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Integrated Multi-Criteria Strategic Framework for Warehouse Location Selection in Growing Distribution Networks

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Abstract

The rapid expansion of distribution networks and increasing demand expectations have intensified the strategic importance of warehouse location selection in modern supply chains. Organizations operating within rapidly growing distribution networks must evaluate potential warehouse locations across multiple decision levels, including external environmental conditions, regional logistic ecosystems, strategic network alignments, and financial feasibility. However, Traditional facility locations often focus primarily on operation or cost-based criteria, which may overlook broader strategic and environmental considerations crucial for long term network developments. This paper proposes an integrated multi-level strategic framework for warehouse location selection designed to address this gap. The proposed framework integrates four complementary analytical components: (1) macro-environmental analysis using the DESTEP model, (2) meso analysis for logistics ecosystems evaluation, (3) strategic filtering aligned with organisational distribution objectives, and (4) financial feasibility assessments. To enhance analytical rigor and support quantitative decision-making, the framework introduces a Hierarchical Scoring Matrix that systematically evaluates and ranks candidate warehouse locations across multiple criteria, including logistic performance and sustainable development considerations. By integrating qualitative strategic analysis with a structured quantitative scoring method, the proposed framework provides a transparent, consistent, and reproducible decision-support tool for warehouse location planning. The framework enables organizations to evaluate alternative locations more comprehensively, particularly rapidly growing distribution networks.

Keywords
Warehouse Location Selection, Distribution Network Design, Multi-Criteria Decision Making, Logistics Network Planning, Strategic Supply Chain Design.

1. Introduction

The rapid growth in global supply chains and increasing demands for faster and reliable distribution services have significantly increased the complexity of logistic network planning. Organisations operating within rapidly growing distribution networks must continuously adapt their infrastructure to accommodate expanding demand, evolving market conditions, and rising service requirements that are increasing operational pressures. Amongst the most critical strategic decisions for supply chain design in this context is warehouse location selection, which directly influences transportation efficiency, inventory management, service promptness, and long-term network performance.

Warehouse location decisions have traditionally been addressed using facility location models and operational optimisation techniques that primarily focus on cost efficiency, transportation distance, and infrastructure accessibility. Though these approaches provide valuable analytical insights, they often evaluate warehouse location from a limited operational perspective causing challenges in systematically incorporating qualitative strategic insights with quantitative decision models. As distribution networks expand, decision-makers must also consider macro-environment conditions, regional logistic ecosystems, strategic network alignments, and financial feasibility when planning future logistic infrastructure. Traditional limitations highlight the importance of integrating strategic analysis with structured quantitative decision-support methodologies. Multi-criteria evaluation methods combined with integrated analytical frameworks allow organisations to systematically evaluate complex supply chain decisions while balancing operational performance, sustainability considerations, and long-term network scalability. This approach supports transparency and replicable decision-making processes. It also promotes innovative research and collaboration between academia and industry to advance Industrial Engineering and Operations Management practices.

To address the traditional challenges, this paper proposes an integrated multi-level strategic framework for warehouse location selection in rapidly growing distribution networks. The proposed framework integrates four complementary analytical tools which are macro-environmental analysis using the DESTEP model, meso-level logistics ecosystem evaluation, strategic filtering aligned with organisational distribution strategy, and financial feasibility assessment. To enhance analytical rigor and support quantitative decision-making, it incorporates a Hierarchical Weighted Scoring Matrix that enables systematic evaluation and ranking of candidate warehouse locations across multiple criterias including logistic performance, infrastructure availability, and sustainability considerations. By integrating qualitative strategic analysis with quantitative multi-criteria evaluation, the proposed framework provides a structured decision-support tool for warehouse location planning. The framework contributes to Industrial Engineering and Operations Management research by offering a comprehensive transparent approach that supports strategic logistics infrastructure development in rapidly expanding distribution networks.

1.1 Objectives

The primary objective of this research is to develop an integrated and quantitative decision-support framework for warehouse location selection within rapidly growing distribution networks. The proposed framework aims to improve the transparency, consistency, and reproducibility of warehouse location planning by integrating strategic and operational evaluation dimensions within a unified multi-criteria methodology. The specific key objectives of this research contributes to:

1. Identify key macro-environmental, logistics, strategic and financial criteria influencing warehouse location selection.
2. Develop an integrated multi-level evaluation framework combining DESTEP analysis, logistic ecosystem evaluation, strategic filtering, and financial feasibility assessment.
3. Apply a Hierarchical Weighted Scoring Matrix (HWSM) based on Multi-Criteria Decision-Making (MCDM) and Analytic Hierarchy Process (AHP) principles for quantitative evaluation and ranking of candidate warehouse locations.
4. Demonstrate applicability of proposed framework through real-world case-based analysis involving alternative warehouse location scenarios.
5. Assess the effectiveness and robustness of the proposed framework in supporting transparent, reproducible warehouse location decision-making.

2. Literature Review

Warehouse location selection is a fundamental component of supply chain and distribution network design because it directly influences transportation efficiency, inventory positioning, service responsiveness, and long-term operational performance. Thuengnaitham (2022) highlighted that warehouse location decisions significantly affect logistics responsiveness and distribution efficiency, particularly within rapidly growing fulfillment and distribution networks. Similarly, Choi et al. (2021) emphasized that increasingly complex and extended supply chains require greater supply chain visibility, coordination, and infrastructure scalability across multiple logistic tiers. Traditional warehouse location approaches primarily focus on transportation distance, operational efficiency, and cost minimization, but often underrepresent broader strategic and environmental considerations required for long-term network development (Durán et al. 2021; Chakraborty et al.2020).

