

An Integrated AHP–PROMETHEE II Framework for Refrigerated Transport Service Provider Selection

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Abstract: Refrigerated transport is essential for preserving the quality of temperature-sensitive products and maintaining continuity across cold chain logistics. Selecting a refrigerated transport service provider is therefore a multidimensional decision involving technical reliability, operational capability, commercial conditions, sustainability, and cost. This study develops an integrated framework combining the Analytic Hierarchy Process (AHP) and the Preference Ranking Organization Method for Enrichment Evaluations II (PROMETHEE II) to evaluate six providers in Ho Chi Minh City, Vietnam. Assessments from nine experts were used to determine the weights of four criteria groups and fifteen subcriteria through AHP, while PROMETHEE II was applied to establish the provider ranking. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and group-weight sensitivity analysis were used to examine the robustness of the results. Service Quality and Cost were the most influential criteria groups, with weights of 0.3981 and 0.2802, respectively. Service cost, temperature compliance, and quotation transparency received the highest subcriterion weights. Provider S2 ranked first under PROMETHEE II, with a net outranking flow of 0.3144, and retained this position under TOPSIS and across most variations in group weights. The proposed framework enables firms to compare providers using a consistent set of criteria, identify the preferred alternative, and assess whether the decision remains stable under different ranking methods and weighting assumptions.

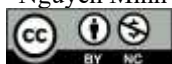
Keywords: AHP; cold chain logistics; PROMETHEE II; refrigerated transport; sensitivity analysis.

INTRODUCTION

Ho Chi Minh City is the economic center of Vietnam's Southern Key Economic Region and one of the country's main centers for trade, manufacturing, port services, and logistics. Under Resolution No. 202/2025/QH15, the present municipality was formed through the administrative reorganization of Ho Chi Minh City, Binh Duong Province, and Ba Ria–Vung Tau Province. It now covers approximately 6,773 km² and has a population of about 14 million (National Assembly of Vietnam, 2025). The reorganization has brought large urban markets, industrial zones, agricultural production areas, seaports, and logistics facilities within a single administrative area. The reorganization broadens the geographic scope of municipal logistics planning by bringing major production, industrial, port, and consumption areas under a single administrative authority. Agricultural products, seafood, and processed foods are particularly important within these flows because they support food processing, urban consumption, domestic distribution, and export activity. For these temperature-sensitive products, quality is determined not only by production conditions but also by the preservation of appropriate storage conditions throughout transportation. Temperature deviations, excessive waiting time, and unsuitable handling practices may shorten shelf life and increase product losses (Chen et al., 2022; Han et al., 2021; Thi et al., 2022). Refrigerated transport therefore provides an essential link between production and processing capacity and the quality standards required by domestic and international markets.

The performance of refrigerated transport is shaped by operating conditions that may change throughout a journey. Travel duration, repeated opening of vehicle doors, loading and unloading practices, and the condition of refrigeration equipment can all affect temperature stability. Sensors and Internet of Things (IoT) technologies enable firms to monitor temperature and humidity, detect abnormal conditions, and issue timely warnings while

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goods are in transit (Cil et al., 2022; Konovalenko et al., 2021). These technologies can improve operational visibility, but they do not remove the economic and environmental costs associated with refrigerated distribution. Vehicles and cooling equipment require considerable energy and fuel, which contributes to operating expenditure and transport emissions (Calati et al., 2022; du Plessis et al., 2023). The assessment of refrigerated transport providers should therefore extend beyond price and basic service performance to include technological capability, risk control, and environmental considerations.

Studies on cold chain supplier and logistics provider selection have increasingly considered sustainability, resilience, uncertainty, and group decision-making (Ali et al., 2025; Ecer et al., 2024). Even so, the requirements of refrigerated road transport are not always represented in sufficient detail. Temperature compliance, incident handling, document traceability, information system compatibility, cold chain risk management, quotation clarity, and contractual flexibility are often treated separately or given limited attention. There is also a tendency to report a single final ranking without examining whether the result changes when another ranking method is used or when the importance assigned to the criterion groups is altered. A ranking that is highly sensitive to such changes may provide a weak basis for provider selection.

This study develops a framework for evaluating and selecting refrigerated transport service providers in Ho Chi Minh City, Vietnam. The framework comprises four criteria groups and fifteen subcriteria covering service quality, operational capability, cost, and sustainability. The Analytic Hierarchy Process (AHP) is used to derive criterion weights from the judgments of nine experts. The Preference Ranking Organization Method for Enrichment Evaluations II (PROMETHEE II) is then applied to rank six candidate providers. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and group weight sensitivity analysis are used to examine the robustness of the results. The analysis seeks to identify the priority structure of the evaluation criteria, establish the relative ranking of the providers, and determine the stability of the leading alternative under different analytical conditions. By combining a criteria system tailored to refrigerated road transport with robustness checks that address both ranking procedures and changes in group weights, the study provides a more reliable basis for provider screening and contract-related decision-making.

