



AHP–TOPSIS–PROMETHEE Hybrid Decision Support Framework for Sustainable Pharmaceutical Cold Chain Vendor Selection

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Abstract. Selecting pharmaceutical suppliers is a crucial process to ensure effective procurement, availability of medicines, compliance with regulations, and sustainable operation of the distribution system. This study proposes a combined Multicriteria Decision Support System (DSS) to prioritize vendors in pharmaceutical cold chain logistics. This study uses Likert AHP, TOPSIS, and PROMETHEE with 5 vendors, 4 characteristics of which are Price, Capacity, Service, and Time, supported by 20 supporting sub-characteristics. There are 10 experts related to procurement and logistics, accompanied by original operational performance data from the institution. AHP analysis shows that delivery time has an importance level of 0.534, while price is 0.200, Capacity is 0.161, and service is 0.105. In the consistency test with Hamming, Euclidean, and Spearman similarities, accompanied by sensitivity tests for each variable. The results obtained by vendor V obtained a high position with AHP and PROMETHEE, while continued with TOPSIS which is on two paths in each path. However, other vendors showed slightly different results, with Euclidean having an average of 59%. The results shown are those that have static changes due to various expert opinions. Thus, a more transparent framework is provided.

Keywords Cold chain logistics, decision support systems, multi-criteria decision analysis, supplier evaluation, sustainability indicators

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1. Introduction

Vendor selection in the pharmaceutical industry is becoming increasingly complex as companies are required to comply with various regulations while maintaining a competitive edge in the market. This

challenge is particularly felt by pharmaceutical importers, who are required to ensure consistent product distribution and avoid significant disruptions. In determining the appropriate vendor, companies need to evaluate a number of criteria, such as delivery accuracy, product cost, product quality, and service quality, considering that each aspect contributes to the smooth operation of operations and the achievement of company goals [1]. Vendors designated for pharmaceutical importers in Indonesia play a strategic role, thus requiring adjustments to all customer desires, complying with government regulations, and ensuring the safety and effectiveness of various foreign products [2].

The success of the supplier selection process is not only determined by price, but also by the vendor's skill in fulfilling the Company's needs. Several previous studies have found that cost is one of the many factors that need to be considered in supplier activities. In pharmaceuticals, product quality assurance is a priority because various supervisors minimize the risk of product recalls after distribution and reduce the risk of dangerous situations [3]. Furthermore, support in service, including helping to handle requests quickly and continuing to assist once the product has been obtained, can help improve the Company's skills when dealing with market dynamics and unpredictable challenges [4]. Timely distribution is also crucial because late delivery of drugs can hinder patient care and reduce public trust in the provision of pharmaceutical products [5].

Indonesia's diverse location and differences in development, facilities, and infrastructure present challenges in distributing pharmaceutical products across regions. These conditions must be considered by companies in ensuring product quality and safety during transit, including controlling transportation costs and minimizing negative impacts. Indonesia's high rate of imported drug use also necessitates thorough evaluation and comparison and ranking of potential vendors based on several shared characteristics. However, research related to pharmaceutical supplier selection in Indonesia is still very limited, including those that integrate price, quality, service, and on-time delivery. Furthermore, environmental concerns are a key concern in pharmaceutical logistics distribution. Efficient fuel and energy consumption during shipping, minimizing waste, and environmentally friendly operations can be key company characteristics in following standard rules and supporting the achievement of corporate social responsibility [6].

In the activity of selecting a pharmaceutical cold chain supplier, it is related to the vendor's skills in economic performance, operations, and a sense of compliance with policies on an ongoing basis, including seeing the quality of goods to always be maintained in shipping activities [7]. Here, researchers also carry out future things with various things on vendor performance that can be seen, including a sense of compliance with existing regulations, precise and continuous in sending, service response, stable product quality, and effective in utilizing human resources. By implementing some of these things, it can help add value to vendor skills in order to increase the time period, operations, reduce risks when storing and during shipping, reduce unwanted costs, and reliability in pharmaceutical supplies on an ongoing basis. Thus, in this study, not only on various general concepts, but related to the work of the vendor being evaluated. All of these things are used in viewing and assessing in order to determine the comfort of the vendor used and help in overall operational effectiveness [8].

