makers need to balance conflicting criteria, as it provides a clear and quantifiable measure of performance.

The integration of BWM and TOPSIS offers a scientifically rigorous and practically applicable framework for supplier selection. BWM ensures the precise determination of criteria weights, while TOPSIS effectively translates these weights into actionable rankings of suppliers. This combined methodology addresses the complexity and strategic significance of supplier selection by providing a systematic, transparent, and robust decision-making process.

3. Methodology

Several steps must be followed to rank suppliers using multicriteria analysis. The process begins with clearly defining the problem in order to identify the criteria and alternatives to construct a decision matrix to incorporate the multicriteria analysis. Since the criteria have varying levels of importance, assigning appropriate weights to each criterion using the BWM Method is crucial. Once the weights are defined, the preference ranking can be generated using the TOPSIS. **Figure 1** summarizes these steps, which will be elaborated on in the following sections.

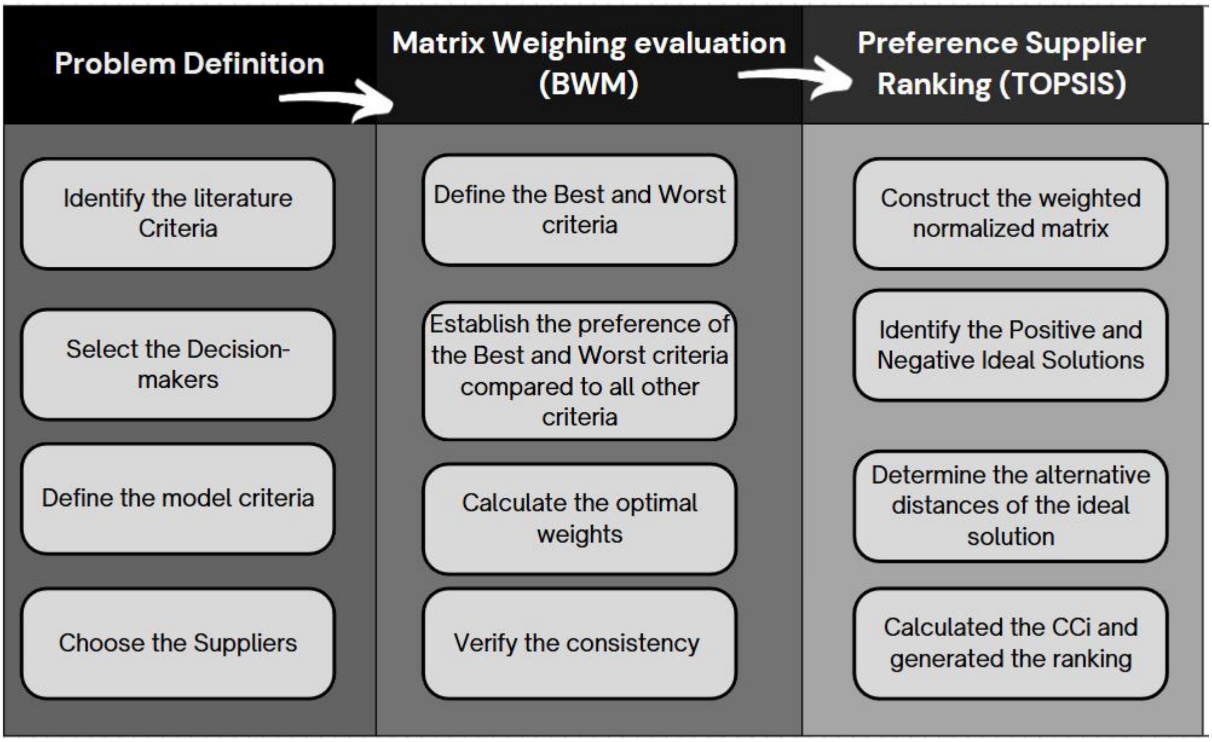

Figure 1. Methodology summarized.

3.1. Problem definition

The research was conducted in a pharmacy chain comprising 23 units, including its headquarters and branches, spread across seven cities in Paraná State, Brazil. Over the past decade, the pharmacy chain has experienced significant market growth. Most of the company's profits are directed toward expanding its network and enhancing customer service. The company employs approximately 400 staff members across various departments, including administration, purchasing, human resources, and finance, as well as operational roles such as cashiers, sales assistants, pharmacists, technicians, and support staff.

The company's primary concern is ensuring it selects the right suppliers to support its operations effectively. To address this issue, the purchasing department manager was designated as the decision-maker responsible for identifying the evaluation criteria and suppliers for the model, enabling a structured approach to supplier selection.