LITERATURE REVIEW

Refrigerated Road Transport and Service Requirements

Refrigerated transport is an integral part of the cold chain and is responsible for moving temperature-sensitive goods using vehicles equipped with refrigeration systems, monitoring devices, and appropriate handling procedures. Its function extends beyond delivering goods to the specified destination on time. It must also maintain products within the required temperature range from the point of collection to final delivery (Ben Taher et al., 2022).

Existing research on refrigerated transport has developed along several related lines, including the monitoring and control of transport conditions, improvements in energy efficiency and emission reduction, and the assessment and selection of service providers. In relation to temperature control, Cil et al. (2022) developed an IoT system that monitors temperature and humidity, transmits data, and identifies abnormal events affecting temperature-sensitive goods at container ports. Konovalenko et al. (2021) proposed a method for predicting cargo temperature in real time using sensor data, thereby supporting the early detection of temperature deviations during transportation. Energy use and emissions from refrigerated vehicles and cooling equipment have also received considerable attention. Fabris et al. (2022) quantified the additional fuel consumption and emissions associated with refrigeration equipment installed on light-duty trucks. Wu et al. (2022), in turn, compared the carbon footprints of a conventional vapor-compression refrigeration system and a cold-storage system using phase-change materials. Studies based on operational data and route models further indicate that payload, travel distance, cooling duration, and journey configuration directly influence fuel consumption and emissions (Rahman et al., 2023; du Plessis et al., 2023).

Research on provider selection has increasingly considered a broader set of organizational and operational capabilities. Zhang et al. (2023) developed an evaluation system for cold chain logistics providers using social network analysis and fuzzy comprehensive evaluation. Sun et al. (2022) proposed criteria relating to service quality, cost, supply capability, green competitiveness, and corporate governance. These studies suggest that refrigerated transport providers should be assessed according to their physical resources, technological capacity, service performance, managerial competence, and environmental responsibility.

Evaluation Dimensions for Provider Selection

The selection of refrigerated transport service providers requires a multidimensional set of criteria that reflects technical requirements, operational capacity, commercial conditions, and longer-term considerations. This approach is consistent with previous studies on cold chain logistics and supplier selection, which have extended evaluation beyond price and basic service quality (Ecer et al., 2024; Sun et al., 2022). Following a synthesis of the

literature and refinement through expert consultation, the present study organizes the evaluation system into four groups: Service Quality, Operational Capability, Cost, and Sustainability.

Service Quality captures the provider's ability to protect cargo and provide verifiable service performance through Temperature Compliance, Real-Time Temperature Monitoring, Schedule Compliance, Incident Response Capability, and Service Information and Document Traceability (Cil et al., 2022; Konovalenko et al., 2021; Krstić & Tadić, 2023). Operational Capability represents the resources and organizational capacity required to perform the service, including Fleet Capacity and Size, Pickup and Delivery Network Coverage, IT and API Integration, and Cold Chain Risk Management Capability (Tu et al., 2022; Zhang et al., 2023). Cost distinguishes Service Cost from Quotation Transparency and Contractual Flexibility, thereby separating the nominal tariff from uncertainty over additional charges and the economic value of adapting service arrangements. Sustainability includes Environmental Impact, Reputation and Commitment to Sustainability, and Implementation of ISO Management Systems, which reflect environmental performance, organizational credibility, and the formalization of management practices (Cui et al., 2024; Hayati et al., 2025; Hendiani & Walther, 2025). This structure avoids treating the lowest quoted rate as equivalent to the lowest total procurement cost.

MCDM Approaches to Logistics Provider Selection

Multiple Criteria Decision Making (MCDM) supports the simultaneous evaluation of alternatives against criteria that differ in measurement units, preference directions, and relative importance. In practice, MCDM methods serve two main analytical purposes: determining criterion weights and ranking alternatives. AHP and the Best–Worst Method (BWM) are frequently used to estimate weights, whereas TOPSIS, PROMETHEE, the Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method, and related techniques are generally used to rank alternatives. More recent models combine these methods with fuzzy numbers, fuzzy inference systems, or machine-learning techniques to account for uncertainty in expert judgments and performance data (Tavana et al., 2024; Raveena & Umamaheswari, 2025).

Within cold chain research, MCDM frameworks have been adapted to incorporate temperature control, infrastructure, transport capacity, delivery reliability, traceability, and incident response. Tu et al. (2022) combined the second version of the Analytic Hierarchy Process sorting method (AHPSort II) with trapezoidal fuzzy numbers to classify cold chain logistics providers into predefined performance categories. Krstić and Tadić (2023) combined the fuzzy Factor Relationship method, known as Fuzzy FARE, with the fuzzy Axial Distance-Based Aggregated Measurement method, known as Fuzzy ADAM, to determine criterion weights and rank cold chain logistics providers. Ecer et al. (2024) and Ali et al. (2025) extended the selection problem by incorporating sustainability, resilience, and uncertainty into group assessments.