Various approaches to vendor selection decisions in pharmaceutical cold chain logistics can incorporate characteristics, including quantitative data or expert opinion. Selecting a single method can yield incomplete results on vendor characteristics and result in varying rankings. To address these challenges, researchers have employed various approaches, including MCDM combined with AHP, TOPSIS, and PROMETHEE. AHP aims to determine the relative weight of criteria based on expert opinion, including consistency testing in assessments. TOPSIS is then used to evaluate alternative vendors based on positive solutions, while PROMETHEE ranks preferences with preference rankings. The use of these three approaches yields different results than in assessing the consistency of decisions. Integrating these three approaches is expected to increase reliability in procurement decisions and support companies in prioritizing vendors to contribute to the sustainability of pharmaceutical cold chain operations [9].

The timing of selecting existing pharmaceutical cold chain logistics services, as evidenced by several previous studies, is crucial for boosting the competitiveness of pharmaceutical companies and

maintaining business in the future. When faced with uncertain expert assessments and complex group decisions involving related criteria, previous results using the combination of the Pythagorean Fuzzy DEMATEL and CoCoSo methods are helpful. The results compare various methods and show that the combination of the two techniques can assist in the evaluation and ranking of logistics providers for greater clarity and consistency, which ultimately becomes the basis for making decisions on service providers [10].

The application of Industry 4.0 technology with digital transformation can help improve several things related to sustainability such as increasing complexity in cold chain logistics management, as according to Görçün et al. who explained the need for innovative use of technology that can help in improving operational performance, information transparency, and reducing the impact on the environment. In order to see technology related to cold chain management, it is necessary to develop an MCDM approach by assessing several criteria such as operational, technological and sustainability. The results obtained if environmental performance is able to adjust according to standards with broader standards as something that can be considered in choosing. Various alternatives analyzed by IoT get a higher position, with the results of the durability test showing that the evaluation results have a level of consistency and reliability that can help in making decisions related to cold chain technology [11]. To improve the digital vaccine supply chain in developing countries, one approach to integration focuses on efficiency, resilience, and the continuity of vaccine distribution [12]. The results of the study overcome limitations of prior studies as it is based on hybrid MCDM technique finding out obstacles, their significance and relations with vaccine supply chain efficiency. The results indicate that the main demand is for huge data and digital instruments including problems relating to the preservation of proper conditions of storage of goods and to the process of transportation. In addition, the issue of funding and technical readiness also raises a number of problems in terms of practical implementation and compliance with regulations. Moreover, the discussed approach requires flexibility in solving different implementation problems which makes it a valuable tool for regulatory authorities and supply chain managers that are trying to create a sustainable healthcare logistics service.

This study proposes a model for selecting biomass cold-chain logistics service providers based on the application and integration of the AHP, TOPSIS, and PROMETHEE methods. The use of various methodologies in this model minimizes the risk of evaluating and selecting service providers based solely on a single technique. For the purposes of assessment and selection, four criteria were established: price, product quality, service, and delivery time, supplemented by expert opinions and the service providers' operational performance data. Additionally, sustainability aspects were considered, as the shipment of pharmaceutical products requires strict attention to product condition and delivery time since these factors can lead to product damage or disruptions in supply availability. Next, all of these methods were applied to determine the weightings of the criteria, rank the service providers, and compare the results of applying the selected methodologies. Finally, a sensitivity analysis was used to estimate the rankings if the criterion weightings were changed.

2. Method

2.1 Research Design

This case study examines the supplier sourcing process undergone by a pharmaceutical importer in Indonesia through the use of AHP, TOPSIS, PROMETHEE, and Likert scales. The multi-criteria model proposed takes into consideration the trade-offs between various criteria (such as price, quality, service, lead time) and regulatory compliance and environmental sustainability to allow companies to make reliable decisions regarding supplier selection.