3.1.1. Definition of the model criteria

A bibliographic review of SCIELO, SCOPUS, ScienceDirect, and Web of Science was conducted to define the most important criteria within partner selection. A total of 41 criteria were identified, as shown in **Table 2.** Based on these criteria, an interview was conducted with the manager of the purchasing department of the pharmacy network participating in the study. In the interview, the manager identified which criteria were already being used and the new criteria that still needed to be added to their priority list for determining their suppliers. The manager decided that some characteristics needed to be considered, such as ease of measure and the company pillars, such as price and quality.

The four most used criteria in the literature review (**Table 2**) were chosen: price (17 articles), delivery (17 articles), quality (16 articles), and after-sales service (7 articles). Other criteria selected were attitude (3 articles), payment terms (2 articles), flexibility (2 articles), performance history (2 articles), and reliability (2 articles). The criteria were divided into three main criteria: Economic, Productivity, and Technological, as shown in **Table 3**.

Table 3. Criteria and sub-criteria selected.

Criteria	Sub-criteria	Reference
	Price	[14, 22-37]
Economic	Payment Terms	[36, 38]
	Attitude	[14, 25, 27]
	Quality	[14, 22-24, 26-28, 30-34, 36, 37, 39]
	Performance History	[14, 27]
Productivity	Reliability	[38, 40]
	Flexibility	[36, 38]
	Delivery	[14, 22-24, 26-28, 30-32, 34-39]
Techonological	After-sales service	[14, 23, 25, 27, 30, 32, 39]

3.1.2. Decision matrix construction

After the criteria section, another interview with the purchasing department manager was conducted. The manager chose to analyze the five top suppliers. The relationship maturity level between the company and the suppliers was over 10 years, indicating well-established partnerships. These suppliers are responsible for providing various pharmaceutical products, including ethical, generic, and similar medications. As all five suppliers are located in the same region and have only one distribution center each, some criteria that could have been interesting, such as lead time and number of bases, were not evaluated since they had the same parameters and ratings. It is worth noting that the distance could also affect lead time if they were from different locations, adding more sub-criteria to this study.

An Odd-Likert scale of 0 to 9 was used to construct the decision matrix. The manager analyzed and scored each criterion for all suppliers individually. The scale used by the manager to score the alternatives is illustrated in **Table 4**. For Price, Quality, and Alter-sales service, the decision-maker chooses between Bad and Excellent. For Attitude, Reliability, Flexibility, Delivery, and Performance History, he chooses between Very High and None. The decision matrix was constructed and validated with the manager.

Table 4. Evaluation Scale.

Score	Price, Payment Terms, After-sales service, Quality	Attitude, Reliability, Flexibility, Delivery and Performance History
9	Excelent	Very High
7	Very Good	High
5	Good	Some
3	Regular	Few
0	Bad	None

The company already had several sub-criteria in place for supplier selection; however, with the addition of important criteria for ranking, the classification becomes more accurate, and the company can take precautions to avoid disruptions in the supply chain. Another benefit of this evaluation is the identification of the strengths and weaknesses of each supplier by the company.

3.4. Matrix weighting evaluation by BWM

This study applies mathematical models based on multicriteria analysis to determine which criteria are most relevant for selecting a partner in the pharmaceutical product supply. In this context, weights are used to assess these criteria due to their different magnitudes of impact on the selection of business partners. Here, weights were defined using the BWM method, following the algorithm described in this section. The method was applied using the spreadsheet provided by the authors, available at: http://bestworstmethod.com/software/

The BWM (Best-Worst Method) was proposed by[6], where the relative weights of the chosen criteria among the others are calculated through pairwise comparisons. The paired comparison is performed between the best and the other criteria and between the worst of the chosen criteria and the others, forming comparison vectors. This method provides greater reliability of results compared to other multicriteria analysis methods that use only a decision matrix.

According to[6], the method is based on six steps:

1st step: The decision-maker must establish the criteria.

$$(c_1, c_2, \ldots, c_n) \tag{1}$$

2nd step: The decision-maker must define the Best and Worst criteria, i.e., the most important and the least important for that problem.

3rd step: The decision-maker must establish the preference of the Best criterion compared to all other criteria using a number between 1 and 9, resulting in the Best-to-Others vector.

$$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn}) \quad (2)$$

where a_{Bj} indicates the preference of the Best criterion B relative to criterion j, and $a_{BB} = 1$.

4th step: The decision-maker must define the preference of the Worst criterion compared to all other criteria using numbers between 1 and 9, resulting in the Others-to-Worst vector.

$$A_w = (a_{1w}, a_{2w}, \ldots, a_{nw}) \quad (3)$$

where a_{jw} indicates the preference of criterion j relative to the Worst criterion W, and $a_{ww} = 1$.