This pattern also appears in the wider supplier-selection literature. Siregar and Hendry (2025) combined AHP and BWM, while Arief et al. (2023) integrated the Taguchi Loss Function, fuzzy BWM, and VIKOR. Raveena and Umamaheswari (2025) combined fuzzy TOPSIS with support vector regression and grey relational analysis. These studies assign different analytical functions to the methods employed, including criterion weighting, representation of uncertainty, processing of performance information, and ranking of suppliers.

The present study uses AHP, PROMETHEE II, and TOPSIS for distinct but related purposes. AHP structures the criteria hierarchically, derives their weights through pairwise comparisons, and evaluates the consistency of expert judgments (Saaty, 1987). PROMETHEE II serves as the principal ranking method because it represents the degree of preference between each pair of alternatives and produces a complete ranking through the net outranking flow (Brans et al., 1986). TOPSIS evaluates each alternative according to its distance from the positive and negative ideal solutions. It therefore provides a different aggregation mechanism for comparing the PROMETHEE II ranking and assessing the robustness of the results (Hwang & Yoon, 1981).

METHOD

The empirical analysis was conducted in five sequential stages. First, the evaluation criteria were identified from the relevant literature and refined through expert consultation, resulting in a hierarchical structure comprising four criterion groups and fifteen subcriteria. Second, nine experts independently completed two questionnaire components: pairwise comparisons of the criterion groups and subcriteria using Saaty's nine-point scale, and performance assessments of six refrigerated transport service providers across the fifteen subcriteria. Third, AHP was applied to aggregate the individual judgments using the geometric mean, verify the consistency of the comparison matrices, and calculate the local and global criterion weights. Fourth, the aggregated provider-performance scores and AHP-derived global weights were incorporated into PROMETHEE II to calculate pairwise preference indices, positive and negative outranking flows, net flows, and the final provider ranking. Finally, the robustness of the ranking was examined by comparing the PROMETHEE II results with those obtained from TOPSIS and by varying each criterion-group weight while proportionally rescaling the remaining group weights. The methodological procedures followed Saaty (1987), Forman and Peniwati (1998), Brans et al. (1986), Hwang and Yoon (1981), and Więckowski and Sałabun (2023). Figure 1 summarizes the complete analytical workflow.

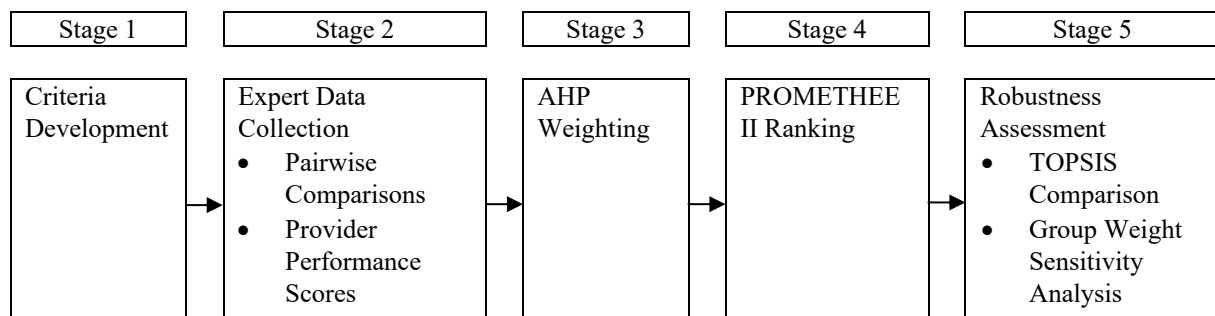


Fig. 1 Research Procedure

Criteria Development, Expert Panel, and Data Collection

The initial criteria set was synthesized from the literature and then validated and refined through expert consultation. The final hierarchy comprised four criterion groups and fifteen subcriteria (Table 1). Service Cost and Environmental Impact were modeled as cost criteria, whereas the remaining criteria were modeled as benefit criteria.

Experts were purposively selected based on their professional experience and direct involvement in supply-chain-related decision-making. Eligible participants were required to have at least three years of relevant professional experience, hold a managerial position in an agricultural, seafood, or food-processing firm, and have responsibilities related to logistics, transportation, procurement, supplier evaluation, warehousing, distribution, or temperature-controlled supply-chain activities. The final panel comprised nine experts with 3–14 years of relevant professional experience, including four from firms handling agricultural products, two from seafood firms, and three from food-processing firms. Their functional backgrounds covered supply chain management and planning, procurement and strategic sourcing, logistics and transportation, export logistics, warehousing, distribution, and cold-chain operations. The panel included managers whose direct responsibilities spanned refrigerated transportation, logistics-provider evaluation, and temperature-controlled operations. The first questionnaire component elicited pairwise comparisons of criterion groups and subcriteria using Saaty's nine-point scale (Saaty, 1987). The second required each expert to score six providers, denoted S1–S6, against the fifteen subcriteria on a 1–9 scale. For benefit criteria, a score of 1 indicated very poor performance, whereas a score of 9 indicated excellent performance. For cost criteria, a score of 1 represented the lowest cost or environmental burden, whereas a score of 9 represented the highest. The directions of the cost criteria were subsequently reversed in the PROMETHEE II and TOPSIS calculations. The providers were anonymized as S1–S6 to protect commercially sensitive information related to pricing, contractual terms, and service performance. Pairwise comparisons were used to estimate AHP weights, while the provider scores formed the decision matrix for PROMETHEE II and TOPSIS.