2.2 Selection of Criteria and Justification

When evaluating suppliers in this research paper, factors such as cost efficiency, quality, service, and distribution performance must be considered. Each of these factors consists of five subcategories. In addition, sustainability parameters that are crucial in distribution must also be taken into account. It is

important to maintain the proper temperature and handle medications correctly to prevent damage. Therefore, organizations must evaluate suppliers based on their performance and reliability, not just on price alone [13].

Given that pharmaceutical companies face conflicting demands namely, affordable costs and high service levels multicriteria decision making is essential. This study applies a combination of methods: AHP to determine the weights of each criterion based on expert evaluation, TOPSIS to assess proximity to target performance levels, and PROMETHEE to compare supplier rankings. This proposed hybrid approach ensures a comprehensive and multifaceted analysis that supports the organization's decision-making process.

2.3 Data Collection

2.3.1 Respondent Selection

In this study, the researchers used a purposive sampling technique and recruited ten experienced professionals who had worked in the field of supply chain and logistics for at least five years. The respondents' in-depth knowledge of pharmaceutical procurement provided support in prioritizing criteria and validating the research framework. In addition, their expertise allowed for a comparison of the approaches used by the researchers in applying the AHP, TOPSIS, and PROMETHEE methods.

2.3.2 Instrument Design and Data Sources

This study chose to use a Likert-scale questionnaire and a specially designed AHP to gain insights from experts and to integrate suppliers' practical performance data into its methodology. Expert ratings obtained through the AHP and PROMETHEE techniques provide criterion weights and relationship rankings, while TOPSIS is used to analyze operational features such as total annual shipping costs, maximum storage capacity, loading space availability, delivery delays, and so on. The combination of subjective assessments and objective operational data results in a balanced and comprehensive supplier analysis.

2.3.3 Data Validation

To ensure the accuracy of research, the approach incorporates triangulation as it relies on the use of questionnaires, interviews with specialists, and corporate documents. Any inconsistency among sources of data is addressed and harmonized so that analytical mistakes are eliminated. Through the use of multiple sources, the research ensures more credible vendor evaluation provided that the quality of data is high and the analysis is carried out with full diligence [14].

2.3.4 Ethical and Data Governance Considerations

This study was conducted in accordance with ethical practices and with respect for the confidentiality of all participants. Before undergoing the assessment, participants were briefed on the study's objectives and asked to participate voluntarily through informed consent. The results report does not disclose participants' identities, as the data presented are aggregated, not individual responses. Vendor performance data was obtained from the organization's internal documents after obtaining approval from the relevant authorities. This information was used solely for the purposes of analysis in this study. All collected information was stored securely and was accessible only to authorized personnel to prevent misuse and maintain the confidentiality of participant information. These measures ensure that participants' rights and data protection regulations were adhered to throughout the study.

2.4 Data Analysis Procedure

2.4.1 Assessment of the Importance of Criteria using the Likert Scale

Data processing begins with an analysis of the responses provided by survey participants via the Likert-scale questionnaire. The ratings given by participants are then aggregated to obtain an average score for each evaluated category. The results of this process are used to determine which criteria categories are considered significant enough to be retained in the vendor evaluation procedure. The relevant criteria

then undergo the next round of evaluation, while the screening conducted at this stage serves as a reference for determining which items should be prioritized. Once this stage is complete, the set of key criteria undergoes a weighting procedure in accordance with the AHP method, which allows users to understand the relative importance of each criterion for decision-making purposes [15].