The pairwise comparison described in steps 3 and 4 needs to be performed based on[6]'s scale in **Table 5**.

Table 5. The Scale of Importance for the BWM Method.

Scale	Importance
1	Indifferent
3	Low
5	Moderate
7	High
9	Extreme
2, 4, 6, 8	Intermediate Values

Source: *Adapted from* [6].

5th step: Calculate the optimal weights with minimized maximum absolute differences $\left|\frac{w_B}{w_j} - a_{Bj}\right| \wedge \left|\frac{w_j}{w_w} - a_{jw}\right|$ for all j, according to the equation 4.

$$\min max_j \left\{\left|\frac{w_B}{w_j} - a_{Bj}\right| \wedge \left|\frac{w_j}{w_w} - a_{jw}\right|\right\} \quad (4)$$

satisfying the conditions:

$\sum w_j = 1$ and $w_j \geq 0$, for all j.

where w_B represents the weight of the Best criterion, w_w is the weight of the Worst criterion, and $w_j$represents the weight of criterion j.

The model is equivalent to

$$\min \xi \quad (5)$$

Satisfying the conditions:

$\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi, \left|\frac{w_j}{w_w} - a_{jw}\right| \leq \xi;$

$\sum w_j = 1; w_j \geq 0$, for all j.

By solving the model, optimal weights and the value of the objective function are obtained.

6th step: Verify the consistency of the application, where the comparison is entirely consistent when $a_{Bj} * a_{jw} = a_{Bw}$ for all j, being a_{Bw} the preference of the Best criterion over the Worst criterion. The consistency index is present in **Table 6**.

Table 6. Consistency Index (CI).

a_{BW}	1	2	3	4	5	6	7	8	9
Consistency Index	0,00	0,44	1,00	1,63	2,30	3,00	3,73	4,47	5,23

Source: *[6]*.

With the consistency index $(CI, \max \xi)$, from **Table 6**, the consistency ratio can be calculated by

$$CR = \frac{\xi^*}{CI} \tag{6}$$

According to Ren, Liang, and Chan (2017), the consistency ratio (CR) represents the level of consistency of the method's application. [6] explains that $CR \in [0,1]$, and the closer the obtained value is to 0, the higher the consistency of the method's application.

One of the main advantages of this method is its algorithm. It is simple and does not require high computational demands for implementation and result verification. According to[55], another advantage is that the algorithm does not require parameter tuning, meaning that the criteria do not necessarily need to be analogous and can use various styles within different parameters.

3.5. Preference supplier ranking by TOPSIS

The fusion of multicriteria analysis methods TOPSIS and BWM was used to rank the supplier's alternatives. Hwang and Yoon proposed the TOPSIS method in 1981[8]. It is a technique for evaluating the performance of alternatives based on their similarity to the ideal solution. This method can consider an unlimited number of alternatives and criteria.

In the classical approach of the TOPSIS method, the matrix's values are part of the crisp number set **[56]**. The basic principle of TOPSIS is to choose an alternative that is as close as possible to the positive ideal solution and as far as possible from the negative ideal solution. The positive ideal solution is formed by taking the best values achieved by the alternatives during the evaluation concerning each decision criterion. In contrast, the negative ideal solution is formed similarly by taking the worst values. The TOPSIS's result can be achieved by following the algorithm below:

1th step: Define a decision matrix D composed of alternatives and criteria. Where $A_i, i = 1, \ldots, n$ represents the feasible alternatives, $C_j, j = 1, \ldots, m$ represents the decision criteria, and x_{ij} indicates the performance of alternative A_i according to criterion C_j. The weight vector $W = w_1, \ldots, w_m$ represents the individual weights of each criterion, where $w_j > 0$ and $\sum w_j$ from $i = 1$ to $m = 1$, which is mandatory for evaluating the criteria.

$$D = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_n \end{matrix} \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2m} \\ \vdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nj} & \cdots & x_{nm} \end{bmatrix}$$

2nd step: Determine the normalized decision matrix (NDM) from the matrix D, which will represent the scores of the generated alternatives. The normalized value r_{ij} is calculated as follows:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^2}} \quad (7)$$

3rd step: Determine the weighted normalized decision matrix (WNDM). The weighted normalized value v_{ij} is obtained by multiplying each element of each column of the normalized decision matrix (NDM) by the weights of the criteria.

$$v_{ij} = w_j * r_{ij} \quad (8)$$

4th step: Determine the Positive Ideal Solution (PIS, A^+) and the Negative Ideal Solution (NIS, A^-) using the following equations:

$$A^+ = \{(max_i\, v_{ij} |\, i\, \epsilon\, J'); \ (min_i v_{ij} |\, i\, \epsilon J'')\} \quad (9)$$

$$A^- = \{(min_i\, v_{ij} |\, i\, \epsilon\, J'); \ (max_i v_{ij} |\, i\, \epsilon J'')\} \quad (10)$$

where J' is associated with benefit criteria and J'' is associated with cost criteria.