Table 1. Evaluation Criteria for Refrigerated Transport Service Providers

Group	Code	Criterion	Direction	Definition
F1 Service Quality	F11	Temperature Compliance	Benefit	Ability to maintain cargo within the specified temperature range throughout transportation.
	F12	Real-Time Temperature Monitoring	Benefit	Ability to monitor and record temperature continuously and issue timely alerts when deviations occur.
	F13	Schedule Compliance	Benefit	Ability to complete pickups and deliveries within agreed time windows.
	F14	Incident Response Capability	Benefit	Speed and effectiveness of containment, communication, and service recovery following operational or temperature-related incidents.
	F15	Service Information and Document Traceability	Benefit	Completeness, accuracy, accessibility, and timeliness of temperature records, incident reports, and delivery documents.
F2 Operational Capability	F21	Fleet Capacity and Size	Benefit	Availability, condition, and capacity of refrigerated vehicles relative to customer demand.
	F22	Pickup and Delivery Network Coverage	Benefit	Geographic reach and ability to connect production areas, processing facilities, seaports, distribution centers, and markets.

	F23	IT and API Integration	Benefit	Ability to exchange operational data with customer systems through digital platforms or application programming interfaces (APIs).
	F24	Cold Chain Risk Management Capability	Benefit	Quality of contingency planning and capability to prevent, mitigate, and recover from cold chain disruptions.
F3 Cost	F31	Service Cost	Cost	Total transportation charge by trip, shipment volume, route, and applicable service conditions.
	F32	Quotation Transparency	Benefit	Clarity and completeness of base rates, surcharges, inclusions, exclusions, and potential additional charges.
	F33	Contractual Flexibility	Benefit	Ability to adjust shipment volumes, schedules, service levels, and commercial terms in response to changing customer requirements.
F4 Sustainability	F41	Environmental Impact	Cost	Environmental burden associated with vehicles, fuel consumption, energy use, refrigerants, and emissions.
	F42	Reputation and Commitment to Sustainability	Benefit	Market reputation and demonstrated commitment to sustainable business practices.
	F43	Implementation of ISO Management Systems	Benefit	Extent to which relevant ISO management systems are implemented, maintained, or certified.

Analytic Hierarchy Process

AHP was used to determine the weights of the criteria groups and subcriteria (Saaty, 1987). The consistency of each expert's comparison matrices was checked before aggregation. As all experts were assigned equal importance, their judgments were combined using the geometric mean (Forman & Peniwati, 1998).

For K experts, the aggregated comparison between criteria i and j was calculated as:

$$\bar{a}_{ij} = \left(\prod_{k=1}^K a_{ij}^{(k)} \right)^{1/K} \quad (1)$$

where $a_{ij}^{(k)}$ denotes the judgment of expert k regarding the relative importance of criterion i compared with criterion j .

The geometric mean of row i in the aggregated comparison matrix was calculated as:

$$g_i = \left(\prod_{j=1}^s \bar{a}_{ij} \right)^{1/s} \quad (2)$$

The weight of criterion i was then obtained by normalizing the row geometric means:

$$w_i = \frac{g_i}{\sum_{r=1}^s g_r} \quad (3)$$

where s is the number of criteria included in the relevant comparison matrix.

Because the evaluation structure was hierarchical, the global weight of subcriterion c belonging to group g was calculated as:

$$w_c^{\text{global}} = w_g^{\text{group}} \times w_{c|g}^{\text{local}} \quad (4)$$

The consistency of each comparison matrix was evaluated using the maximum eigenvalue, the Consistency Index (CI), and the Consistency Ratio (CR):

$$\lambda_{\max} = \frac{1}{s} \sum_{i=1}^s \frac{(Aw)_i}{w_i} \quad (5)$$

$$CI = \frac{\lambda_{\max} - s}{s - 1} \quad (6)$$

$$CR = \frac{CI}{RI_s} \quad (7)$$

where RI_s is the Random Index corresponding to a comparison matrix of size s . A matrix was considered acceptably consistent when $CR < 0.10$ (Saaty, 1987).