To address increasing logistic complexity, Multi-Criteria Decision-Making (MCDM) methods have been widely applied in warehouse and supply chain planning. Stanujkic et al. (2020) explained that MCDM approaches improve transparency and consistency in logistics evaluation by enabling simultaneous assessment of quantitative and qualitative criteria. Taletović (2023) further noted that MCDM methods are increasingly used in warehouse management and location selection due to their ability to quantitatively evaluate operational, strategic, and sustainability-related factors. Among these approaches, the Analytical Hierarchy Process (AHP) is commonly applied to structure decision problems hierarchically and assign relative importance to criteria and sub-criteria through weighted evaluation mechanisms (Pamučar et al. 2021). Thuengnaitham (2022) demonstrated that AHP-based warehouse location models effectively support hierarchical evaluation and transportation, facilities, workforce, and market-related criteria.

Recent studies demonstrated the growing integration of weighted scoring, ranking, and MCDM approaches for warehouse location selection. Bairagi (2022) proposed a Fuzzy Multi-Criteria Analysis (FMCA) model combining subjective and objective criteria through weighted aggregation and Benefit-Cost Ratio (BCR) evaluation to support quantitative warehouse location selection under conflicting decision criteria. Taletović (2023) investigated that the application of MCDM methods such as TOPSIS, VIKOR, ELECTRE, and GIS-based evaluation methods became increasingly important in warehouse management systems particularly location selection, equipment selection, inventory management, and performance evaluation. While these approaches provide structured methods for ranking alternatives and improvement of decision-making, they focus on specific operational dimensions or individual quantitative evaluation methods, highlighting the importance of translating qualitative logistics considerations into measurable evaluation criteria to provide a foundation for developing a more comprehensive warehouse location evaluation framework.

The use of optimization-based methods also increased to improve decision-making under transportation, capacity, and demand constraints. Yazdani et al. (2020) proposed an integrated decision-making model combining Data Envelopment Analysis (DEA), Full Consistency Method (FUCOM), and Combined Compromise Solution (CoCoSo) to demonstrate the importance of integrated analytical approaches and sensitivity analysis in improving decision robustness. Wang and Xia (2019) further applied Genetic Algorithms (GA) for optimizing warehouse location and improving warehouse efficiency, highlighting the growing use of optimization techniques in warehouse planning. Artificial Intelligence techniques also gained increasing attention in supply chain and logistics management for their ability to support predictive analytics, adaptive decision-making, machine learning, and processing of large complex operational datasets (Baryannis et al., 2019). These approaches enhance analytical capabilities and optimization performances, but often require extensive datasets, computational resources, and specialists or experts, limiting their practical applicability for strategic warehouse planning decisions, particularly in organizations with constrained data availability, lack of computational resources or technical expertise.

Despite the availability of various MCDM, optimization-based, and AI-driven approaches, existing studies often apply macro-environmental analysis, logistics ecosystem evaluation, strategic assessment, and financial feasibility independently, creating fragmented decision-making processes with limited integration of qualitative strategic analysis and quantitative evaluation models. Existing approaches primarily emphasize operational performance, rank optimization, or cost efficiency, while providing limited integration of macro-environmental considerations, strategic alignments, logistics ecosystem evaluation, and financial dimensions in a single decision-support framework. Therefore this research proposes an integrated multi-level strategic framework supported by a Hierarchical Weighted Scoring Matrix (HWSM) that combines DESTEP-based macro-environmental analysis, logistics ecosystem evaluation, strategic filtering, and financial feasibility assessment within a unified quantitative decision-support methodology. This proposed framework supports the systematic evaluation, scoring, and ranking of candidate warehouse locations, providing a transparent and reproducible approach for warehouse location planning in rapidly growing distribution networks.

3. Methods

This study proposes an integrated multi-level decision-making framework to support warehouse location selection in a complex distribution network. The case study used in this research is based on a real-world warehouse planning project in Europe. Due to confidentiality constraints associated with the industrial partner, the actual location choices are anonymized and represented as Location A, B, C, and D together with the company's operational data. However, the hierarchical structure and decision logic remains representative of real-world warehouse location planning practices and form the basis of the proposed Hierarchical Weighted Scoring Matrix (HWSM). The original project did not explicitly employ Analytical Hierarchy Process (AHP), instead the warehouse location decisions were supported through stakeholder consultations, DESTEP analysis, logistic ecosystem assessment, strategic evaluation and financial feasibility studies for its recommendations. To improve methodological transparency and support systematic quantitative evaluation, the strategic priorities and decision criteria documented during the original project were reconstructed into an AHP-compatible hierarchical structure, then incorporated into the proposed HWSM Framework. Due to the original project involving multiple stakeholders from logistics, operations, and strategic planning departments, the identified priorities were reviewed across project documentation and cross-functional assessments to ensure consistency with the final warehouse recommendation process. These documents were developed during different phases of the warehouse planning process and served as the basis for the final recommendation. The project documentation included logistic planning assessments, strategic expansion evaluations, and financial feasibility analysis. Therefore, the reconstructed weighting structure reflects consensus priorities documented throughout the original project rather than individual subjective judgments. This approach provides a transparent basis for translating the original decision rationale into the proposed HWSM framework while maintaining consistency with the final warehouse location recommendation.

3.1 Criteria Identification and Hierarchy Development

The evaluation criteria were derived from the anonymized industrial warehouse location planning project in a rapidly growing distribution company operating within Europe, conducted to support long-term warehouse expansion decisions under increasing operational pressure caused by capacity limitations, rising labor costs, increasing transportation expenses, and future growth requirements. Criteria identification was based on stakeholder consultations, strategic evaluation, macro-environmental assessment, logistics ecosystem analysis, and financial feasibility studies during the original project, resulting in the identification of decision factors considered most influential in warehouse location selection.

