

# **Cross-Border E-Commerce Warehouse Location-Allocation Optimization in Southeast Asia: Integrating Qualitative and Quantitative Decision Criteria Using AHP and Goal Programming**

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## **Abstract**

The success of cross-border e-commerce operations can be evaluated through financial performance, customer satisfaction, and operational resilience. However, previous research has rarely captured those metrics simultaneously when selecting the cross-border e-commerce warehouse. Therefore, this paper proposed an integrated method of the Analytic Hierarchy Process and Goal Programming. First, the alternative locations' qualities, such as political and macroeconomic stability, logistics infrastructure quality, clarity of the trade regulation, connectivity to the transportation network, availability of workforce, and customs clearance efficiency, are evaluated using AHP, which produces the priority score representing the relative attractiveness of each location. Secondly, the priority level of each alternative that results from AHP is incorporated as parameters in the Goal Programming model, along with quantitative performance such as profitability, lead time, and operational costs. The expected output of this model is to identify the top three locations that satisfy the multi-goals objective for cross-border e-commerce warehouse location.

## **Keywords**

Analytic Hierarchy Process, Cross-Border E-Commerce, Goal Programming, Location-Allocation, and Operations Research.

## **1. Introduction**

Supported by the rapid growth in digital adoption and internet access, Southeast Asia has emerged as one of the fastest-growing e-commerce markets worldwide. With a population of approximately 660 million, the regional e-commerce gross merchandise value is projected to reach 300 billion USD by 2030 (Thirawat 2022). However, several challenges must be addressed to satisfy this growing demand. A high number of SKUs and volatile demand increase operational complexity, particularly when companies operate warehouses in multiple countries (Patil and Divekar 2024). Additionally, the location of the e-commerce warehouse that is not well planned may lead to higher costs, longer lead times, and unstable long-term operational performance. To address this, e-commerce companies must adjust their

fulfillment strategies and network design to meet demand while maintaining manageable operational complexity and cost. One of the solutions is to adopt cross-border operations. Cross-border operations allow firms to expand into multiple markets while reducing warehouse investment (Han and Li 2025). However, cross-border operations are not without challenges, especially for the Southeast Asia region, where the country members are separated by sea and exhibit diverse institutional and logistical characteristics. Delivering the products to other countries increases supply chain complexity, which leads to a longer lead time and poor customer experience (Zhu et al. 2023). In the long term, institutional risks may also arise due to infrastructure quality, economic and political instability in warehouse host countries (Wang et al. 2024). To ensure that these challenges are in check, the cross-border e-commerce warehouse must be located not only geographically but also strategically. The success of the cross-border e-commerce operations is reflected in the financial performance, customer satisfaction, and operational resilience. While financial performance and customer satisfaction have traditionally been managerial priorities, having resilient operations most of the time is often overlooked. According to Lelièvre et al. (2019), volatility that may impact operations has increased due to economic, geopolitical, and technological disruptions. Hence, a cross-border e-commerce warehouse that geographically and strategically fits can improve operational efficiency and resiliency. It will reduce warehouse and transportation costs, enhance customer experience, and strengthen operational stability. Therefore, warehouse location directly influences all three success indicators. Numerous studies have investigated cross-border e-commerce warehouse location problems. However, existing research tends to emphasize either qualitative evaluation or quantitative optimization, with limited integration of both perspectives. For example, Liu et al. (2022) primarily focuses on qualitative assessment using E-TOPSIS, whereas Guan (2021) emphasizes quantitative optimization through Game Theory. This separation highlights the need for a more integrated decision-making framework. To overcome this limitation, this study proposes an integrated framework combining Analytic Hierarchy Process (AHP) and Goal Programming (GP), where AHP evaluates qualitative location attributes, and GP optimizes quantitative performance metrics. The proposed model identifies the top three most suitable cross-border warehouse locations among ten candidate countries in Southeast Asia and the allocation of market demand to each warehouse, forming a location–allocation optimization model.

## **1.1 Objectives**

The objective of this study is to:

1. Identify significant qualitative criteria and quantitative parameters for selecting cross-border e-commerce warehouse locations.
2. Develop an integrated AHP and Goal Programming model based on the identified criteria and parameters to determine the most suitable cross-border e-commerce warehouse location.

## **2. Literature Review**

### **2.1. Cross-border e-commerce warehouse location selection**

Cross-border e-commerce (CBEC) refers to an order fulfillment process conducted across national borders through internet-based platforms (Rusachenko, 2020). Along with the rapid growth of the global e-commerce market, the adoption of CBEC has increased steadily. E-commerce trends in 2025 indicate that approximately 59% of online consumers have made purchases from foreign sellers (DHL eCommerce, 2025).

CBEC has become a key strategy for e-commerce companies to expand international trade, given its characteristics of multinational reach, ease of access, reduced reliance on physical documentation, and relatively low entry barriers. The increasing importance of CBEC has also attracted growing academic attention. Zhu (2023) reported that research on cross-border e-commerce began in 2003 and experienced a significant surge in 2020 during the COVID-19 pandemic. Existing studies on CBEC cover a broad range of topics, including technological infrastructure, consumer behavior, and business processes. Recent studies have also focused on CBEC warehouse location selection done by Liu et al. (2022), Guan (2021), and Chen and Sun (2022).