5th step: For each evaluated alternative, calculate the distance D_i^+ between the normalized and weighted performance values from the matrix (8) and the values of the PIS, and calculate the distance D_i^- between the values and the NIS.

$$D_j^+ = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^+)^2} \quad (11)$$

$$D_j^- = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^-)^2} \quad (12)$$

6th step: Calculate the Closeness Coefficient (CC_i) according to equation (13), which corresponds to the overall performance of the alternatives.

$$CC_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (13)$$

7th step: Classify the alternatives in descending order. The alternative with the highest CC_i, closest to 1, is the best ranked.

4. Results and discussion

4.1. BWM application

As mentioned, the criteria were defined through research, as well as the ranking that composed each sub-criteria, forming a range of options to plan a mix of qualities in the search for the best suppliers in the company. The BWM model was used to determine these sub-criteria and criteria weights.

For this purpose, the company's procurement department defined the best and worst criteria for ranking and classifying their suppliers. All criteria were compared to the best and worst criteria, following the BWM algorithm. The comparison was conducted using a Likert scale from 1 to 9 (**Table 5**), based on[6]'s study. The scale represents values that can be defined in various linguistic forms, enabling the evaluation of both qualitative and quantitative criteria.

Afterward, the best and worst of criteria and sub-criteria were determined, resulting in **Table 7**.

Table 7. Best and Worst selected for the application of the BWM method.

CRITERIA	PRINCIPAL
Best	Economic
Worst	Technological
ECONOMIC SUB-CRITERION	
Best	Price
Worst	Attitude
PRODUCTIVITY SUB-CRITERION	
Best	Quality
Worst	Flexibility
TECHNOLOGICAL SUB-CRITERION	
Best	After-sales services
Worst	After-sales services

The importance of each criterion and sub-criteria was determined in the sequence based on the BWM algorithm. The results from the BWM for the main criteria, economic sub-criteria, and productivity sub-criteria, are shown in Tables 8, 9 and 10, respectively. The tables also show the degree of consistency of each group of sub-criteria and the criteria, where values closer to zero represent higher consistency.

Table 8. Weight Results.

Criteria	C1	C2	C3
Name	Economic	Productivity	Technological
BWM	*Best*	***	*Worst*
Best to Others*	1-	5	9
Others to the Worst	9	7	1
Assigned weights	0,748	0,193	0,059
Ksi*	0,218		

Table 9. Application of Economic Sub-criteria.

Economic	C11	C12	C13
Name	Price	Payment Terms	Attitude
BWM	*Best*	***	*Worst*
Best to Others*	1	6	9
Others to the Worst	9	7	1
Assigned weights	0,772	0,169	0,059

Ksi*	0,242

Table 10. Productivity Sub-criteria.

Productivity	**C21**	**C22**	**C23**	**C24**	**C25**
Name	Quality	Performance History	Reliability	Flexibility	Delivery
BWM	*Best*	*****	*****	*Worst*	*****
Best to Others*	1	9	5	9	5
Others to the Worst	9	5	8	1	7
Assigned weights	0,570	0,084	0,152	0,042	0,152
Ksi*	0,188				

The weights were normalized by multiplying the criteria-assigned weight by the sub-criteria weight. The final weights are presented in **Table 11**.

Table 11. Paired comparison table of vector scores for each sub-criterion to the others.

Criteria	**Weights**	**Sub- criteria**	**Weights**	**Normalized Weights**
		C11	0,772	0,577
C1	0,748	C12	0,169	0,126
		C13	0,059	0,044
		C21	0,570	0,110
		C22	0,084	0,016
C2	0,193	C23	0,152	0,029
		C24	0,042	0,008
		C25	0,152	0,029
C3	0,059	C31	0,059	0,059

In the next section, this final weight obtained by the BWM methodology was used in the TOPSIS method to calculate the actual ranking of the suppliers.

4.2. TOPSIS application

To construct the decision matrix, an Odd Likert Scale, ranging from 1 to 9 (**Table 4**), was used to evaluate the chosen supplier (named as F1, F2, F3, F4 and F5). The scores were evaluated by the procurement department, where 9 indicates a good evaluation for the assessed parameter, and the lower the score, the worse the evaluation result.

To simplify the evaluation performed, all criteria and sub-criteria were used as terms to be maximized. In the price criteria, for example, the lower the price of products, the higher the score. Thus, all sub-criteria were assessed in a way that maximized scores represent a positive/good sense in the evaluation. **Table 12** represents the decision matrix for the application of the TOPSIS method.