2.4.2 Criteria Weighting through AHP

The weighting in the AHP method is calculated by combining the assessments of 10 experts using a geometric mean. This method is used to obtain group comparison values while maintaining the reciprocal relationships in the AHP matrix. The matrix is compiled at each hierarchical level, starting from the main criteria, subcriteria, to vendor comparisons based on each subcriteria. In the matrix, the comparison values must fulfill a reciprocal relationship, that is, the value in the opposite position is the inverse of the previous value. After the matrix is formed, the priority weights are derived by normalizing the principal eigenvectors which signify the degree of impact of the respective elements. The research makes use of a particular method known as the Consistency Ratio (CR) to check how consistent the judgments given in the matrix. The CR equals to the Consistency Index (CI) divided by the Random Index (RI) which has values of 0.90 for the fourth-degree matrix and 1.12 for the fifth-degree matrix. The CR value should be 0.10 or less, however, in the report CR value more than 0.10 can be presented.

2.4.3 Vendor Ranking with TOPSIS

The TOPSIS method was applied to the operational performance data of these five suppliers, using one metric for each determining factor as listed below: transportation cost per kg for price; scheduled monthly capacity for quality/capacity; availability of space corresponding to order requests for service; and on-time departure for time. Since these metrics are measured in different units, they were all converted into three categories represented by values (10, 20, or 30), using the Sturges formula ($k = 1 + 3.3 \log n$). The cost metric is represented by low transportation costs, whereas the quality, capacity, service, and time metrics result in performance with lower values being ranked higher than others; this leads to the interpretation that all listed criteria represent types of benefits. The set of scores is normalized and weighted according to the AHP analysis approach, which enables the calculation of the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS), as well as the final ranking of suppliers based on their proximity coefficients.

2.4.4 Vendor Rating with PROMETHEE

To rank providers, PROMETHEE II took ten expert assessments using geometric means and developed single representative scores. Because the criteria data was ordinal with unspecified preference thresholds, a Type I preference function was chosen. AHP weights gave relative importance of the criteria. The analysis was based on the comparison of positive outflows and negative inflows to derive net flow values; thus, a final ranking was established in which the suppliers with net flow above zero have a higher general preference compared to other suppliers according to the parameters of the analysis.

2.4.5 Sensitivity Analysis

To test the robustness of the vendor ranking results, this study applies a sensitivity analysis by changing the weight of each criterion in turn. Each weight is adjusted using a multiplier of 0.5; 0.8; 1.2; and 1.5, then renormalized so that the total weight remains at one. Based on these changes, the ranking calculation using the TOPSIS and PROMETHEE methods is rerun for each of the 16 scenarios formed. The results of this analysis are used to identify the extent to which changes in the relative importance of criteria affect the vendor ranking order and provide information for management in assessing the consistency and robustness of the supplier selection decision results [16].

2.5 Application Case Study

This research procedure was implemented at PT XYZ, a pharmaceutical importer operating in Indonesia, involving five major cold chain logistics service providers. The operational indicator data used in the

TOPSIS analysis were obtained from the company's internal documentation for the 2020 period. To ensure the accuracy and consistency of the information, the data were further verified through cross-checking with internal audit results and the company's procurement documents.

2.6 Validation and Reproducibility

The reliability of the outcomes was assured through the validation of the AHP's pairwise comparison matrix [17]. This was done by using a Consistency Ratio of 0.10 or lesser value in line with protocols. Subsequently, the Hamming similarity index, Euclidean similarity index, and Spearman's rank correlation were utilized to check the compatibility of the AHP, TOPSIS, and PROMETHEE supplier rankings [18]. Eventually, the final rankings and conclusions were discussed with the procurement leadership to obtain feedback from the experts and get it validated by the stakeholders [19].

3. Results and Discussion

3.1. Case Study Context and Vendor Selection

The research investigated five suppliers of PT XYZ, pharmaceutical import firm based in Indonesia, selected based on internal procurement data and cold chain supply. The suppliers were referred to as Vendor A, B, C, D, and E in order to maintain their anonymity. All of the vendors fulfilled the compulsory distribution requirements, for example, Good Distribution Practice and Good Drug Distribution Method, but some of them were certified with additional accreditation, for example, GMP, IDAK, CDAKB, and ISO 9001 depending on their operational capabilities.