### **2.2 AHP**

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method that evaluates alternatives through pairwise comparison and priority weighting (Saaty and Vargas 2022). The core procedure of AHP involves conducting pairwise comparisons to derive priority weights for each criterion and alternative. One of the main advantages of AHP lies in its simplicity and its ability to manage inconsistency in human judgments (Saaty, 1987), as the results of pairwise comparisons are evaluated using a consistency ratio to ensure acceptable logical coherence. The typical decision hierarchy of AHP is as shown in Figure 1.

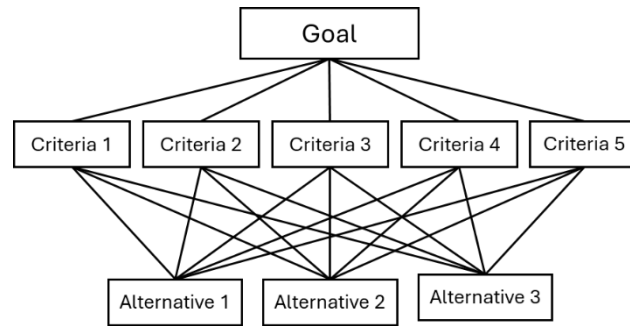


Figure 1. AHP Decision Hierarchy

Given that AHP incorporates human judgment, it can support decision-making based on both qualitative and quantitative criteria. However, to evaluate qualitative criteria, most studies transform expert judgments into quantitative weights or quantify such criteria using external data sources. Mogbojuri and Olanrewaju (2025) use AHP to evaluate project portfolios according to qualitative criteria that have been transformed into quantitative values using expert judgement. Carrodano et al. (2023) transform qualitative criteria into quantitative ones using both expert judgement and external data. Hence, AHP is appropriate for evaluating qualitative attributes of candidate countries, such as institutional quality and logistics readiness.

### 2.3 Goal Programming

Goal Programming (GP) is a multi-objective decision-making technique that aims to handle problems involving several conflicting objectives by minimizing deviations from predefined target values (Orumie and Ebong 2014). Instead of optimizing only one objective, GP allows decision makers to specify aspiration levels for each goal and then seeks a solution that best satisfies these goals. Since not all goals can be achieved simultaneously, GP provides a structured way to manage trade-offs among objectives. The formulation and solution of a GP model depend on the structure of the problem and the type of data used.

Several GP variants have been developed in the literature. Binary Goal Programming focuses on decisions between two competing goals and has been applied by Alhussain and Khorramshahgol (2025) and Elghanam et al. (2023). Lexicographic Linear Goal Programming (LGP) prioritizes goals according to a predefined hierarchy and has been used by Fourati et al. (2023) and Lozano and Contreras (2022). Weighted Goal Programming assigns relative importance to goals through weighting schemes, allowing explicit trade-offs among objectives, as demonstrated by Hashemi-Amiri et al. (2023).

Due to its capability to handle multiple objectives simultaneously, Goal Programming is well-suited for location-allocation problems, which typically involve competing performance measures such as profit, cost, and lead time. For example, Kuvvetli (2023) addressed the location-allocation of COVID-19 test sampling centers by minimizing total distance, the number of laboratories, and service distances. Similarly, Ertugrul et al. (2025) optimized community center locations by maximizing beneficiaries and facility coverage while minimizing total cost. Therefore, Goal Programming provides an appropriate framework for solving location-allocation problems in the CBEC context.

### 2.4 Research Gap

In location problems, qualitative approaches can be used, such as Yesilcayir et al. (2024) integrating IF AHP and TOPSIS to find a suitable location for a transit warehouse in disaster logistics, and Garipağaoğlu and Çelikoğlu (2023) using AHP to select a suitable location for smart bike cages. The advantage of qualitative approaches is their ability to focus on qualitative criteria. However, their application is often limited to location selection and does not explicitly address the allocation problem. Therefore, quantitative approaches are more suitable for solving allocation problems. For example, Liu et al. (2024) employed a bi-level mixed integer program (BMIP) to determine facility locations and allocate inbound travelers for quarantine facilities.

In the context of CBEC, studies related to facility location problems remain largely focused on location selection without jointly addressing the allocation problem. In addition, many previous studies tend to emphasize either

qualitative or quantitative criteria. For instance, Liu (2022) selected warehouse locations in the Belt and Road Initiative region using TOPSIS for qualitative evaluation and complex network theory for structural analysis, but did not explicitly incorporate key operational parameters such as costs and lead time. Meanwhile, Guan (2021) employed Game Theory with a strong emphasis on quantitative parameters such as cost and distance. Therefore, an integrative approach is necessary to overcome the limitations of single-perspective methods, particularly for cross-border e-commerce warehouse location problems that require both allocation optimization and comprehensive evaluation of location quality. However, existing CBEC warehouse location studies rarely integrate institutional, logistics, and regulatory evaluation with operational performance indicators such as cost, profit, and lead time within a single location-allocation framework.

### 3. Methods

This study proposes an integrated AHP–Goal Programming framework to comprehensively evaluate qualitative criteria and quantitative parameters. The procedure consists of six main steps. First, the decision hierarchy was constructed by identifying qualitative criteria relevant to CBEC warehouse location selection and defining the set of alternatives. Second, pairwise comparisons are conducted with domain experts using the Saaty 1–9 scale. Third, the survey results are processed using the AHP model to obtain the priority level of each alternative. Fourth, the AHP-derived priority scores are incorporated into the Goal Programming model as one of the quantitative inputs. Fifth, the quantitative parameters, decision variables, constraints, and objective functions are formulated. Finally, the Goal Programming model is solved to obtain the optimal solution. The detailed methodology is presented in Figure 2.