The identified decision factors were organized into a hierarchical structure following the principles of AHP. The resulting hierarchy consists of four primary dimensions: (1) Macro-Environmental Attractiveness, (2) Logistics Ecosystem Suitability, (3) Strategic Alignment, and (4) Financial Feasibility. Each primary dimension is further decomposed into measurable sub-criteria to enable consistent evaluation across candidate locations. Macro-environmental includes economic performance, infrastructure availability, and regulatory conditions using DESTEP. Logistics ecosystem includes demand proximity, supplier accessibility, and distribution network connectivity. Strategic alignment includes scalability, service level alignment, and supply chain responsiveness. Financial feasibility includes investment costs, operational costs, and cost efficiency. This hierarchical structure enables the integration of qualitative strategic considerations and quantitative operational indicators for the HWSM framework while preserving the decision logic documented in the original project.

3.2 AHP-Based Weight Determination Process

For methodological transparency, the four primary evaluation dimensions were structured using AHP principles to reconstruct and evaluate the weighting structure documented in the original project. Pairwise comparison judgements were reconstructed from the original project's priorities such as strategic priorities, stakeholder assessments, and decision rationales at that time. The relative importance assigned for each criteria reflected the emphasis on the identified factors of the original project resulting in the four primary dimensions.

The original project indicated that Logistics Ecosystem Suitability consistently received greatest emphasis due to transportation efficiency, supplier accessibility, inventory positioning, and distribution performance as the primary operational drivers influencing warehouse deployment decisions, receiving the highest relative priority. Macro-environmental and Financial feasibility were considered equally important due to long-term business attractiveness and economic viability being necessary conditions for sustainable warehouse expansion. Strategic Alignment remained an important dimension, but received a lower priority due to it supporting long-term growth and network development objectives rather than immediate operational feasibility, receiving the lowest relative priority.

The original documented project priorities were translated into reconstructed criteria weights, which were subsequently normalized to sum to 1.00 (100%) for an AHP-compatible pairwise comparison matrix. The reconstructed pairwise comparison matrix developed represents the relative importance of the four evaluation dimensions, with the formula below:

$$\Sigma wi \;=\; 1.00 \qquad \textit{and} \qquad \boldsymbol{aij} \;=\; \frac{\boldsymbol{wi}}{\boldsymbol{wj}}$$

Where Σwi represents the sum of all normalized criteria weights, equal to 1.00 (100%)
aij = pairwise comparison value between criteria i and criteria j
wi = weight of criteria i
wj = weight of criteria j

The resulting reconstructed pairwise comparison matrix is presented in Table 1, which reflects the relative priority structure identified in the original warehouse planning project and serves as the basis for subsequent consistency analysis. The reconstructed weights correspond to the documented relative priorities assigned to the four primary evaluation dimensions and were used to generate the pairwise comparison values through ratio-based reconstruction.

Table 1. Reconstructed Pairwise Comparison Matrix Derived from Normalized Criteria Weight Ratios

Criteria	Reconstructed Weight (wi)	Macro (aij)	Logistics (aij)	Strategic (aij)	Financial (aij)
Macro	0.25	1.0	0.83	1.25	1.0
Logistics	0.30	1.2	1.0	1.5	1.2
Strategic	0.20	0.8	0.67	1.0	0.8
Financial	0.25	1.0	0.83	1.25	1.0
Total	1.00				

The criteria weights in Table 1 were normalized to sum to 1.00 (100%) and converted into pairwise comparison values using the ratio-based relationship of aij where it represents the relative importance of criteria i compared to criteria j. The weighting structure reflects relative priorities identified throughout the original warehouse project as mentioned previously. Since the original project didn't employ AHP or Saaty's fundamental pairwise comparison scale, ratio-based reconstruction was applied to preserve the documented relative priority structure of the original project while enabling consistency assessment within an AHP-compatible framework.

3.3 Consistency Analysis

To evaluate the internal consistency of the reconstructed pairwise comparison matrix, standard AHP consistency measures were applied. The consistency analysis assesses the relative importance assigned between criteria remains logically coherent throughout the comparison structure. Since the matrix was derived from normalized criteria weight ratio, reciprocal relationships between criteria are preserved by definition. The ratio-based reconstruction maintains internal consistency across comparison relationships due to each pairwise value derived from the same underlying weighting structure. The reconstructed matrix exhibits internally coherent comparison relationships and is therefore suitable for consistency assessment using standard AHP measures.

The maximum eigenvalue λmax was calculated to assess the consistency of Table 1. For a fully consistent matrix, the maximum eigenvalue equals the number of criteria (n). The calculated value obtained from Table 1 was λmax = 4, hence the Consistency Index (CI) and Consistency Ratio (CR) is calculated with the following formula:

$$CI = \frac{\lambda max - n}{n - 1} \qquad CR = \frac{CI}{RI}$$

Table 2. Consistency Analysis Calculation

Parameter	Value
n	4
λmax	4.00
CI	0.00
RI	0.90
CR	0.00

RI represents Saaty's Random Index, and Table 1 reconstructed matrix was generated from normalized weight ratios where λmax equals the number of criteria ($n = 4$), resulting in CI of 0 and a CR of 0 using RI 0.90 based on the n value (Saaty, 1980) . The CR is below the accepted threshold of <0.10 recommended by Saaty (2008), indicating that the reconstructed pairwise comparison matrix exhibits internally consistent comparison relationship and is suitable for application in the HWSM. Though it should be noted that the consistency assessment evaluates the reconstructed weighting structure rather than the original stakeholder decision process for transparency and prevention of overclaiming.