PROMETHEE II Analysis

PROMETHEE II was applied to rank the six providers using the AHP weights and aggregated performance scores (Brans et al., 1986). The performance score of provider i on criterion j was first calculated as the arithmetic mean of the scores assigned by the K experts:

$$x_{ij} = \frac{1}{K} \sum_{k=1}^K x_{ij}^{(k)} \quad (8)$$

where $x_{ij}^{(k)}$ is the score assigned by expert k to provider i on criterion j .

Although the 1–9 ratings are ordinal, they were treated as an approximately equally spaced numerical scale for aggregation because all experts evaluated the same providers using the same scale and were assigned equal importance. The arithmetic mean was therefore used to obtain a common panel-level assessment, with this treatment regarded as a modeling approximation rather than an assumption of empirically equal intervals between adjacent rating categories.

The aggregated performance values were normalized to the interval $[0, 1]$ using min-max normalization:

$$r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \quad (9)$$

Normalization placed all performance differences on a common scale. The preference direction was not reversed in the original data but was incorporated when the difference between two alternatives was calculated.

For a benefit criterion, the performance difference between alternatives a and b was defined as:

$$d_j(a, b) = r_{aj} - r_{bj} \quad (10a)$$

For a cost criterion, the direction of the difference was reversed:

$$d_j(a, b) = r_{bj} - r_{aj} \quad (10b)$$

Under these definitions, $d_j(a, b) > 0$ always indicates that alternative a performs more favorably than alternative b on criterion j .

The performance difference was converted into a preference degree using the V-shape preference function without an indifference region (Brans et al., 1986):

$$P_j(d) = \begin{cases} 0, & d \leq 0, \\ \frac{d}{p_j}, & 0 < d < p_j, \\ 1, & d \geq p_j. \end{cases} \quad (11)$$

The V-shape specification was selected because the aggregated performance scores, after normalization, were treated as approximately continuous. No positive indifference threshold was introduced because no empirical or contractual evidence supported treating small favorable differences as negligible. Since favorable differences for all criteria were bounded between 0 and 1 after normalization, and no criterion-specific preference benchmarks were available, the preference threshold was set uniformly to $p_j = 1$ for all criteria. Under this specification, preference increased linearly over the full range of positive differences and reached complete preference only when the normalized difference equaled 1. The common threshold was therefore treated as an explicit modeling assumption rather than an empirically estimated parameter.

The aggregated preference index of alternative a over alternative b was calculated as:

$$\pi(a, b) = \sum_{j=1}^m w_j P_j[d_j(a, b)] \quad (12)$$

where w_j is the global weight of criterion j , subject to:

$$\sum_{j=1}^m w_j = 1, w_j \geq 0 \quad (13)$$

The positive outranking flow measures the extent to which alternative a is preferred to the remaining alternatives:

$$\varphi^+(a) = \frac{1}{n-1} \sum_{b \neq a} \pi(a, b) \quad (14)$$

The negative outranking flow measures the extent to which alternative a is outperformed by the remaining alternatives:

$$\varphi^-(a) = \frac{1}{n-1} \sum_{b \neq a} \pi(b, a) \quad (15)$$

The net outranking flow was calculated as:

$$\varphi(a) = \varphi^+(a) - \varphi^-(a) \quad (16)$$

Providers were ordered by descending net outranking flow. A larger net flow indicates that a provider dominates competing alternatives more strongly on the weighted criteria.

Robustness Assessment

The robustness of the provider ranking was examined using TOPSIS and group weight sensitivity analysis. TOPSIS was applied to the same performance matrix and AHP weights used in PROMETHEE II (Hwang & Yoon, 1981). After vector normalization and weighting, each provider's distances from the positive and negative ideal solutions were calculated. The relative closeness coefficient was obtained as:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (17)$$

where D_i^+ and D_i^- denote the distances from provider i to the positive and negative ideal solutions, respectively. Providers were ranked in descending order of C_i . Agreement between the PROMETHEE II and TOPSIS rankings was evaluated using Spearman's rank correlation coefficient (Spearman, 1904):

$$\rho_s = 1 - \frac{6 \sum_{i=1}^n d_i^2}{n(n^2-1)} \quad (18)$$

where d_i is the difference between the ranks assigned to provider i by the two methods. A value closer to 1 indicates stronger agreement.

Sensitivity analysis was conducted by varying the weight of one criterion group at a time over the interval $[0, 1]$, while keeping the local weights of its subcriteria unchanged. The remaining group weights were adjusted proportionally to their original values (Więckowski & Sałabun, 2023):

$$W'_h(\theta) = \theta \quad (19)$$

$$W'_g(\theta) = W_g \frac{1-\theta}{1-W_h}, \quad g \neq h \quad (20)$$

Under this adjustment, each provider's PROMETHEE II net flow is a linear function of the varied group weight. The stability boundaries were therefore determined analytically from the weight values at which the net flows of adjacent providers in the original ranking became equal. The intersection of the resulting inequalities defined the interval over which the complete ranking was preserved. The first-place stability interval was determined similarly by comparing the leading provider with each of the remaining alternatives. Because the boundaries were obtained analytically rather than through a discrete grid search, no step-size resolution was imposed; the resulting values were reported to four decimal places.