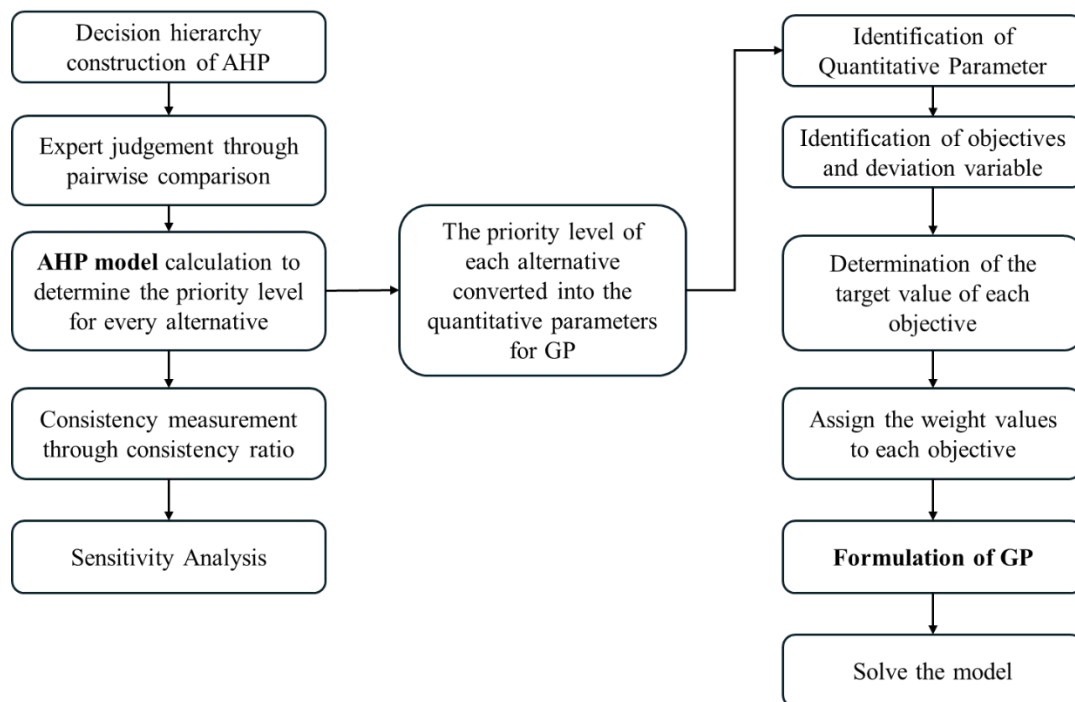


Figure 2. Methodology of the study

#### 3.1. Qualitative Criteria Evaluation through the AHP model

This study develops the decision hierarchy by considering all Southeast Asian countries as alternatives. The evaluation criteria are selected based on their frequency of appearance in prior CBEC and logistics location studies, complemented by expert input. The performance scores of each alternative with respect to each criterion are quantified using relevant external data obtained from multiple sources, such as the World Bank and other international organizations. Pairwise comparisons are conducted only to determine the relative importance of the criteria, while the performance scores of the alternatives are derived from the external datasets. The relative importance of each criterion is then evaluated through pairwise comparisons.

The pairwise comparison survey is conducted using Saaty's 1–9 scale as summarized in Table 1, where a value of 1 indicates equal importance between two criteria, while a value of 9 indicates that one criterion is extremely more important than the other.

Table 1. Pairwise comparison scale

| Verbal Judgement         | Numerical value |
|--------------------------|-----------------|
| Extremely more important | 9               |
|                          | 8               |
| Strongly more important  | 7               |
|                          | 6               |
| More important           | 5               |
|                          | 4               |
| Slightly more important  | 3               |
|                          | 2               |
| Equally important        | 1               |

The results of the pairwise comparison survey are entered into a comparison matrix, which is then normalized, finally calculating the geometric mean weight of each criterion.

$$\text{Pairwise comparison matrix } X = \begin{bmatrix} \frac{w_1}{w_1} & \dots & \frac{w_1}{w_n} \\ \frac{w_1}{w_1} & \ddots & \vdots \\ \vdots & \ddots & \frac{w_n}{w_n} \\ \frac{w_n}{w_1} & \dots & \frac{w_n}{w_n} \end{bmatrix}$$

Consistency measurement was conducted using the consistency ratio to ensure the reliability of the judgment.

$$CR = \frac{CI}{RI}$$

The consistency of expert judgments is evaluated using the consistency ratio (CR), where values below 0.1 indicate acceptable consistency. Consistency index is calculated as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Where max represents the maximum eigenvalue, while n represents the number of criteria. Saaty and Vargas (2022) have provided the average random consistency index in Table 2.

Table 2. Random Consistency Index

| n  | 1 | 2 | 3    | 4    | 5    | 6    | 7    | 8    |
|----|---|---|------|------|------|------|------|------|
| RI | 0 | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 |

Finally, to examine the robustness of the results, a sensitivity analysis is performed.