3.4 Framework Implementation Procedure

After establishing the consistency of the reconstructed weighting structure, the resulting criteria weights were incorporated into the HWSM for quantitative evaluation and ranking of candidate warehouse locations. The implementation procedure consists of three stages:

- Step 1 : Data preparation and normalization
- Step 2 : Weighted Scoring using Hierarchical Weighted Scoring Matrix (HWSM)
- Step 3 : Ranking of Candidate Locations

The implementation procedure enables the integration of qualitative and quantitative indicators within a unified warehouse location evaluation framework. To quantify the evaluation, the framework applies the Hierarchical Weighted Scoring Matrix (HWSM), which is grounded in Muli-Criteria Decision Making (MCDM) and the Analytic Hierarchy Process (AHP). Within the proposed framework, AHP principles are used to structure evaluation criteria, reconstruct criterion weights, and assess consistency of the weighting structure. Rather than deriving weights through a new expert elicitation process, the weights used in this study were reconstructed from documented project priorities and incorporated into the HWSM framework.

The weights are normalized so that the sum of all weights equals one. Each candidate warehouse location is then scored against every sub-criterion using predefined measurement scales. The overall score of candidate location j is calculated using the weighted aggregation model:

$$Sj = \sum_{i=1}^{n} w_i \, x_{ij} \quad \text{with} \quad \sum_{i=1}^{n} w_i = 1$$

where Sj is the overall score of candidate warehouse location j, w_i is the normalised weight criterion i, and x_{ij} is the performance score of location j with respect to criterion i. All quantitative indicators are normalized using min-max transformation to a 0-10 scale. For benefit criteria, higher values indicate better performance, while for cost criteria, inverse normalization is applied. Qualitative assessments are converted into numerical scores using predefined ordinal scales to ensure consistency and comparability across all alternatives. Section 5 Results and Discussion will demonstrate the model's application.

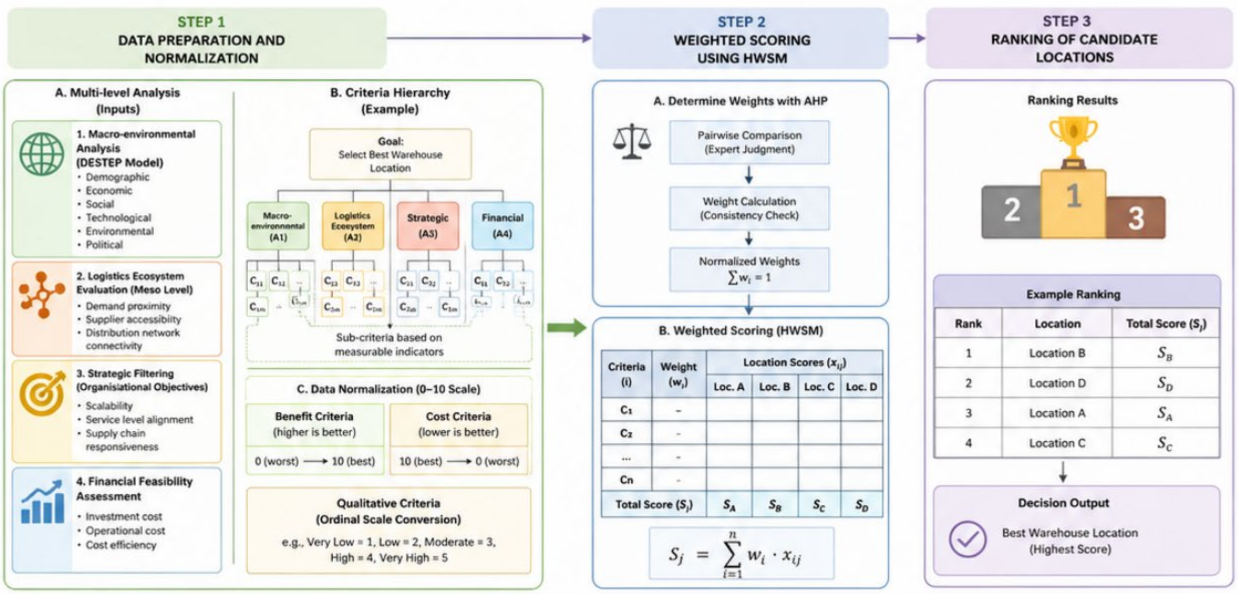

Figure 1. Integrated HWSM Framework for Warehouse Location Selection

Figure 1 summarizes the complete HWSM implementation process, beginning with data preparation and normalization, followed by weighted evaluation, and concluding with the ranking of candidate warehouse locations.

4. Data Collection

The research applies the proposed framework to a real-world warehouse location selection problem involving four candidate locations in the European region represented as Location A, B, C, and D due to confidentiality constraints. The dataset reflects actual logistic planning conditions and provides evaluation inputs required for the HWSM presented in 3. Methods. The collected information is organized into macro-environmental, logistics, strategic, and financial dimensions before being transformed into standardized scoring inputs for the quantitative evaluation presented later in 5. Results and Discussion.