Table 12. Decision Matrix.

Supplier	Criteria								
	C1			C2					C3
	C11	C12	C13	C21	C22	C23	C24	C25	C31
F1	7	7	7	9	9	9	9	9	7
F2	7	7	7	7	7	9	5	9	5
F3	9	5	7	7	5	9	5	7	9
F4	5	5	5	7	7	7	5	8	5
F5	5	5	5	7	5	9	5	7	7

To start the TOPSIS algorithm, the matrix was normalized and weighted, by using equations 7 and 8, respectively, resulting in **Tables 13 and 14**.

Table 13. Normalized Matrix.

Supplier	Criteria								
	C1			C2					C3
	C11	C12	C13	C21	C22	C23	C24	C25	C31
F1	0,463	0,532	0,499	0,541	0,595	0,466	0,669	0,500	0,463
F2	0,463	0,532	0,499	0,421	0,463	0,466	0,372	0,500	0,330
F3	0,595	0,380	0,499	0,421	0,330	0,466	0,372	0,389	0,595
F4	0,330	0,380	0,356	0,421	0,463	0,362	0,372	0,444	0,330
F5	0,330	0,380	0,356	0,421	0,330	0,466	0,372	0,389	0,463

Table 14. Weighted Matrix.

Supplier	Criteria								
	C1			C2					C3
	C11	C12	C13	C21	C22	C23	C24	C25	C31
F1	0,267	0,067	0,022	0,060	0,010	0,014	0,005	0,015	0,027
F2	0,267	0,067	0,022	0,046	0,008	0,014	0,003	0,015	0,019
F3	0,343	0,048	0,022	0,046	0,005	0,014	0,003	0,011	0,035
F4	0,191	0,048	0,016	0,046	0,008	0,011	0,003	0,013	0,019
F5	0,191	0,048	0,016	0,046	0,005	0,014	0,003	0,011	0,027

From **Table 14**, the positive (A+) and negative (A-) ideal solutions were defined, using equations 9 and 10, resulting in **Table 15**.

Table 15. Positive and negative ideal solutions for each sub-criteria.

	C11	C12	C13	C21	C22	C23	C24	C25	C31
A+	0,343	0,067	0,022	0,060	0,010	0,014	0,005	0,015	0,035
A-	0,191	0,048	0,016	0,046	0,005	0,011	0,003	0,011	0,019

In the sequence, using equations 11 and 12, the distance of each alternative from the positive and negative ideal solution was calculated, resulting in **Tables 16 and 17**, respectively.

Table 16. Distances between Alternatives and Positive Ideal Solution.

Supplier	Criteria								
	C1			C2					C3
	C11	C12	C13	C21	C22	C23	C24	C25	C31
F1	0,00582	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00006
F2	0,00582	0,00000	0,00000	0,00018	0,00000	0,00000	0,00001	0,00000	0,00024
F3	0,00000	0,00037	0,00000	0,00018	0,00002	0,00000	0,00001	0,00001	0,00000
F4	0,02330	0,00037	0,00004	0,00018	0,00000	0,00001	0,00001	0,00000	0,00024
F5	0,02330	0,00037	0,00004	0,00018	0,00002	0,00000	0,00001	0,00001	0,00006

Table 17. Distances between Alternatives and Negative Ideal Solution.

Supplier	Criteria								
	C1			C2					C3
	C11	C12	C13	C21	C22	C23	C24	C25	C31
F1	0,00582	0,00037	0,00004	0,00018	0,00002	0,00001	0,00001	0,00001	0,00006
F2	0,00582	0,00037	0,00004	0,00000	0,00000	0,00001	0,00000	0,00001	0,00000
F3	0,02330	0,00000	0,00004	0,00000	0,00000	0,00001	0,00000	0,00000	0,00024
F4	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000
F5	0,00000	0,00000	0,00000	0,00000	0,00000	0,00001	0,00000	0,00000	0,00006

Finally, equation 13 was used to calculate the Closeness Coefficient ($\boldsymbol{CC_i}$), generating the suppliers' raking, as shown in **Table 18**.

Table 18. Final Ranking Scores obtained from TOPSIS.

Supplier	Si*	Si-	CCi*	Ranking
F1	0,077	0,081	0,513	**2**
F2	0,079	0,079	0,500	**3**
F3	0,024	0,154	0,864	**1**
F4	0,155	0,003	0,017	**5**
F5	0,155	0,008	0,051	**4**

4.3. Results analysis

The application of the TOPSIS method enabled a systematic evaluation of the criteria for assessing suppliers in the pharmacy network, resulting in a ranked list of suppliers based on priority. This approach provided a quantitative framework, allowing the procurement department to identify key strengths and weaknesses of each supplier across defined parameters. Notably, the top-ranked supplier differed from the one with the highest scores in individual evaluations conducted by the procurement department. However, this supplier scores highest in the criteria with the highest assigned weights, securing its leading position among the available alternatives. This outcome highlighted the value of an MCDM, as it effectively integrates diverse and weighted perspectives to derive balanced conclusions.