### 3.2. Integration of AHP to Goal Programming

Normally, AHP is used to rank alternatives based on the priority levels obtained from the analysis. However, in this study, the priority level of each alternative is incorporated as a quantitative input in the Goal Programming model alongside other quantitative parameters. Profit and lead time are the primary quantitative parameters considered, as they represent the company's financial performance and customer experience. Profitability is decomposed into revenue and cost components, while lead time is divided into first-mile delivery time and customs clearance time.

Revenue depends largely on demand fulfillment and product price. Cost consists of warehouse fixed costs (license fees and rental costs), warehouse variable costs (labor costs), and transportation costs (first-mile delivery cost and import tax). The operational data used in this study are obtained from the internal data of multinational e-commerce companies, while first-mile delivery lead time and rates are based on market data from DHL.

Additional parameters are introduced to support the model and capture the trade-off inherent in cross-border logistics operations. Since longer cross-border delivery lead times are known to reduce customers' willingness to purchase from foreign markets, only a certain portion of market demand is assumed to be fulfillable through cross-border delivery. This parameter is defined as Demand Effective.

Parameter:

|                  |                                                                           |
|------------------|---------------------------------------------------------------------------|
| $D_j$            | Demand in the market $j$                                                  |
| $P_j$            | Product price in the market $j$                                           |
| $\tau_j$         | Import tax in the market $j$                                              |
| $L_i$            | License fee in the warehouse $i$                                          |
| $r_i$            | The rent cost in the warehouse $i$                                        |
| $c_i^{var}$      | Labor cost in the warehouse $i$                                           |
| $q_i$            | Quality score in the warehouse $i$ (obtained from AHP)                    |
| $c_{ij}^{trans}$ | First-mile delivery cost from $i$ to $j$                                  |
| $LT_{ij}^{fm}$   | First-mile delivery lead time from $i$ to $j$                             |
| $LT_j^{cc}$      | Custom clearance process lead time in the market $j$                      |
| $LT_{ij}$        | Total lead time from $i$ to $j$                                           |
| $\alpha$         | Area per product unit (sqm/pcs)                                           |
| $K$              | Number of warehouses                                                      |
| $w_g$            | Weight for each goal                                                      |
| $D_{ij}^{eff}$   | Demand effective from $i$ to $j$ (if $i = j$ , 100%, otherwise $\gamma$ ) |

The GP model of this study is given by the following set of equations:

Constraints

Total demand to be fulfilled

$$\sum_{i \in I} D_i + d_D^- - d_D^+ = T_D$$

Revenue

$$\sum_{i \in I} \sum_{j \in J} P_j D_{ij}^{eff} y_{ij} + d_R^- - d_R^+ = T_R$$

Fixed cost

$$\sum_{i \in I} (L_i x_i + r_i S_i) + d_{FC}^- - d_{FC}^+ = T_{FC}$$

Variable cost

$$\sum_{i \in I} c_i^{var} D_i + d_{VC}^- - d_{VC}^+ = T_{VC}$$

Transportation cost

$$\sum_{i \in I} \sum_{j \in J} (c_{ij}^{trans} + \tau_j) D_{ij}^{eff} y_{ij} + d_{TC}^- - d_{TC}^+ = T_{TC}$$

Profit

$$\sum_{i \in I} \sum_{j \in J} P_j D_{ij}^{eff} y_{ij} - \sum_{i \in I} (L_i x_i + r_i S_i) - \sum_{i \in I} c_i^{var} D_i - \sum_{i \in I} \sum_{j \in J} (c_{ij}^{trans} + \tau_j) D_{ij}^{eff} y_{ij} + d_{PROF}^- - d_{PROF}^+ = T_{PROF}$$

Lead time

$$\sum_{i \in I} \sum_{j \in J} D_{ij}^{eff} (LT_{ij}^{fm} + LT_j^{cc}) y_{ij} + d_{LT}^- - d_{LT}^+ = T_{LT} \sum_{j \in J} D_j$$

Quality

$$\sum_{i \in I} q_i x_i + d_Q^- - d_Q^+ = T_Q$$

To determine the size of the warehouse, an additional constraint has been introduced to represent inventory turnover.

$$\alpha D_i \leq S_i \leq M x_i \quad \forall i \in I$$

Decision variable

$$x_i = \begin{cases} 1, & \text{if warehouse } i \text{ is open} \\ 0, & \text{otherwise} \end{cases}$$

$$y_{ij} = \begin{cases} 1, & \text{if market } j \text{ is fulfilled by warehouse } i \\ 0, & \text{otherwise} \end{cases}$$

$$D_i \geq 0$$

$$S_i \geq 0$$

$$d_g \geq 0 \quad g \in \{FC, VC, TC, LT, D, R, Q\}$$

Objective Function

$$\text{Min } Z = w_{PROF} \frac{d_{PROF}^-}{T_{PROF}} + w_R \frac{d_R^-}{T_R} + w_D \frac{d_D^-}{T_D} + w_{FC} \frac{d_{FC}^+}{T_{FC}} + w_{VC} \frac{d_{VC}^+}{T_{VC}} + w_{TC} \frac{d_{TC}^+}{T_{TC}} + w_{LT} \frac{d_{LT}^+}{T_{LT}} + w_Q \frac{d_Q^-}{T_Q}$$

The objective function of this model attempts to minimize the sum of deviations of each goal that has been normalized to its target, making the penalty fair for each goal.