4.1 Data Sources and Case Context

The data used is derived from a real-world logistics planning case involving warehouse expansion within a rapidly growing distribution network. The company experienced continuous annual growth of approximately 40-50%, creating increasing pressure on its warehousing and distribution infrastructure. Operational challenges included limited storage capacity, rising labor costs, and increasing transportation expenses. Monthly outsourced warehousing labor costs were estimated at €90.000-€100.000, while storage costs ranged between €40.000-€50.000 per month. These operational constraints motivated the need for a more scalable and cost-efficient warehouse location strategy. Multiple candidate location alternatives were therefore evaluated based on logistics accessibility, infrastructure conditions, strategic positioning, and financial feasibility. Although anonymized, the evaluation conditions reflect realistic logistics network planning environments.

4.2 Data Structuring and Criteria Mapping

The collected data were categorised into four evaluation dimensions : macro-environmental, logistics ecosystem, strategic alignment, and financial feasibility. The data is mapped into specific evaluation variables for each candidate warehouse location, that are derived from prior logistics analysis where multiple geographic alternatives were compared across the macro and meso-level factors.

- Macro-environmental data (DESTEP) included economic indicators (GDP), infrastructure readiness, and sustainability-related metrics.
- Logistics ecosystem data included Logistic Performance Index (LPI), transportation connectivity, supplier accessibility, demand proximity, and distribution network integration characteristics affecting operational efficiency.
- Strategic data included scalability potential, service responsiveness, and alignment with long-term distribution objectives.
- Financial data included investment requirements, operational cost efficiency associated with each candidate location.

Collected information allows structured mapping into measurable criteria and sub-criteria supporting quantitative evaluation within the HWSM framework.

4.3 Data Preparation and Quantitative Transformation

All evaluation variables are standardized prior to quantitative analysis within the HWSM. This process ensures comparability across different evaluation dimensions and enables integration of both quantitative and qualitative indicators into a unified assessment structure. Quantitative variables such as GDP, Logistics Performance Index (LPI), sustainability metrics and financial cost estimates were normalized using proportional scaling techniques. Benefit criteria, where higher values represent stronger performance were normalized using min-max transformation. Cost-related criteria, including labor, storage, and transportation expenses, applied inverse normalization to ensure lower costs produce higher relative scores. Qualitative variables such as strategic alignment, scalability potential, and service responsiveness were converted into numerical scores using predefined ordinal evaluation scales. This transformation enabled strategic and operational considerations to be evaluated consistently with measurable logistics and financial indicators.

For qualitative evaluation variables such as GDP strength classification, scalability potential, service responsiveness, and strategic alignment, predefined ordinal scoring scales were developed based on relative performance categories identified during the original warehouse planning project. Higher scores represent stronger alignment with warehouse deployment objectives, while lower scores indicate comparatively weaker performance. The scoring scales were applied consistently across all candidate locations to improve transparency, comparability, and reproducibility of the evaluation process. The preparation process starts with compiling logistics, operational, financial datasets. Then classification of variables into evaluation criteria, continued with normalization of quantitative indicators and conversion of qualitative assessments into numerical scores. These will then be assigned normalized criteria weights. The standardized dataset will provide the quantitative inputs required for scoring, ranking, and validation analysis in Section 5.

4.4 HWSM Evaluation Matrix Preparation

After normalization and standardization, all criteria scores are consolidated into a structured decision matrix for implementation within the Hierarchical Weighted Scoring Matrix (HWSM). The rows represent candidate warehouse locations, columns represent evaluation criteria, and cell values represent standardized performance scores

Each criteria was assigned a corresponding weight reflecting its relative importance within the integrated evaluation framework. The criteria weights applied within the HWSM correspond to the reconstructed weighting structure presented in Table 1 and reflect the documented priorities identified during the original warehouse planning project. The weighted aggregation process then enables calculation of overall performance scores for each candidate location using the HWSM model in Section 3. By structuring the data in this manner, the framework ensures that the evaluation process is systematic, transparent, and reproducible, allowing candidate warehouse locations to be assessed consistently within rapidly growing distribution networks.

5. Results and Discussion

Following Section 3 and Section 4, the proposed integrated multi-level framework was applied to evaluate four candidate warehouse locations incorporating macro-environmental, logistics, strategic, and financial dimensions using the HWSM formula :

$$Sj = \sum_{i=1}^{n} w_i \cdot x_{ij} \text{ with } \sum_{i=1}^{n} w_i = 1$$

Adding Section 4.3, economic indicators such as GDP are incorporated within the macro-environmental dimension and treated as a benefit criteria, while cost criteria are evaluated within the financial feasibility dimension. This separation ensures that the external economic attractiveness and internal cost efficiency are assessed independently before being integrated through the weighted scoring model. Quantitative indicators will be macro-environmental (DESTEP), Logistics Performance Index (LPI), and Financial costs, where qualitative indicators will be Strategic alignments. This results to the formula :

- Logistic Performance Index (LPI) with Min-Max Normalization

$$xij = \frac{Xij - Xmin}{Xmax - Xmin} \times 10$$

- Macro-environmental (DESTEP) Score : combining GDP, LPI, Sustainability with Min-Max Normalization

$$Macro(j) = \frac{LPI + Sustainability + GDP}{3}$$

- Financial Score : combining labor cost, storage cost, and transport cost inversely normalized

$$Financial(j) = inverse\ xij = \frac{Xmax - Xij}{Xmax - Xmin} \times 10$$

- Strategic Score :

$$Strategic(j) = \frac{1}{n}\sum_{k=1}^{n} sjk$$

In which sjk is the score of sub-criteria k for location j and n = number of sub-criteria

5.1 Numerical Results

The overall performance score for each candidate warehouse location is calculated using the transformed weighted aggregation model from Section 3 and Section 5 :

$$Sj = w1 \cdot Macro(j) + w2 \cdot Logistics(j) + w3 \cdot Strategic(j) + w4 \cdot Financial(j)$$

Starting with LPI calculation, Table 3 presents the normalized Logistics Performance Index (LPI) scores for each candidate location

Table 3. Normalized LPI Score

Location	Logistics Performance Index (LPI)	Normalized Score
A	4.20	10.00
B	4.02	7.27
C	4.04	7.57
D	3.54	0.00

Location A demonstrates the strongest logistics ecosystem performance. This continues to Table 4 for Sustainability score.