Among the criteria, the economic criterion was identified as the most significant, with a weight of 0.748, followed by quality (0.193) and technological aspects (0.059). Price and payment terms emerged as the most influential within the economic sub-criteria, with Price having the most significant impact. This result aligns with the company's strategic emphasis on cost efficiency, reflecting the industry's competitive landscape. In the quality main criterion, the sub-criteria quality of products, delivery, and reliability demonstrated higher importance, with weights of 0.570 and 0.152 for the latter two. The remaining sub-criteria in this category had negligible influence, reaffirming the department's focus on core operational dependability over less critical factors.

Although a single sub-criterion represented the Technological main criterion, its overall contribution to the ranking was minimal due to its lower weight (0.059). This highlights the pharmacy network's prioritization of economic and quality factors over technological advancements. The results were presented and discussed with the company, which agreed that this rank is ideal and meets the order requisition history. The company demonstrated interest in running the model for all suppliers in the future.

4.4. Sensitivity analysis

A sensitivity analysis was performed to validate the robustness of the model. One commonly used approach involves varying the criteria weights to examine how the alternatives respond to these changes [57,58]. This study created five scenarios for each main criterion (Economics, Production, and Technology) by adjusting their weights to 0.00, 0.25, 0.50, 0.75, and 1.00, while maintaining the remaining weights as determined by the Best-Worst Method (BWM). This resulted in a total of 15 scenarios, with the weight variations illustrated in **Figure 2**.

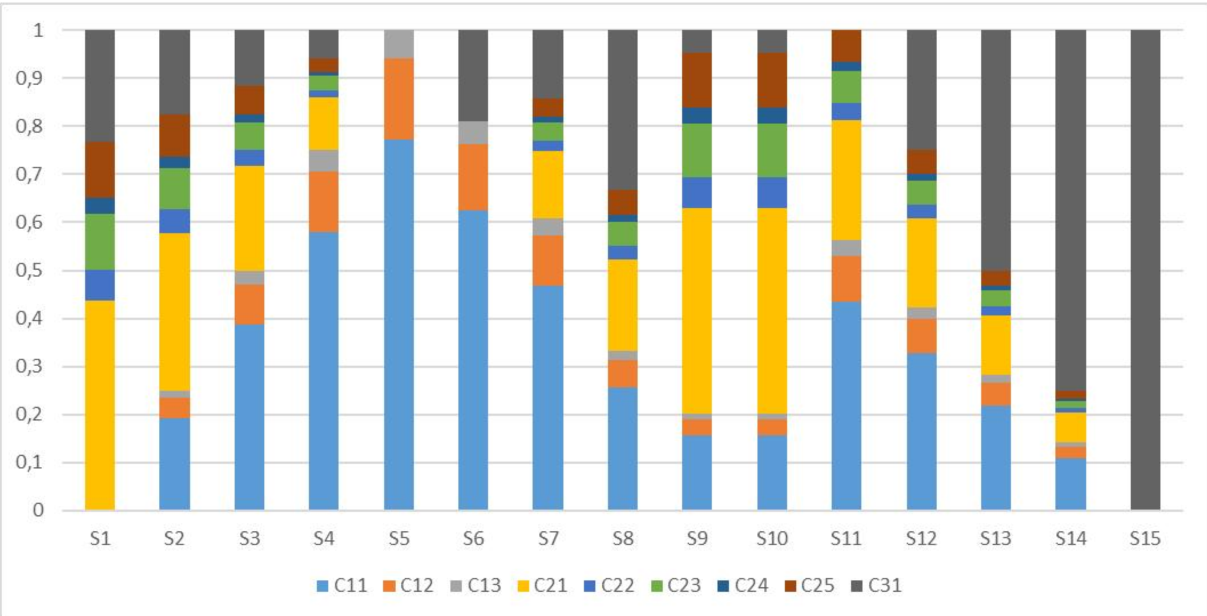

Figure 2. Weighted Scenarios for Sensitivity Analysis.

As expected, changes in the criteria weights influenced the final rankings of the alternatives. **Figure 3** depicts the supplier performance across all scenarios.