3.2. Criteria Weighting Results

Table 1 presents the criteria and subcriteria weights generated through the AHP assessment process by combining the opinions of ten experts. Local weights represent the level of importance of each subcriteria to its parent criterion, while global weights are calculated by multiplying the weight of the main criterion by the local weight of the relevant subcriteria.

Table 1.Weight of Criteria and Sub-Criteria Obtained from AHP

Criteria	Criteria Weight	Code	Sub-Criteria	Local Weight	Global Weight
Price	0.200	P1	Suitability and reasonableness of prices	14.5%	0.029
		Page 2	Ability to provide price discounts	25.2%	0.050
		P3	Policy on price increases during peak season	29.4%	0.059
		Page 4	Price adjustments according to company policy	17.2%	0.034
		Page 5	Fast resolution of product warranty claims.	13.8%	0.027
Quality (Capacity)	0.161	Question 1	Aircraft availability according to schedule.	6.4%	0.010
		Q2	Space availability at the time of booking.	22.5%	0.036
		Q3	The accuracy of the space volume is in accordance with the order volume.	12.0%	0.019
		Q4	Compliance of flight schedule with booking order.	6.1%	0.010
		Q5	The goods arrived at their destination in good condition.	53.0%	0.085
Serve	0.105	S1	Speed in providing order confirmation	12.6%	0.013
		S2	The ability to present information clearly and easily understood.	9.2%	0.010
		S3	Responsiveness during loading and unloading process	48.0%	0.050
		S4	Ease of booking and room blocking procedures.	14.0%	0.015

Criteria	Criteria Weight	Code	Sub-Criteria	Local Weight	Global Weight
Time	0.534	S5	Ease of access to communicate	16.1%	0.017
		T1	On-time flight departure at the point of origin	12.7%	0.068
		T2	Timeliness of incoming and outgoing aircraft manifests	8.8%	0.047
		T3	Timeliness of transit storage at connecting stations.	48.2%	0.257
		T4	Pre-cooling and post-cooling time accuracy	13.9%	0.074
		T5	Consistency of time and schedule	16.5%	0.088

Source: Author's analysis

The results of AHP suggest that the most important element in choosing pharmaceutical cold-chain suppliers is the on-time delivery which has the highest weight of 0.534, followed by price (0.200), quality/capacity (0.161), and service (0.105). Such a hierarchy proves that the companies are more inclined to focus on timely delivery than on the low price due to the properties of pharmaceutical products. Among the subcriteria, the fastest means of transportation (48.2%) has received the most significant priority score, proving how essential it is to ensure that no delays as well as temperature deviations will occur.

The subcriterion of response speed is the most important service feature, accounting for 48% of the overall importance of this criterion. In the case of price analysis, the focus is on factors such as the pricing strategy of the supplier (29.4%) and volume discounts (25.2%). The transit duration also plays an important part since it carries an overall weight of 25.7%, showing that price is not the only element of the procurement decision-making process. At the same time, it is crucial to assess the capacity of a supplier to keep products intact and move them properly in order to reduce the risk of their damage as well as costs related to product returns.

3.3. Consistency of Expert Assessment

As per the findings in Table 2 referring to consistency tests, the primary criteria maintained an acceptable consistency ratio of 0.073, while the sub-criteria matrices were above the limit of 0.10, where Price scored 0.104, Quality scored 0.230, Service scored 0.199, and Time scored 0.196. Furthermore, only 12 out of the 20 vendor comparison matrices passed the consistency checks, with CR values between 0.025 and 0.361. These discrepancies indicate that some discrepancies in the judgment of experts still exist despite the fact that there are techniques such as geometric means which eliminate these discrepancies to a certain level. Thus, it can be stated that these values can be regarded as collaborative priorities rather than exact measurements, which indicates that it is necessary to use range-based main weights while applying TOPSIS and PROMETHEE together with sensitivity checks.