Table 4. Normalized Sustainability Score

Location		Assigned Score	Normalized Score
A		82.48	10.00
C		82.19	8.72

B		81.56	5.93
D		80.22	0

The results indicate relatively consistent sustainability performance across Locations A,B, and C, while location D demonstrates comparatively weaker sustainability conditions. This continues to Table 5 for GDP score. GDP strength categories were derived from relative economic performance classifications identified during the original project and converted into ordinal scores to facilitate comparative evaluation across candidate locations.

Table 5. Normalized GDP Strength Score

Location	GDP Strength	Assigned Score	Normalized Score
A	Highest	10	10.00
B	High	9	6.67
C	Moderate-High	8	3.33
D	Moderate	7	0.00

The 3 Tables are combined and aggregated to produce overall macro-environmental DESTEP score (Table 6).

Table 6. Macro-environmental DESTEP Score

Location	Macro DESTEP Score
A	10.00
B	6.62
C	6.54
D	0.00

Location A consistently outperforms the remaining alternatives across macro-environmental indicators, reflecting stronger economic and infrastructure conditions.

Strategic alignment results using predefined ordinal scares results in Table 7. Strategic scores were based on relative scalability potential, service responsiveness, and alignment with long-term distribution objectives identified during the original project.

Table 7. Strategic Score

Location	Scalability	Service	Responsiveness	Normalized Score
A	9	9	9	9.00
B	8	9	8	8.33
C	8	8	8	8.0
D	7	8	7	7.33

Location A achieves the strongest strategic alignment, while Locations B and C demonstrates relatively balanced performance. This then continues to financial feasibility scores based on inverse normalization of operational costs presented in Table 8.

Table 8. Normalized Financial Feasibility Score

Location	Relative Cost Level	Normalized Score
D	Lowest	10.00
C	Medium	6.00
B	High	5.50
A	Highest	5.00

Location D demonstrates the strongest financial feasibility due to lower operational costs, while Location A shows weaker cost efficiency.

The aggregated HWSM evaluation results are then calculated in Table 9.

Table 9. HWSM evaluation results for candidate warehouse locations (Sj)

Criteria	Weight	Location A	Location B	Location C	Location D
Macro-environmental (DESTEP)	0.25	10	6.62	6.54	0
Logistics Ecosystem (LPI)	0.30	10	7.27	7.57	0
Strategic Alignment	0.20	9.0	8.33	8.00	7.33
Financial Feasibility	0.25	5.0	5.50	6.00	10.0
Total Score (Sj)	**1.00**	**8.55**	**6.83**	**6.92**	**3.96**

The final results indicate that Location A achieves the highest overall score due to consistently strong macro-environmental, logistics, and strategic performance. Although Location D demonstrates the strongest financial feasibility, weaker logistics and macro-environmental conditions significantly reduce its ranking. Overall, the numerical results show that warehouse location selection cannot be effectively evaluated through financial criteria alone. The integrated framework provides a more balanced evaluation by capturing trade-offs between operational performance, strategic alignment, macro-environmental conditions, and financial feasibility.

5.2 Graphical Results

The graphical analysis complements the numerical evaluation by illustrating the comparative performance of each candidate warehouse locations across the four evaluation dimensions. Figure 2 presents the aggregated HWSM scores for Locations A, B, C, and D.

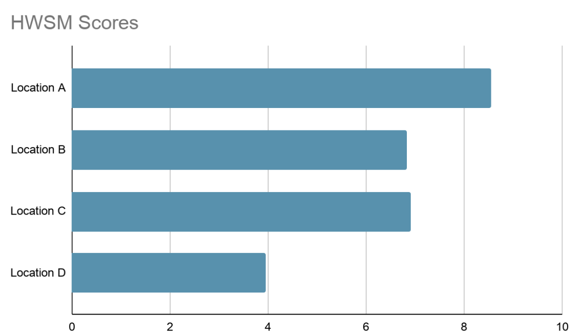

Figure 2. HWSM Scores by Candidate Warehouse Locations

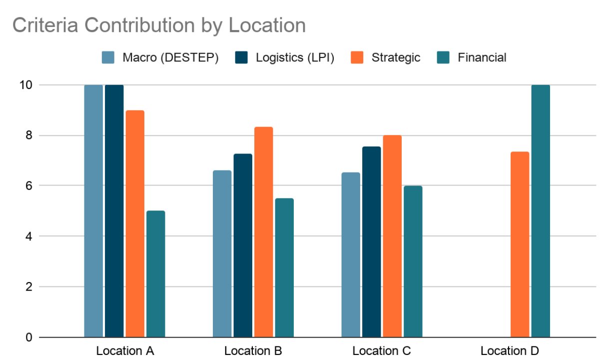

Figure 3. Comparative Evaluation by Criteria Dimension

Location A achieved the highest overall performance score, followed by Locations C, B, and D. The results visually confirm the numerical evaluation presented in Table 9. Locations B and C show relatively similar overall scores, indicating comparable operational suitability. Location C slightly outperforms B due to stronger financial feasibility, while B demonstrates marginally stronger logistic ecosystem performance (Figure 3). This result suggests that moderate improvements in either operational or cost efficiency may influence the final ranking between both alternatives.