## 4. Data Collection

### 4.1 Decision hierarchy

As the first step of the study, qualitative criteria were identified through a review of prior research on CBEC warehouse location selection. The identified criteria were subsequently validated through expert interviews, during which experts were also given the opportunity to propose additional relevant criteria. The final set of qualitative criteria used to evaluate the alternatives is presented as follows:

1. Political Stability and Governance Quality (C1)  
Political stability and governance quality are measured using the World Governance Indicators (Kaufmann, 2024).
2. Logistics and National Infrastructure Quality (C2)  
Infrastructure quality is measured using the World Bank Logistics Performance Index, particularly the quality of trade and transport infrastructure.
3. Clarity and Favorability of Trade Regulations (C3)  
According to the Trade Facilitation Indicator, clarity of trade regulation is tied to cross-border cooperation and coordination with neighboring countries.
4. Macroeconomic Stability and Market Environment (C4)  
According to Ohakwe and Wu (2025) macroeconomic conditions of a country significantly influence the efficiency and power of its logistics system. Factors such as an increase in GDP, trade openness, and urbanization increase logistics performance.
5. Connectivity to Major International Transport Hubs (C5)  
A location with access to sea and air can give flexibility to inbound and outbound products.
6. Availability of Workforce (C6)  
Workforce availability is proxied by the labor force participation data published by the World Bank.

#### 7. Custom Clearance Process Efficiency (C7)

Ten Southeast Asian countries are considered as candidate locations. Each country is represented by a major logistics city with access to international ports and industrial areas. These include Bandar Seri Begawan (Brunei), Phnom Penh (Cambodia), Bekasi (Indonesia), Vientiane (Laos), Klang Valley (Malaysia), Yangon (Myanmar), Clark (Philippines), Singapore, Samut Prakan (Thailand), and Hanoi (Vietnam).

The complete hierarchy decision for this study is presented in Figure 3.

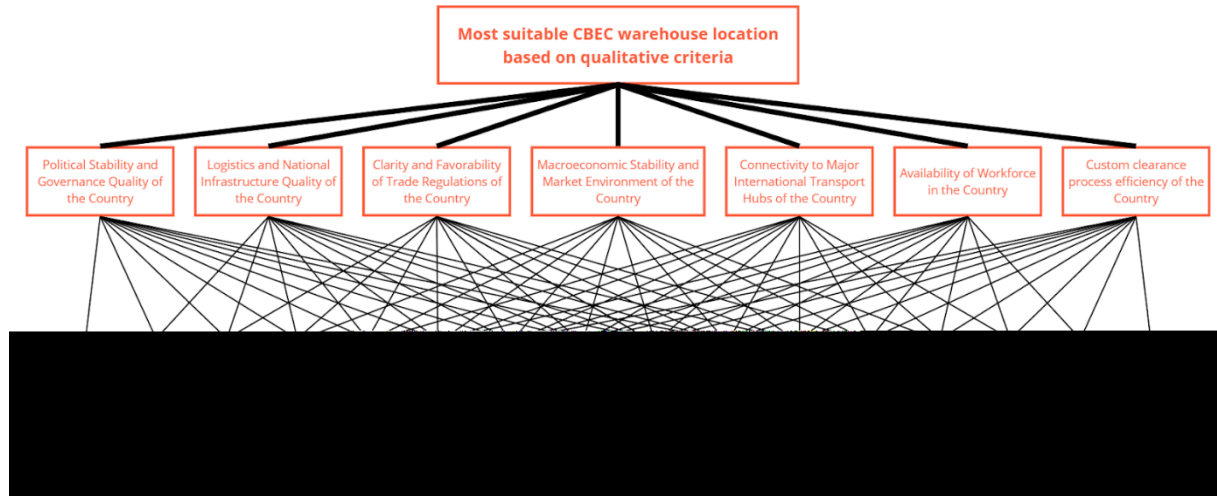


Figure 3. Decision hierarchy of the study

#### 4.2. Alternative Scores for Qualitative criteria

This study utilizes external data sources to quantify the performance of each alternative with respect to the qualitative criteria. This approach reduces the number of pairwise comparison judgments required from experts. With seven criteria and ten alternatives, a full pairwise comparison would result in 315 comparisons per expert, which may impose a substantial cognitive burden on respondents.

For political stability, the six sub-indicators are aggregated using the World Governance Indicators reported by Kaufmann (2024). Data for macroeconomic conditions, workforce availability, and customs clearance efficiency are obtained from the World Bank. Infrastructure quality is measured using the Logistics Performance Index (LPI). Clarity of trade regulation is sourced from the OECD Trade Facilitation Indicators. Air connectivity data are obtained from IATA, while maritime connectivity is measured using the Liner Shipping Connectivity Index (LSCI). Table 3 summarizes the alternative score of each qualitative criterion.