RESULT

Priority Structure of the Evaluation Criteria

The individual pairwise-comparison judgments were aggregated using the geometric mean after the consistency of each expert's matrices had been verified. The resulting aggregated pairwise-comparison matrices for the criterion groups and subcriteria are provided in the supplementary materials. All individual pairwise-comparison matrices satisfied the consistency requirement of $CR < 0.10$; the highest individual CR was 0.0645. After aggregation, CR equaled 0.0110 for the criterion-group matrix and 0.0112, 0.0041, 0.0142, and 0.0133 for the F1–F4 subcriteria matrices, respectively. Kendall's coefficient of concordance was also used to examine inter-expert agreement. Based on the within-expert rankings derived from the individual global weights of the fifteen subcriteria, Kendall's W was 0.4287 and statistically significant at the 0.001 level, indicating a moderate degree of concordance among the nine experts.

Figure 2 shows that Service Quality received the largest group weight (0.3981), followed by Cost (0.2802), Operational Capability (0.1858), and Sustainability (0.1359). Service Quality and Cost accounted for a combined 67.83% of the total weight. The weighting pattern indicates that buyers place primary emphasis on reliable service execution and commercial performance, while treating operating capability and sustainability as supporting but still material considerations.

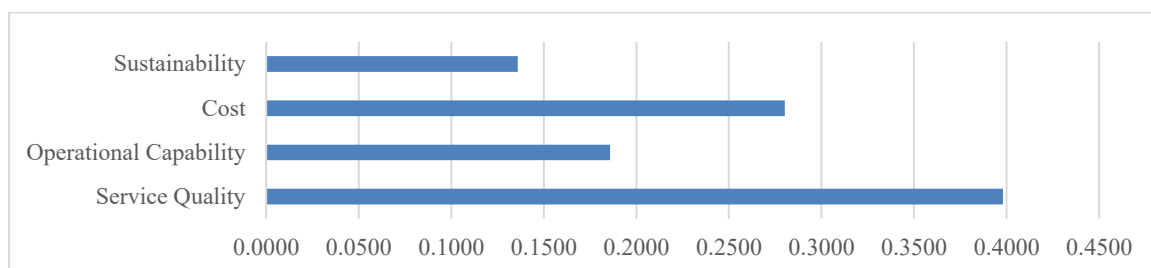


Fig. 2 Weights of the Four Criteria Groups

At the subcriterion level, Service Cost had the largest global weight (0.1183), followed by Temperature Compliance (0.1043), Quotation Transparency (0.0892), Real-Time Temperature Monitoring (0.0889), and Schedule Compliance (0.0830). Together, these five subcriteria accounted for 48.37% of total weight. Decision priority was therefore concentrated on the realized cost of service, preservation of temperature integrity, transparency of commercial terms, and dependable execution. Table 2 presents the local and global weights of all fifteen subcriteria, along with their ranks, criterion groups, and preference directions.

The within-group weights provide additional insight. Temperature Compliance, Real-Time Temperature Monitoring, and Schedule Compliance accounted for 69.37% of Service Quality. Operational Capability weights were comparatively balanced, ranging from 0.2271 to 0.2784 locally, suggesting that the experts assigned broadly similar importance to the four operational capabilities. Within Cost, Service Cost represented 42.23%, whereas

Quotation Transparency and Contractual Flexibility jointly represented 57.77%. Environmental Impact received the largest local weight within Sustainability.

Table 2. Local and Global Weights of the Fifteen Subcriteria

Rank	Code	Subcriterion	Direction	Local weight	Global weight
1	F31	Service Cost	Cost	0.4223	0.1183
2	F11	Temperature Compliance	Benefit	0.2620	0.1043
3	F32	Quotation Transparency	Benefit	0.3184	0.0892
4	F12	Real-Time Temperature Monitoring	Benefit	0.2232	0.0889
5	F13	Schedule Compliance	Benefit	0.2085	0.0830
6	F33	Contractual Flexibility	Benefit	0.2593	0.0727
7	F41	Environmental Impact	Cost	0.4592	0.0624
8	F14	Incident Response Capability	Benefit	0.1548	0.0616
9	F15	Service Information and Document Traceability	Benefit	0.1515	0.0603
10	F21	Fleet Capacity and Size	Benefit	0.2784	0.0517
11	F22	Pickup and Delivery Network Coverage	Benefit	0.2546	0.0473
12	F23	IT and API Integration	Benefit	0.2399	0.0446
13	F24	Cold Chain Risk Management Capability	Benefit	0.2271	0.0422
14	F43	Implementation of ISO Management Systems	Benefit	0.2724	0.0370
15	F42	Reputation and Commitment to Sustainability	Benefit	0.2684	0.0365

Provider Ranking and Outranking Performance

The individual provider ratings were aggregated across the nine experts using the arithmetic mean. The resulting provider-performance matrix, which served as the common input for the PROMETHEE II and TOPSIS analyses, is also provided in the supplementary materials. These aggregated scores were subsequently normalized and converted into criterion-specific performance differences according to the preference direction of each criterion. Normalized pairwise performance differences were transformed through the V-shape function and aggregated using the global criterion weights to obtain the preference index $\pi(a, b)$. Table 3 presents the resulting bilateral preference structure.