The graphical comparison highlights the trade-offs between operational performance and financial feasibility. Location D shows strongest financial performance due to lower operational costs, but records substantially lower macro-environmental and logistic scores. Location A achieves consistently high scores across criteria dimensions despite higher relative costs. The graphical analysis also indicates macro-environmental and logistic ecosystem performance contribute significantly to the final ranking outcomes. Locations with stronger infrastructure accessibility, transportation connectivity, and economic conditions consistently achieve higher overall HWSM scores compared to locations evaluated primarily on financial efficiency. Overall, graphical results reinforce the importance of integrated multi-criteria evaluation in warehouse location planning. The analysis demonstrates that relying solely on cost-based evaluation may overlook operational and strategic factors that significantly influence long-term distribution network performance and scalability.

5.3 Proposed Improvements

The evaluation results indicate that the proposed framework can support warehouse location ranking, identification of operational and strategic improvement opportunities across candidate locations. Comparative analysis highlights that differences in overall performance are primarily influenced by logistic ecosystem accessibility, macro-environmental conditions, and financial efficiency trade-offs. The results also demonstrate that balanced performance across macro-environmental, logistics, strategic, and financial dimensions produces stronger overall evaluation outcomes compared to single-criteria cost-based approaches.

From a methodological perspective, the proposed framework may be further enhanced through sensitivity analysis by varying criteria weights to evaluate their influence on ranking outcomes. Future extensions may also incorporate real-time logistic indicators, simulation models, and dynamic demand forecasting to support more adaptive warehouse location planning.

5.4 Validation

To evaluate the consistency of the proposed framework, the HWSM ranking results were compared with baseline single-criteria rankings such as cost-only or logistics-only using Spearman Rank Correlation analysis. Spearman correlation was selected because the evaluation focuses on ranked alternatives, rather than continuous predictive outputs. It enables the assessment of whether the proposed framework produces consistent or fundamentally different decision outcomes. This aligns with the objective of validating the framework's ability to capture multi-dimensional trade-offs in warehouse location selection. Given that the evaluation involves four candidate locations, analysis focuses on ranking consistency rather than statistical interference based on large datasets. Furthermore, since the dataset used in this study is derived from a case-based analysis involving a limited number of alternative locations mentioned previously, parametric statistical methods like Pearson correlation are less appropriate, as they assume linear relationships and interval-scale data distributions instead. Spearman rank correlation being non-parametric doesn't require assumptions of normality or linearity, and is designed to assess the strength and direction of association between ranked variables. This makes it particularly suitable for validating multi-criteria decision-making (MCDM) models, where rankings are the primary output. This approach is consistent with the structure of the proposed multi-level framework, where decision outcomes are derived through weighted aggregation of normalized criteria and transformed as ranked alternatives. The goal isn't to test prediction accuracy, but to validate ranking consistency in a multi-criteria decision framework.

The Spearman Rank Correlation coefficient formula is mentioned below :

$$\rho = 1 - \frac{6\Sigma d_i^2}{n(n^2 - 1)}$$

In which d_i is the difference between the ranks of the same alternative locations under two different ranking methods. It can be decided between a suggestion of cost-only or logistic-only as mentioned previously as a single-criteria. Using the results from Table 9. HWSM, an example of choosing the single-criteria of cost-only, can be applied with Table 8, using the formula (Table 10):

$$d_i = Rank_{HWSM,i} - Rank_{Cost,i}$$

Table 10. Ranking Comparison and Spearman Correlation Analysis

Location	HWSM Rank	Cost Rank	d_i	d_i^2
A	1	4	-3	9
B	3	3	0	0
C	2	2	0	0
D	4	1	3	9

The rank differences are computed with the formula :

$$\Sigma d_i^2 = 9 + 0 + 0 + 9 = 18$$

Then applying the Spearman formula mentioned previously with $n = 4$ locations resulting in :

$$\rho = 1 - \frac{6 \times 18}{4(4^2 - 1)} = 1 - 1.8 = -0.8$$

The result of (ρ = -0.8) indicates a strong negative correlation between the two rankings of HWSM and cost-based criteria. This demonstrates that cost-focused evaluation alone produces substantially different outcomes compared to the proposed multi-level framework. Locations that perform well in cost-based evaluation doesn't necessarily achieve high rankings when evaluated across the macro-environmental (DESTEP), logistics (LPI), and strategic dimensions. Similar discrepancies have been widely reported in recent logistics and supply chain studies, where multi-criteria decision-making (MCDM) approaches produce significantly different rankings compared to cost-based methods due to the inclusion of operational, infrastructural, and strategic factors (Stanujkic et al., 2020; Chakraborty et al., 2020).

The choice of comparing HWSM ranking with baseline single-criteria rankings (cost-only or logistics-only) is further supported by existing practices in warehouse location selection and logistics planning, where multi-criteria decision-making (MCDM) approaches are used to capture complex trade-offs beyond cost minimization. Previous studies have demonstrated that incorporating multiple dimensions such as accessibility, infrastructure, and strategic alignment can significantly alter ranking outcomes compared to single-criterion approaches (Durán et al., 2021; Pamučar et al., 2021). This analysis confirms that the proposed framework captures multi-dimensional trade-offs that aren't reflected in traditional cost-based decision models, supporting the main objective of the research which is to provide a quantifiable, transparent, and reproducible decision-support methodology for warehouse location selection in rapidly growing distribution networks.