Table 3. Alternative score of each qualitative criterion

|     | C1   | C2  | C3    | C4    | C5    | C6          | C7   |
|-----|------|-----|-------|-------|-------|-------------|------|
| A1  | 0.38 | 2.5 | 1.273 | 4.2   | 4.28  | 233,520     | 2.62 |
| A2  | 0.10 | 2.1 | 1.273 | 6.02  | 5.86  | 9,903,822   | 2.2  |
| A3  | 0.55 | 2.9 | 1.273 | 5.03  | 25.71 | 143,143,940 | 2.8  |
| A4  | 0.14 | 2.3 | 1.364 | 4.25  | 1.00  | 3,584,797   | 2.3  |
| A5  | 0.57 | 3.6 | 1.4   | 5.11  | 51.15 | 18,264,000  | 3.3  |
| A6  | 0.03 | 2   | 1.273 | -0.97 | 5.65  | 22,741,699  | 2.17 |
| A7  | 0.47 | 3.2 | 1.273 | 5.69  | 18.94 | 50,979,290  | 2.8  |
| A8  | 0.62 | 4.6 | 1.545 | 4.39  | 58.34 | 3,722,265   | 4.2  |
| A9  | 0.46 | 3.7 | 1.364 | 2.53  | 30.80 | 40,623,017  | 3.3  |
| A10 | 0.25 | 3.2 | 1.4   | 7.09  | 37.40 | 57,133,476  | 3.1  |

#### 4.3. Criteria weightings using AHP

Five experts with more than five years of experience in e-commerce operations, cross-border logistics, and supply chain management participated in the pairwise comparison survey. Table 4 shows the weight of each qualitative criterion based on the expert judgement after normalization. The result shows that clarity of the trade regulation has the highest weight, followed by political and macroeconomic stability. While the lowest weight is the availability of the workforce.

The consistency of the expert judgement is evaluated using the consistency ratio. The result of this test is shown in Table 5, showing that the consistency ratio of every expert judgement was below 0.1, which means that the result is accepted.

Table 4. Weight of each criterion

| Criteria | Geometric Mean |
|----------|----------------|
| C1       | 0.163          |
| C2       | 0.106          |
| C3       | 0.24           |
| C4       | 0.138          |
| C5       | 0.106          |
| C6       | 0.09           |
| C7       | 0.121          |

Table 5. Consistency Ratio

|                        | Overall | Expert A | Expert B | Expert C | Expert D | Expert E |
|------------------------|---------|----------|----------|----------|----------|----------|
| Consistency Index (CI) | 0.05    | 0.114    | 0.087    | 0.122    | 0.094    | 0.11     |
| Random Index (RI)      | 1.32    | 1.32     | 1.32     | 1.32     | 1.32     | 1.32     |
| Consistency Ratio (CR) | 0.038   | 0.086    | 0.066    | 0.092    | 0.071    | 0.083    |

#### 4.4. Quantitative parameter score

In this study, the Goal Programming model utilizes data from multiple sources. The quality score of each candidate country is obtained from the priority values generated through the AHP analysis. Several operational parameters are derived from internal operational data provided by a multinational e-commerce company operating in Southeast Asia. These include product price information, warehouse operational data used to estimate labor cost per unit, and the inventory turnover parameter ( $\alpha$ ), which is 5.26. Labor cost per unit is estimated by converting the minimum monthly wage of each country in 2025 into a unit cost using the ratio of outbound volume to total warehouse man-days obtained from the company's operational records. Internal operational data from the same company also indicates that cross-border delivery accounts for approximately 13.75% of the total market demand of a country, which is used as a parameter in the model.

For countries without company operations, product prices are estimated through interpolation based on national GDP. Import tax data are obtained from the World Trade Organization, while warehouse license fees and rental costs are collected from publicly available sources.

Market demand is estimated from the 2025 Temasek e-commerce report, assuming the model captures 0.5% of regional GMV. The 0.5% assumption represents a conservative market penetration scenario for a newly established cross-border warehouse network. These data are summarized in Table 6.

This study also establishes benchmark values as targets for each goal. For lead time, a benchmark model is first developed to estimate the minimum achievable lead time within the warehouse network. The purpose of this benchmark model is to identify the lowest theoretical lead time when lead time is treated as the sole optimization objective, excluding other objectives such as cost, profit, or quality. Benchmarks for transportation cost, variable cost, and fixed cost are derived from operational benchmarks provided by the e-commerce company and are expressed as fractions proportional to revenue.

The demand target is set at at least 80% of the total market demand, while revenue and profit depend on the level of demand fulfilled. Revenue is calculated as fulfilled demand multiplied by the product price in each country, while profit is defined as total revenue minus total operational costs. The target for quality score is determined as the maximum achievable score based on the three countries with the highest AHP priority values.

Table 6. Parameter data for weighted goal programming

|     | Demand<br>(pcs/month) | Product<br>price per<br>unit<br>(USD) | Import<br>Tax | Warehouse<br>License Fee<br>(USD/month) | Warehouse<br>Rent Fee<br>(USD/sqm) | Labor Cost<br>per unit<br>(USD/unit) | Country's<br>Quality<br>Score |
|-----|-----------------------|---------------------------------------|---------------|-----------------------------------------|------------------------------------|--------------------------------------|-------------------------------|
| A1  | 8,022                 | 35.51                                 | 0.60%         | 465.63                                  | 12.8                               | 0.57                                 | 0.078                         |
| A2  | 14,743                | 16.38                                 | 9.00%         | 800                                     | 3.8                                | 0.11                                 | 0.07                          |
| A3  | 937,789               | 28.88                                 | 8.00%         | 799.4                                   | 3.85                               | 0.17                                 | 0.139                         |
| A4  | 5,500                 | 9.06                                  | 8.60%         | 11.56                                   | 0.83                               | 0.06                                 | 0.065                         |
| A5  | 218,723               | 30.48                                 | 5.30%         | 591.94                                  | 5.92                               | 0.21                                 | 0.125                         |
| A6  | 22,708                | 7.29                                  | 7.60%         | 23.8                                    | 1.33                               | 0.05                                 | 0.051                         |
| A7  | 281,622               | 31.07                                 | 6.00%         | 84.12                                   | 8.78                               | 0.12                                 | 0.11                          |
| A8  | 105,604               | 35.51                                 | 0.00%         | 4,327.27                                | 4.3                                | 0.85                                 | 0.135                         |
| A9  | 349,914               | 25                                    | 9.30%         | 956.05                                  | 4.78                               | 0.16                                 | 0.108                         |
| A10 | 29,608                | 14.83                                 | 9.40%         | 38.07                                   | 4.26                               | 0.1                                  | 0.118                         |