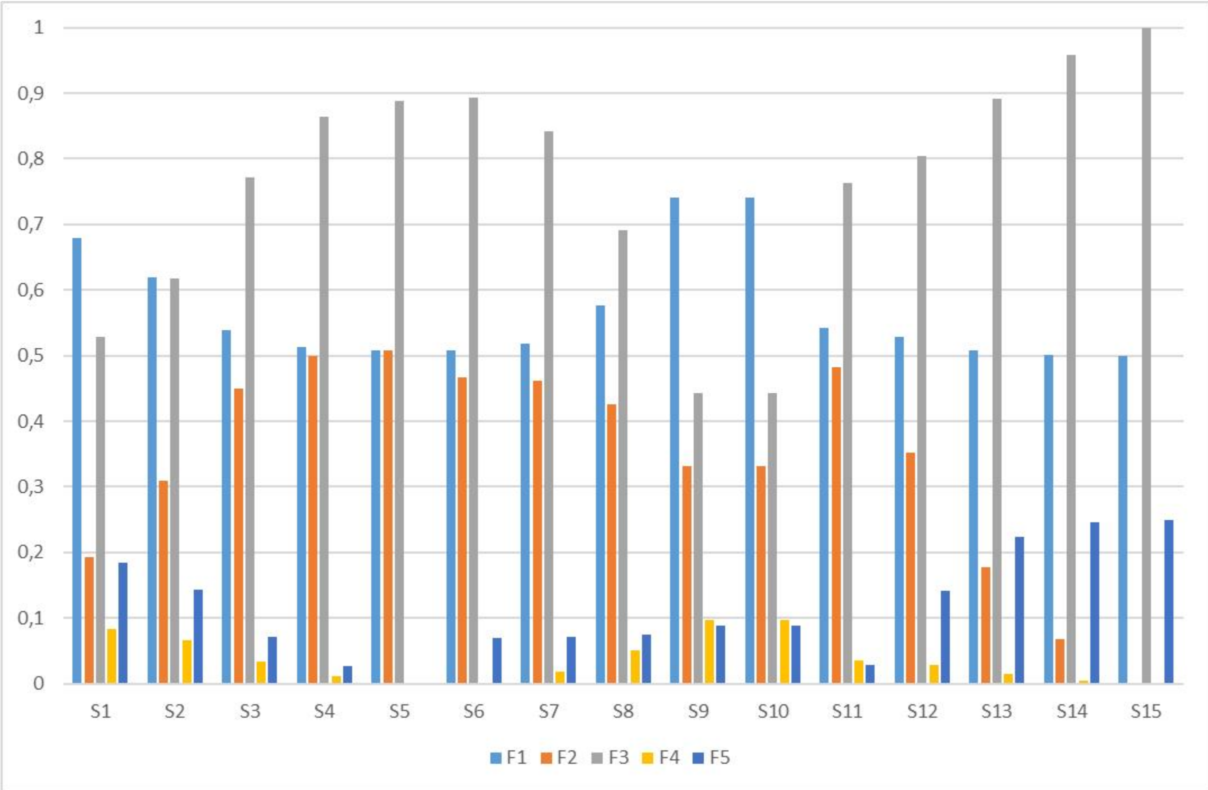

Figure 3. Supplier Performance Across Weighted Scenarios.

Supplier 3 (F3) consistently outperformed the others in most scenarios (73%). However, it did not secure the top rank when the weight for Economics was very low (0.00 and 0.25) or the weight for Productivity was very high (0.75 and 1.00). This can be attributed to the supplier's strong performance in the economic criterion—having the lowest price, which is the most significant sub-criterion in this category—and its notable performance in the technical criterion. However, its lack of differentiation in the productivity criterion explains its lower rank in scenarios with high weights for Productivity.

Another notable observation is regarding the consistent underperformance of Supplier 4 (F4), which ranked in the bottom positions (4th and 5th) across all scenarios. While this supplier does not have the lowest scores for some sub-criteria, such as Performance History (C22) and Delivery (C25), its overall performance remains in the lower levels, justifying its lower rankings. **Figure 4** highlights the suppliers' positions in the sensitivity analysis.