Table 2. Consistency of Pooled Pairwise Comparison Matrices

Matrix	N	λ_{max}	CI	CR	Evaluation
Main criteria	4	4,196	0.065	0.073	Consistent
Price sub-criteria	5	5,465	0.116	0.104	Slightly above the threshold
Quality sub-criteria	5	6,029	0.257	0.230	Above the threshold
Service sub-criteria	5	5,892	0.223	0.199	Above the threshold
Time sub-criteria	5	5,876	0.219	0.196	Above the threshold
Vendor matrix (20)	5	—	—	0.025–0.361	12 out of 20 consistent

Source: Author's analysis

3.4. Vendor Ranking Results

The performance of all vendors is displayed in Table 3 using AHP, AHP–TOPSIS, and AHP–PROMETHEE methods. Vendor B has emerged on top in AHP (0.305) and PROMETHEE (0.974) methods, and second in TOPSIS (0.542), so it is the only vendor to be ranked among the top two all three times. Vendor A topped TOPSIS ranking (0.737) thanks to being 99.80% punctual in delivering products but additionally ranked third in PROMETHEE and fourth in AHP. This indicates that great

operational performance does not necessarily conform to the preference of experts where Vendor B was very good in pricing, capacity, service, and timeliness.

Table 3. Vendor Scores and Rankings Based on AHP, AHP-TOPSIS, and AHP-PROMETHEE

Seller	AHP		AHP-TOPSIS			AHP-PROMETHEE				
	Global score	Rank	D+	D−	CC	Rank	φ^+	φ^-	φ	Rank
A	0.144	4	0.089	0.250	0.739	1	0.500	0.500	0,000	3
B	0.305	1	0.129	0.152	0.542	2	0.974	0,000	0.974	1
C	0.073	5	0.151	0.133	0.467	3	0,000	1,000	-1,000	5
D	0.174	3	0.248	0.107	0.301	4	0.750	0.224	0.526	2
E	0.304	2	0.258	0.055	0.176	5	0.250	0.750	-0.500	4

Note: CC = proximity coefficient; ϕ^+ , ϕ^- , and ϕ = outflow, inflow, and net flow. Source: Author's analysis

3.5. Agreement Rating and Resilience Analysis

The validity and consistency of the developed hybrid decision support model were evaluated by comparing the vendor ranking results generated by the AHP, AHP-TOPSIS, and AHP-PROMETHEE methods. This evaluation process used three statistical indicators: Hamming similarity, Euclidean similarity, and Spearman's rank correlation. Hamming similarity was used to identify the proportion of vendor ranking positions that were similar among the compared methods. Meanwhile, Euclidean similarity was calculated by subtracting the root mean square of the normalized ranking differences from one, with four as the divisor representing the maximum ranking difference across five vendors. Spearman's rank correlation was used to assess the strength of the relationship between the ranking orders generated by each method. These three indicators serve to assess the level of agreement between the methods in generating vendor rankings, not to determine the predictive accuracy of the models used. The results of the ranking suitability measurement based on these three indicators are presented in Table 4.

Table 4. Agreement Ratings Across AHP, AHP-TOPSIS, and AHP-PROMETHEE Methods

Seller	Rank			Hamming similarity	Absolute ranking difference			Euclid's Similarity
	AHP (I)	TOPSIS (II)	PROMETHEE (III)		I, I, I	I, I, I, I	II-III	
A	4	1	3	0%	3	1	2	46%
B	1	2	1	33%	1	0	1	80%
C	5	3	5	33%	2	0	2	59%
D	3	4	2	0%	1	1	2	65%
E	2	5	4	0%	3	2	1	46%
Average				13%				59%

The comparison metrics shown in Table 4 indicate the differences in rankings depending on the method used, with the average metrics of the method being 59% Euclidean and 13% Hamming. Vendor B demonstrated the highest level of stability with 80% Euclidean similarity, while vendors A and E were quite different with 46% Euclidean similarity. Although experts AHP and PROMETHEE had relatively strong correlation ($\rho = 0.70$), TOPSIS was not so closely correlated due to its measuring internal parameters only without input of the expert. The results indicate that in order to avoid incomplete vendor evaluations, companies should use different multi-criteria methods.