The weights assigned to each goal reflect the success indicators of cross-border e-commerce operations identified in this study. Financial performance is represented by operational profitability, customer satisfaction is represented by delivery lead time, and operational resilience is represented by the quality score. These targets and weights are summarized in Table 7.

Table 7. Target and weight for weighted goal programming

| Parameter | Target     | Weight |
|-----------|------------|--------|
| LT        | 0.466      | 10     |
| Demand    | 1,751,154  | 3      |
| Revenue   | 62,183,493 | 3      |
| Quality   | 0.399      | 10     |
| TC        | 2,430,602  | 3      |
| FC        | 437,789    | 3      |
| VC        | 218,894    | 3      |
| Profit    | 59,096,208 | 10     |

## 5. Results and Discussion

The AHP model was calculated using Super Decisions version 3.2.0. Table 8 presents the results of the AHP evaluation. Based on expert judgments and the performance scores of each alternative across the qualitative criteria, Indonesia, Singapore, and Malaysia rank as the top three candidate locations. Indonesia achieves the highest priority score due to its strong performance in several criteria, particularly political stability and workforce availability. Although workforce availability receives the lowest weight among the evaluated criteria, Indonesia demonstrates a

substantial advantage in this attribute compared with other countries. Singapore and Malaysia rank second and third, respectively, mainly due to their strong performance in connectivity, political stability, infrastructure quality, and clarity of trade regulations, as shown in Table 3.

However, the final warehouse decision cannot rely solely on qualitative evaluation because operational cost, demand distribution, and lead time must also be considered. Therefore, the priority scores obtained from the AHP analysis are incorporated as one of the parameters in the Weighted Goal Programming model.

The Weighted Goal Programming model was implemented in Python using Pyomo as the algebraic modeling language and solved using the HiGHS solver. The results, presented in Table 9, indicate that Indonesia, the Philippines, and Thailand are selected as the optimal warehouse locations, balancing profitability, lead time, and qualitative location attributes. Indonesia serves as the primary fulfillment hub, supplying most markets except the Philippines and Thailand. This allocation is influenced by Indonesia's large base demand and relatively lower warehouse rental costs compared with the other candidate locations. Meanwhile, the Philippines and Thailand are selected as additional warehouse locations due to their relatively high domestic demand levels. Given the constraint that only 13.75% of demand can be fulfilled through cross-border operations, the model prioritizes warehouse locations in countries with larger base demand to maximize demand fulfillment and operational efficiency.

Table 10 presents the deviation of each parameter when Indonesia, the Philippines, and Thailand are selected as the warehouse location, with the minimized objective function being 0.219. Referring to the normalized penalty column, where the deviation is normalized to the weight of each goal, profit shows the largest deviation among all goals, mainly driven by transportation costs exceeding the predefined target. This result highlights the trade-off between profitability and transportation costs in cross-border warehouse network design.

Table 8. AHP model calculation result

| Alternative              | Priority Level |
|--------------------------|----------------|
| <b>Brunei Darussalam</b> | 0.079015       |
| <b>Cambodia</b>          | 0.0077280      |
| <b>Indonesia</b>         | 0.140197       |
| <b>Laos</b>              | 0.070126       |
| <b>Malaysia</b>          | 0.119420       |
| <b>Myanmar</b>           | 0.055003       |
| <b>Philippines</b>       | 0.113035       |
| <b>Singapore</b>         | 0.128313       |
| <b>Thailand</b>          | 0.115599       |
| <b>Vietnam</b>           | 0.102012       |

Table 9. Weighted Goal Programming model location-allocation result

| Market/Warehouse         | Warehouse-Indonesia | Warehouse Philippines | Warehouse-Thailand |
|--------------------------|---------------------|-----------------------|--------------------|
| <b>Brunei Darussalam</b> | 962                 | -                     | -                  |
| <b>Cambodia</b>          | 3,832               | -                     | -                  |
| <b>Indonesia</b>         | 937,789             | -                     | -                  |
| <b>Laos</b>              | 2,583               | -                     | -                  |
| <b>Malaysia</b>          | 30,074              | -                     | -                  |
| <b>Myanmar</b>           | 13,258              | -                     | -                  |
| <b>Philippines</b>       | -                   | 281,622               | -                  |
| <b>Singapore</b>         | 14,521              | -                     | -                  |
| <b>Thailand</b>          | -                   | -                     | 433,320            |
| <b>Vietnam</b>           | 8,499               | -                     | -                  |