The validation results indicate that the proposed framework produces decision outcomes that differ substantially from single-criteria cost-based evaluation approaches, demonstrating its ability to capture multi-dimensional trade-offs in warehouse location selection. However, the validation remains limited to a single case study and comparison against a baseline ranking approach. Additional validation using alternative MCDM methods such as TOPSIS, VIKOR, or ELECTRE, together with sensitivity analysis across multiple case scenarios, would further strengthen the assessment of framework robustness and generalizability. Zavadskas et al. (2020) and Pamučar et al.(2021) also emphasize that the robustness of MCDM models is often evaluated through the stability and consistency of rankings across different evaluation methods rather than absolute score comparison. Future research may extend validation by applying the framework to multiple case studies, conducting sensitivity analysis across a broader range of scenarios, and comparing results with alternative MCDM or Optimization-based approaches. The proposed framework supports decision-making but also improves the reliability and consistency of warehouse location selection in complex distribution environments. With the inclusion of the Spearman Rank Correlation, the validation process becomes more transparent and reproducible.

6. Conclusion

The results in Section 5 demonstrate that the proposed integrated multi-level framework supports warehouse location selection by capturing trade-offs across macro-environmental, logistics, strategic, and financial criteria. The HWSM evaluation shows that locations with strong macro and logistics ecosystem performance achieve higher overall rankings, even when financial costs are less favorable, highlighting the importance of multi-criteria decision-making over cost-driven approaches. The validation results further indicate that the framework produces decision outcomes that differ substantially from single-criteria cost-based rankings, suggesting its ability to capture multi-dimensional considerations within warehouse location planning.

Several limitations should be acknowledged. The framework was demonstrated using a single anonymized industrial case study involving four candidate warehouse locations, which limits the generalizability of the findings. In addition, the weighting structure was reconstructed from documented project priorities rather than derived through a dedicated AHP expert elicitation process. The validation approach was limited to comparison against a baseline cost-based ranking using Spearman Rank Correlation. Further research should incorporate sensitivity analysis, alternative MCDM validation approaches such as TOPSIS, VIKOR, or ELECTRE, and additional case studies to further evaluate framework robustness and applicability across different logistics environments.

Overall, this research contributes to the advancement of warehouse location planning by providing a structured, multi-level, and quantitatively driven decision-support framework that integrates macro-environmental assessment, logistics ecosystem evaluation, strategic alignment, and financial feasibility within a unified evaluation model. The proposed framework improves transparency, consistency, and decision support for warehouse planning in complex distribution network environments and provides a foundation for future research on integrated supply chain location decision-making.

References

Bairagi, B., A novel MCDM model for warehouse location selection in supply chain management, *Decision Making: Applications in Management and Engineering*, vol. 5, no. 1, pp. 194-207, 2022.

Bairagi, B. (2022). Warehouse Location Selection Using Fuzzy Multi-Criteria Analysis. *International Journal of Supply Chain Management*, 11(3), 45–56.

Baryannis, G., Validi, S., Dani, S., & Antoniou, G. (2019). Supply Chain Risk Management and Artificial intelligence: State of the Art and Future Research Directions. *International Journal of Production Research*, *57*(7), 2179–2202. https://doi.org/10.1080/00207543.2018.1530476

Choi, T. Y., Narayanan, S., Novak, D., Olhager, J., Sheu, J.-B. and Wiengarten, F., Managing extended supply chains, *Journal of Business Logistics*, vol. 42, no. 2, pp. 200-206, 2021.

Durán, O., Aguilo, J. and Sanchez, A., A multi-criteria decision-making approach for warehouse location selection, Sustainability, vol. 13, no. 3, pp. 1–15, 2021.

Stanujkic, D., Zavadskas, E. K. and Turskis, Z., A review of multi-criteria decision-making methods in logistics, Transport, vol. 35, no. 2, pp. 1–15, 2020.

Taletović, M., Application of multi-criteria decision-making methods in warehouse: A brief review, *Spectrum of Engineering and Management Sciences*, vol. 1, no. 1, pp. 26-37, 2023.

Thuengnaitham, A., Application of analytic hierarchy process for fulfillment warehouse location selection, *International Scientific Journal of Engineering and Technology*, vol. 6, no. 1, pp. 8-15, 2022.

Zavadskas, E. K., Turskis, Z. and Antucheviciene, J., Advances in multi-criteria decision-making methods: An overview, Technological and Economic Development of Economy, vol. 26, no. 1, pp. 1–20, 2020.

Chakraborty, S., Zavadskas, E. K. and Antucheviciene, J., Applications of MCDM methods in supply chain management: A review, Informatica, vol. 31, no. 3, pp. 1–20, 2020.

Pamučar, D., Stević, Ž. and Sremac, S., A new model for determining weight coefficients in multi-criteria decision-making models, Symmetry, vol. 13, no. 3, pp. 1–20, 2021.

Saaty, T. L. (1980). *The analytic hierarchy process : planning, priority setting, resource allocation*. Mcgraw-Hill International Book Co. New York, 1980.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, *1*(1), 83. https://doi.org/10.1504/ijssci.2008.017590

Wang, X., & Xia, Q. (2019). Optimization of Logistics Warehouse Location Based on Genetic Algorithm. *Advances in Intelligent Systems and Computing*, *928*, 745–752. https://doi.org/10.1007/978-3-030-15235-2_102

Yazdani, M., Chatterjee, P., Pamucar, D., & Chakraborty, S. (2020). Development of an integrated decision making model for location selection of logistics centers in the Spanish autonomous communities. *Expert Systems with Applications*, *148*, 113208. https://doi.org/10.1016/j.eswa.2020.113208

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