3.6. Sensitivity Analysis

The results of the individual sensitivity analyses are summarized in Table 5. The PROMETHEE rankings ($B > D > A > E > C$) remained unchanged across all 16 scenarios, and the TOPSIS rankings ($A > B > C > D > E$) remained unchanged across 15 of the 16 scenarios. The only change occurred when the Time weight was halved (from 0.534 to 0.365 after renormalization): under TOPSIS, Vendor B

moved to first place and Vendor A to second, while Vendors C and D swapped positions. Thus, Vendor B remained in the top two positions under both methods in each scenario, while Vendor A's first position under TOPSIS depended on the high weight given to the Time criterion.

Table 5. Vendor Rating Sensitivity to Criteria Weight Changes

Scenario	Price w	Quality	w service	Time	AHP-TOPSIS Ranking	AHP-PROMETHEE Rating
Base	0.200	0.161	0.105	0.534	A > B > C > D > E	B > D > A > E > C
Price × 0.5	0.111	0.179	0.116	0.594	A > B > C > D > E	B > D > A > E > C
Price × 0.8	0.166	0.168	0.109	0.557	A > B > C > D > E	B > D > A > E > C
Price × 1.2	0.231	0.155	0.100	0.514	A > B > C > D > E	B > D > A > E > C
Price × 1.5	0.272	0.147	0.095	0.486	A > B > C > D > E	B > D > A > E > C
Quality × 0.5	0.217	0.088	0.114	0.581	A > B > C > D > E	B > D > A > E > C
Quality × 0.8	0.206	0.133	0.108	0.552	A > B > C > D > E	B > D > A > E > C
Quality × 1.2	0.194	0.187	0.101	0.518	A > B > C > D > E	B > D > A > E > C
Quality × 1.5	0.185	0.224	0.097	0.495	A > B > C > D > E	B > D > A > E > C
Service × 0.5	0.211	0.170	0.055	0.564	A > B > C > D > E	B > D > A > E > C
Service × 0.8	0.204	0.165	0.085	0.546	A > B > C > D > E	B > D > A > E > C
Service × 1.2	0.196	0.158	0.123	0.524	A > B > C > D > E	B > D > A > E > C
Service × 1.5	0.190	0.153	0.149	0.508	A > B > C > D > E	B > D > A > E > C
Time × 0.5	0.273	0.220	0.143	0.365	B > A > D > C > E	B > D > A > E > C
Time × 0.8	0.224	0.181	0.117	0.479	A > B > C > D > E	B > D > A > E > C
Time × 1.2	0.180	0.146	0.094	0.579	A > B > C > D > E	B > D > A > E > C
Time × 1.5	0.158	0.127	0.082	0.633	A > B > C > D > E	B > D > A > E > C

Source: Author's analysis

3.7. Discussion and Managerial Implications

Vendor selection in pharmaceutical cold chain distribution requires considering several aspects simultaneously, because low costs do not necessarily indicate good delivery performance. The results of the study found that the Time criterion had the highest weighting, namely 0.534, while Vendor B showed a more stable position when assessed using different methods. This indicates that the vendor's ability to meet the company's needs is not only seen from price, but also from quality, service and delivery accuracy. Vendors who are able to maintain a balance in several aspects can be a more suitable choice for the company. These results are in line with Sheykhizadeh et al. who explained that the selection of pharmaceutical suppliers requires considering cost efficiency, operational resilience, the environment and service quality together [20]. Al Doghan et al. also explained that supply chain sustainability is not enough to be achieved through financial improvements alone, but needs to be supported by operational performance and the use of technology [21].