Table 10. Weighted Goal Programming model calculation result

| Parameter             | Target     | AHP-GP Model Deviation | Normalized Deviation | Normalized Penalty |
|-----------------------|------------|------------------------|----------------------|--------------------|
| <b>Profit</b>         | 59,096,208 | 15,871,575             | 0.266                | 0.059              |
| <b>Demand</b>         | 1,751,154  | 24,693                 | 0.014                | 0.001              |
| <b>Revenue</b>        | 62,183,493 | 13,741,844             | 0.221                | 0.015              |
| <b>Fixed Cost</b>     | 437,789    | 92,896                 | 0.212                | 0.014              |
| <b>Variable Cost</b>  | 218,894    | 93,684                 | 0.428                | 0.029              |
| <b>Transport Cost</b> | 2,430,602  | 1,810,931              | 0.745                | 0.050              |
| <b>Lead Time</b>      | 0.466      | 0.06                   | 0.130                | 0.029              |
| <b>Quality</b>        | 0.404      | 0.04                   | 0.105                | 0.023              |
| <b>Total</b>          |            |                        |                      | 0.219              |

## 5.2 Validation

Since Indonesia's top ranking in the AHP results is partly influenced by its strong workforce availability, an additional test was conducted to examine the robustness of the results when this criterion is excluded from the model. Table 11 presents the updated priority scores of each country after removing the workforce availability criterion. The results show that although Indonesia's priority score decreases, it remains among the top three locations after Singapore and Malaysia. This indicates that Indonesia's overall attractiveness as a warehouse location remains strong even without considering workforce availability.

For the Goal Programming model, sensitivity analysis was conducted to examine how the model responds to changes in the relative importance of the objectives. Table 12 shows that when the weight is concentrated on profitability while lead time and quality are ignored, the warehouse located in the Philippines serves most of the regional market, while Indonesia and Thailand mainly serve their domestic demand. This outcome is largely driven by the relatively lower transportation cost from the Philippines to most Southeast Asian countries. Conversely, when the weights emphasize quality and lead time, Malaysia replaces Thailand as one of the selected warehouse locations to maximize the qualitative performance of the network, while Indonesia and the Philippines remain selected.

Finally, a comparison between the AHP-only approach and the integrated AHP–Goal Programming model was conducted. When location selection is based solely on qualitative criteria, operational considerations such as cost and profitability are not adequately captured. As shown in Table 13, the AHP-only scenario results in significantly higher deviations from cost targets. Since the AHP model cannot determine allocation decisions, the simulation assumes lead time as the only optimization goal. Under this condition, most cost-related targets are exceeded, resulting in higher deviations compared with the integrated AHP–Goal Programming model.

Table 11. Sensitivity Analysis AHP Model

| Alternative       | Priority Level |
|-------------------|----------------|
| Brunei Darussalam | 0.087122       |
| Cambodia          | 0.075930       |
| Indonesia         | 0.112396       |
| Laos              | 0.072459       |
| Malaysia          | 0.134740       |
| Myanmar           | 0.050228       |
| Philippines       | 0.108348       |
| Singapore         | 0.150263       |
| Thailand          | 0.109163       |

|         |          |
|---------|----------|
| Vietnam | 0.099351 |
|---------|----------|

Table 12. Sensitivity Analysis GP Model

| Market            | Warehouse origin |                        |                  |
|-------------------|------------------|------------------------|------------------|
|                   | As-is weight     | Profitability oriented | Quality oriented |
| Brunei Darussalam | Indonesia        | Philippines            | Malaysia         |
| Cambodia          | Indonesia        | Philippines            | Indonesia        |
| Indonesia         | Indonesia        | Indonesia              | Indonesia        |
| Laos              | Indonesia        | Philippines            | Malaysia         |
| Malaysia          | Indonesia        | Philippines            | Malaysia         |
| Myanmar           | Indonesia        | Philippines            | Malaysia         |
| Philippines       | Philippines      | Philippines            | Philippines      |
| Singapore         | Indonesia        | Philippines            | Indonesia        |
| Thailand          | Thailand         | Thailand               | Malaysia         |
| Vietnam           | Indonesia        | Philippines            | Indonesia        |

Table 13. Comparison of the AHP-only model with AHP-GP model

| Goal           | Deviation |        |
|----------------|-----------|--------|
|                | AHP-only  | AHP-GP |
| Profit         | 0.56      | 0.266  |
| Demand         | 0.21      | 0.014  |
| Revenue        | 0.35      | 0.221  |
| Fixed Cost     | 3.45      | 0.212  |
| Variable Cost  | 1.00      | 0.428  |
| Transport Cost | 4.03      | 0.745  |
| Lead Time      | 0.00      | 0.130  |

## 6. Conclusion

A cross-border e-commerce warehouse location decision should consider not only qualitative attributes but also quantitative operational factors. Qualitative aspects ensure that the selected location supports resilient and sustainable long-term operations, while quantitative factors ensure profitability and maintain customer satisfaction in terms of delivery speed and reliability.

This study proposes an integrated decision framework combining the Analytic Hierarchy Process (AHP) and Goal Programming to evaluate both qualitative and quantitative aspects in selecting cross-border e-commerce warehouse locations. The application of this approach demonstrates that integrating both models enables a comprehensive evaluation of location quality while simultaneously optimizing operational performance. The framework also provides flexibility for decision makers to adjust the strategic focus of the company, whether emphasizing profitability, delivery speed, or location quality, by modifying the weights assigned to each goal.

In addition, the use of Goal Programming allows the model not only to determine the most suitable warehouse locations but also to optimize the allocation of demand across the warehouse network. Therefore, the proposed framework offers a practical decision-support tool for designing cross-border e-commerce fulfillment networks in Southeast Asia.

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