The strongest bilateral preference was $\pi(S2, S4) = 0.7777$. S2 also recorded substantial preference over S1, S3, S5, and S6, with values of 0.3089, 0.2747, 0.2019, and 0.2499, respectively. By contrast, S4 showed only weak preference over every competitor and was strongly outranked in the reverse comparisons. The pairwise pattern therefore points to a broad-based advantage for S2 and a systematic disadvantage for S4 rather than outcomes driven by a single comparison.

Table 3. Pairwise Aggregated Preference Matrix

Provider	S1	S2	S3	S4	S5	S6
S1	—	0.0424	0.1019	0.4875	0.0999	0.1131
S2	0.3089	—	0.2747	0.7777	0.2019	0.2499
S3	0.1177	0.0240	—	0.5151	0.0710	0.0945
S4	0.0355	0.0592	0.0473	—	0.1183	0.0710
S5	0.1938	0.0293	0.1491	0.6643	—	0.1346
S6	0.2160	0.0863	0.1816	0.6259	0.1436	—

S2 recorded the highest positive flow ($\phi^+ = 0.3626$), the lowest negative flow ($\phi^- = 0.0482$), and the largest net flow (0.3144), placing it first (Table 4). S6 and S5 ranked second and third with net flows of 0.1181 and 0.1073, separated by only 0.0108. S3 and S1 occupied the middle-lower positions with net flows of 0.0135 and -0.0054 , while S4 ranked last at -0.5478 .

The net-flow margin between S2 and S6 was 0.1963, far larger than the margin between S6 and S5. The result identifies S2 as a distinct first-choice provider, whereas the second- and third-ranked alternatives should be regarded as close substitutes whose relative positions may depend on additional operational evidence.

Table 4. PROMETHEE II Outranking Flows and Provider Rankings

Provider	ϕ^+	ϕ^-	Net flow	Rank
S2	0.3626	0.0482	0.3144	1
S6	0.2507	0.1326	0.1181	2
S5	0.2342	0.1269	0.1073	3
S3	0.1645	0.1509	0.0135	4

S1	0.1690	0.1744	-0.0054	5
S4	0.0663	0.6141	-0.5478	6

Ranking Robustness

As shown in Table 5, TOPSIS produced the same provider ranking as PROMETHEE II, with a Spearman rank correlation coefficient of 1.000. The ranking was therefore invariant to replacing the outranking mechanism with an ideal-solution distance approach.

Table 5. Cross-Method Comparison of Provider Rankings

Provider	Net flow	PROMETHEE II rank	TOPSIS C_i	TOPSIS rank
S1	-0.0054	5	0.5076	5
S2	0.3144	1	0.7209	1
S3	0.0135	4	0.5549	4
S4	-0.5478	6	0.2608	6
S5	0.1073	3	0.5773	3
S6	0.1181	2	0.6732	2

TOPSIS also confirmed the separation of S2 from the remaining providers. S2 achieved the largest closeness coefficient (0.7209), followed by S6 (0.6732) and S5 (0.5773), while S4 remained last (0.2608). Agreement across the two methods strengthens the evidential basis for selecting S2.

Weight stability was examined by varying one criterion-group weight at a time, proportionally rescaling the remaining group weights, and recalculating the PROMETHEE II ranking. Table 6 summarizes the intervals over which the original complete ranking was preserved. The lower and upper bounds represent analytical crossing points at which adjacent providers attained equal net flows; the strict original ordering was maintained between these points.

The strict complete ranking was preserved between the analytical boundary values of 0.2686 and 0.6853 for Service Quality, 0 and 0.4525 for Operational Capability, 0.2095 and 0.4611 for Cost, and 0 and 0.2092 for Sustainability. More importantly, S2 remained first across the entire feasible range from 0 to 1 for Service Quality, Operational Capability, and Cost, and until the Sustainability weight reached an analytical crossing point of approximately 0.9144. The leading provider was therefore substantially more stable than the complete ordering of all six alternatives.