The results of the ranking comparison show that Vendor B is the only vendor capable of being in the top two positions in all three methods used, namely AHP, TOPSIS and PROMETHEE. This position illustrates that Vendor B's performance is quite balanced based on the criteria determined in the study. Aspects considered include price, service response, delivery accuracy and operational capacity. Meanwhile, Vendor A and Vendor E experienced greater changes in ranking when calculations were carried out using different methods. This condition indicates that the results of the assessment of both vendors are more influenced by the evaluation method used. Taherdoost and Mohebi stated that supplier selection is a multi-criteria decision-making problem, because each method has a different way of assessing the advantages and disadvantages of alternatives. Therefore, the use of more than one method can provide additional considerations for companies before determining which vendor to choose [22].

The differences in the results obtained from the three methods are also evident in the Hamming similarity value of 13% and the Euclidean similarity of 59%. These values indicate that the suitability of the rankings is still limited and the assessment results are not completely identical between one method and another. AHP and PROMETHEE use expert assessments as the basis for evaluation, while TOPSIS uses operational data that has been grouped into three performance levels. These differences in

sources and assessment methods can cause changes in the resulting vendor ranking. By combining the three methods, companies can view the evaluation results from multiple perspectives before making a decision. This is in line with research by Alastal et al., which states that integrating several decision-making methods can help combine different analytical approaches in the supplier selection process [23]. Sun et al., also emphasize the importance of testing the robustness of decisions in cold chain management, because this activity has several competing criteria and the risk of uncertainty in the distribution process [24].

In the procurement process, the specialized AHP-TOPSIS-PROMETHEE model can help organizations conduct structured vendor evaluations. The use of practitioner assessments and business reports serves as the foundation for evaluation, setting aside the personal perspectives of decision-makers. By using this model, the importance weights of the criteria can be identified through AHP, and the rankings of alternatives can then be further calculated using TOPSIS and PROMETHEE. The results of these three methods can be compared to determine whether the selected supplier remains in the same rank or whether its position has changed. Sheykhizadeh et al. demonstrate that systematic supplier evaluation can improve the quality of decisions made due to the availability of metrics related to service quality and operational performance factors that are particularly critical in the pharmaceutical industry, where the wrong supplier choice can lead to supply disruptions and compromised product quality [20].

Current operational indicators are still limited in assessing energy consumption and waste generation, which means they are insufficient for determining sustainable logistics practices. Environmental awareness and knowledge are important foundations for informed environmental decision-making and sustainability-oriented behavior [25]. Future efforts should utilize science-based environmental indicators to effectively measure sustainability outcomes. The factors cited by Fatorachian and Pawar as the most important include energy conservation, temperature control, and waste reduction [26]. Wu et al. further state that digitalization helps improve both sustainability and logistics [27].

This research proposes a new supplier assessment model that is not confined to traditional cost-oriented and managerial techniques. The integration of AHP, TOPSIS, and PROMETHEE allows for the systematic assignment of weights, proximity assessment, and supplier preference evaluation, showing that judgments made based on a single method are biased. Going forward, future research should supplement this model with concrete environmental criteria and investigate its performance in various healthcare organizations and business.

4. Conclusion

This study employed a multi-criteria decision-making approach using the AHP, TOPSIS, and PROMETHEE methods. The highest weight of 0.534 was obtained for the time criterion, while Vendor B consistently ranked as the most trustworthy. Differences in rankings among the other vendors were due to variations in the evaluation process. The limitations of this study include its focus on a single organization and the high consistency ratio. Future research is recommended to increase expert participation, integrate actual operational data into the evaluation process, perform consistency checks early on, and incorporate fuzzy logic, risk assessment, and sustainability measures into the analysis.

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Declaration of AI and AI-assisted technologies in the writing process

During the preparation of this work, the author used ChatGPT to assist with language refinement, grammar checking, sentence restructuring, and clarity of academic writing. After using this tool/service, the author carefully reviewed and edited the content as needed and takes full responsibility for the content of the publication.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could be construed as influencing the work reported in this paper.

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