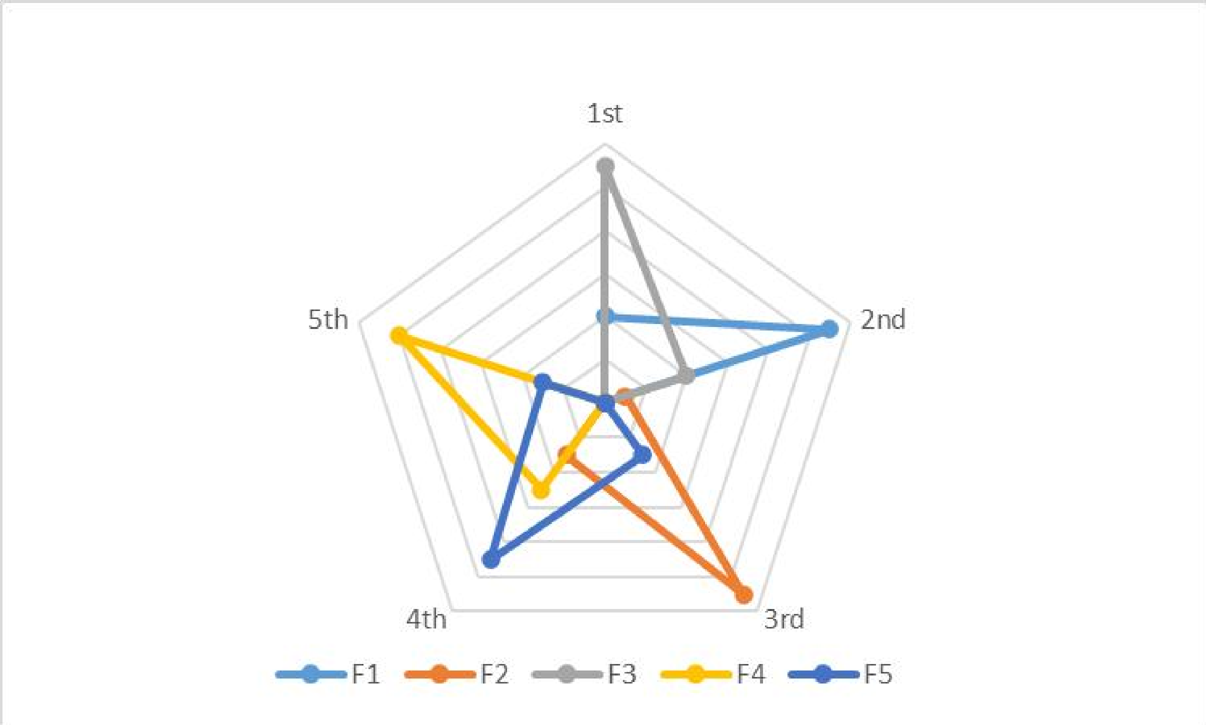

Figure 4. Supplier Rankings from Sensitivity Analysis.

From **Figure 4**, one can notice that Supplier 3 (F3) secured the first position in 11 scenarios and the second in 4. Supplier 1 (F1) alternated between the second position (11 times) and the first position (4 times). Supplier 2 (F2) predominantly held the third position (11 times), with occasional appearances in the fourth (3 times) and second (1 time) positions. Supplier 5 (F5) mostly ranked fourth, with three occurrences each in the third and fifth positions. Finally, Supplier 4 (F4) occupied the fifth position in 10 scenarios and the fourth in the remaining 5.

5. Conclusion

This study presented a robust framework for supplier evaluation and ranking within a pharmacy network using multicriteria decision-making methods, specifically TOPSIS and BWM. The study systematically analyzed the performance of five suppliers against defined economic, quality, and technological criteria, providing actionable insights to guide the company strategies.

The proposed method enables companies to establish comparative parameters between suppliers, fostering mutually beneficial relationships that drive improvement in deficient areas and enhance existing strengths. The findings underline the importance of maintaining high operational standards to avoid disruptions in critical supply chains, such as those for medicine. Prospective suppliers must meet stringent requirements to ensure supply chain stability while existing suppliers can use the feedback from this evaluation to address weaknesses and reinforce their strengths. This creates a dynamic and continuous improvement cycle, ensuring long-term efficiency and reliability.

The primary limitation of this study lies in the reliance on subjective evaluations by the procurement department for specific criteria and sub-criteria. Although these assessments were informed by extensive experience and long-term relationships with suppliers, the lack of objective measurement tools may reduce the precision of the rankings. Future studies could address this limitation by incorporating real-time data collection and advanced analytical tools to minimize subjectivity. Additionally, the relatively low weight assigned to technological criteria reflects the specific context of this case study. However, it may limit the generalizability of the findings to industries where technology plays a more critical role. Extending the framework to include a broader range of criteria and sub-criteria could enhance its applicability to other sectors.

This work addresses a pressing need in supply chain management for transparent, systematic, and adaptable supplier evaluation methods. The proposed approach enables organizations to navigate the complexities of supplier selection with greater confidence and precision. By integrating decision-making frameworks like BWM and TOPSIS, this study provides a practical tool that aligns with the evolving demands of modern supply chains. The research also contributes to the scientific community by offering insights into how multicriteria methods can be tailored to specific contexts, ensuring their relevance and applicability. As disruptions in global supply chains continue to present challenges, this study's findings are both timely and valuable, offering a foundation for future innovations in supplier evaluation.

Conflict of interest

The authors declare that they have no conflict of interest.

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