Table 6. Group Weight Stability Intervals Preserving the Complete Ranking

Code	Criteria group	Current weight	Lower bound	Upper bound	Width
F1	Service Quality	0.3981	0.2686	0.6853	0.4167
F2	Operational Capability	0.1858	0.0000	0.4525	0.4525
F3	Cost	0.2802	0.2095	0.4611	0.2516
F4	Sustainability	0.1359	0.0000	0.2092	0.2092

DISCUSSIONS

The results reveal a procurement logic in which technical reliability and commercial control are valued together. Quotation Transparency received a global weight close to that of Real-Time Temperature Monitoring, indicating that information about charges is nearly as important as information about cargo conditions. Transparent quotations reduce uncertainty over actual expenditure and limit the risk that a low initial tariff becomes a high total service cost through surcharges or incomplete service coverage. The similar weights assigned to Service Cost and Temperature Compliance suggest that the expert panel considered cost control and temperature integrity to be comparably important in provider selection.

The importance assigned to temperature control, schedule reliability, incident response, and traceability is consistent with research that views cold chain performance as a combination of monitoring capability and dependable service execution (Cil et al., 2022). The inclusion of operational resources, digital integration, risk management, and sustainability also reflects the broader direction of logistics provider-selection research (Ecer et al., 2024). This study adds to that literature by bringing these dimensions into a criteria system designed specifically for refrigerated road transport and by testing the stability of the ranking across methods and weighting assumptions.

Service Quality was the dominant criterion group, whereas Service Cost was the most important individual subcriterion. These findings are not contradictory. Buyers seek to control expenditure, but they assess price as part of a wider service package that includes temperature integrity, reliability, responsiveness, and information quality. The relevant objective is therefore not the lowest quoted price, but the best risk-adjusted value. A provider with a

moderately higher tariff may be preferable when stronger controls reduce expected spoilage, disruption, monitoring, and contract-management costs.

The robustness tests strengthen the recommendation of S2. TOPSIS examined whether the ranking depended on the aggregation method, while sensitivity analysis examined whether it depended on the weights assigned to the criterion groups. S2 ranked first under both methods and retained its leading position under substantial weight variation. The recommendation is therefore supported by both cross-method agreement and stability across plausible preference structures. Most ranking changes occurred below first place, particularly between S6 and S5 and among the middle-ranked providers. The evidence is therefore stronger for the leading alternative than for the exact ordering of the remaining providers. Firms selecting a backup or second-source provider should supplement the ranking with current capacity, route-specific performance, and commercial due diligence.

The findings also have practical implications for providers and purchasing firms. Providers can strengthen their competitive position through investment in temperature monitoring, schedule compliance, incident response, document traceability, system integration, and cold chain risk management. Sustainability remains relevant because environmental performance, organizational commitment, and management systems affect longer-term risk and operational credibility. Purchasing firms should translate the highest-weight criteria into measurable contractual indicators, including the proportion of transport time within the required temperature range, monitoring frequency, on-time pickup and delivery rates, incident response time, and document completeness. Quotation templates should clearly specify routes, payloads, temperature ranges, service duration, inclusions, and surcharges, while contracts should define adjustment mechanisms for volume, schedule, service level, and commercial terms.

The academic contribution lies primarily in the evaluation structure rather than in algorithmic novelty. The study combines technical service outcomes, operational resources, commercial conditions, and sustainability within a refrigerated-road-transport-specific framework. It also reports the normalization rules, preference function, threshold assumption, cross-method comparison, and weight-stability results, thereby improving transparency and allowing readers to distinguish a stable recommendation from a ranking that is sensitive to model assumptions. The findings should nevertheless be interpreted considering several limitations. The expert panel was relatively small, the provider performance scores were judgment-based and reflected conditions during a single assessment period, and a common preference function and threshold were applied across all criteria. Future research should use larger and more diverse expert samples, validate expert assessments against objective operational data, and derive criterion-specific thresholds from contractual requirements.

CONCLUSION

The analysis shows that refrigerated transport procurement is governed by a balance between service assurance and commercial discipline. Service Quality and Cost were the dominant criterion groups, while Service Cost, Temperature Compliance, Quotation Transparency, Real-Time Temperature Monitoring, and Schedule Compliance formed the core decision priorities. The results therefore favor a value-based selection logic in which price is assessed together with expected service performance and risk.

PROMETHEE II ranked S2 first, followed by S6 and S5, and TOPSIS reproduced the same order. Sensitivity analysis further showed that S2 retained first place across the entire feasible range from 0 to 1 for Service Quality, Operational Capability, and Cost, and until the Sustainability weight reached an analytical crossing point of approximately 0.9144. The choice of S2 is consequently robust, although the narrow gap between S6 and S5 suggests that the selection of a secondary provider should draw on additional operating evidence.

The study contributes a transparent decision framework that converts the technical, operational, commercial, and sustainability requirements of refrigerated transport into a structured procurement process. The framework can support provider scorecards, service-level agreements, standardized quotations, contract design, and due diligence. Its principal value lies in combining a context-specific criteria system with explicit tests of whether the preferred decision remains stable under alternative methods and weighting assumptions.

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