Application of Analytic Hierarchy Process for Fulfillment Warehouse Location Selection

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***Abstract*—The objective of this research is to apply the analytic hierarchy process to select the best fulfillment warehouse location for a 4PL (Fourth Party Logistics Service Provider) company that is seeking a new warehouse to support the growth of its business. The pairwise comparison judgments were collected from the company's management team by using a questionnaire to consider five location candidates in the Bangkok Metropolis Region and Vicinity. In the study, three main criteria and nine sub-criteria related to the facilities, transportation, market, and workforce were analyzed. The results show that the proposed model is able to determine the importance weights of criteria and sub-criteria for the fulfillment warehouse location selection. The highest priority criterion is transportation (41.7%). The subsequent priorities were assigned to facilities (37.6%) and market and workforce (20.7%) when selecting a fulfillment warehouse location according to the obtained weights. Finally, fulfillment warehouse location 2 (24.6%) is the first priority for location, followed by location 1, location 5, location 4, and location 3, respectively.**

***Index Terms*—Multi-Criteria Decision Making, Analytic Hierarchy Process, Warehouse Location Selection, Fulfillment Warehouse**

I. Introduction

The COVID-19 outbreak has disrupted the entire world in terms of health, society, economy, and business operations. In particular, COVID-19 has had a direct impact on the supply chains of goods and services [1]. The new normal of domestic and international consumption has quickly caused the common business model to be adjusted from offline to online on e-commerce platforms. Logistics entrepreneurs and startup companies have seen an opportunity to adapt their business model to B2C (business to customer) as well as to develop the business from C2C (customer to customer), which is just a provider of parcel delivery, to become a B2B2C (business to business to customer) business, which is an area where demand is increasing rapidly.

The logistics service provider is an integral part of any organization by providing the most efficient supply chain management and adding value to their client's business. Moreover, the logistics service provider having efficient logistics systems will help the organization that is using the service to compete with competitors in terms of speed of transportation, delivery accuracy, and quick response to the customers' needs with low-cost operations [2]. This research is a study of a logistics startup company located in Bangkok that provides 4PL (Fourth Party Logistics Service Provider) services between merchants and carriers, including warehouse rental service and delivery of goods service (fulfillment warehouse). Fulfillment warehouses are the places where converted online customer orders to parcel delivery packages, which are then transferred to the customers with the operational goal of fast fulfillment [3], [4]. Because fulfillment warehousing helps to yield the desired level of customer service at the least total cost, it is an essential component of any logistics system. The completion of warehouse activities is the bridge between the producer and the client, and it is becoming increasingly important in logistics operations. Due to the rapid growth of e-commerce during the COVID-19 outbreak, the company has gained more customers in both B2B and B2C. To avoid future difficulties, such as product delivery delays, a new warehouse location must be located to fulfill customer demands, promptly react to customer needs, and gain a competitive edge in terms of time and space. Such action also contributes to lower total logistics costs. Using Multiple Criteria Decision Making (MCDM), this study intended to identify a new warehouse location in Bangkok and vicinities to serve as the nation's distribution hub. The Analytic Hierarchy Process (AHP) is a decision-making tool that can be used to conduct decision-making in cases through the use of a rating assessment having a scale from 1 to 9 through pairwise comparison of alternatives on each decision criteria. It uses a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives [5].

The majority of prior research has centered on robotic mobile fulfillment or dynamic demand fulfillment. The research on the placement of fulfillment warehouses is still in its early phases. As a result, the goal of this paper is to find the optimal fulfillment warehouse location for a startup company operating in the Bangkok metropolitan area to maintain a steady sales growth rate and avoid any uncertainties that might harm the company's overall performance. We utilized a common multi-criteria decision-making method, the Analytic Hierarchy Process (AHP), to decide the best alternative. There are five alternatives locations for the company to select from. The warehouses' name is not provided due to confidentiality reasons, but the location names will be shown.

II. Literature Review

A. Warehouse Location

Warehouses are a key link in a supply chain network in both regional and global markets [6]. With regard to supply chain networks, the speed and efficiency of supply chains are defined by the location of the warehouse [3], [7]. Alberto stated that the location of warehouses should be selected in an area where the overall efficiency of the company's supply chain can be increased and value can be added to the business [8]. Thus, the selection of warehouse location is a highly important undertaking due to the possibility of major losses, for example, increased production costs and delays in the delivery process, occurring for the company, due to an incorrect decision [6], [9]. There are several dimensions such as short lead-time, flexibility, and profitability, which are being achieved through warehousing. Especially in the globalized market and with the growth of e-commerce, warehouse location selection has become one of the most crucial strategic decisions for companies [10]. Onal et al. explained that order fulfillment is related to warehouse location decisions. If a warehouse is situated near the markets during high demand, it can deliver the products at the correct time [11]. The concept of warehouse location selection involves the travel distance between the warehouse and the markets [6]. Warehouse location parameters can be generated using both quantitative and qualitative requirements. The quantitative features can be measured using figures. Many of the most frequent geographical variables used in warehouse location are market, transportation, labor, site constraints, raw materials and services, utilities, government regulations, neighborhood, and ecology [12], [13]. Previous studies looked at the costs, labor qualities, facilities, markets, and taxes, as well as workforce feasibility [9]. Various critical factors have been used by researchers in the warehouse location selection process that broadly include four factors, proximity to market; proximity to transportation; building availability; and workforce availability [6], [8], [9], [12], [13].

B. Fulfillment Warehouse

Fulfillment warehouses also called 3PL or 4PL providers, are an essential part of the e-commerce business. These 3PL and 4PL service providers help e-commerce brands and retailers fulfill customers' orders. A fulfillment warehouse is utilized for the packing and delivery of a product to customers. Therefore, the structure and operations of fulfillment warehouses are different from those of traditional warehouses, which are used to store products or bulk inventory for long periods of time [14]. In contrast, a fulfillment warehouse is used to keep inventory for short time periods, until the e-commerce orders need to be shipped to customers. According to Hilletofth who explained that limited amounts of commodities are stored in fulfillment warehouses for brief periods [15]. Furthermore, fulfillment warehouses may handle various jobs, whereas traditional warehouses operate on a set schedule. The fulfillment time required to meet customer demands is fundamental to the fulfillment warehouse operation. Rapid fulfillment is the key aim of online merchants, with the mission of same-day, next-day, or two-day delivery [16]. As a result, fulfillment warehouse concepts are designed for rapid selection and precise delivery in order to maximize customer satisfaction. In addition, a substantial link between order fulfillment delays and consumer purchasing behavior was found by Nguyen et al. [17].

C. Analytical Hierarchy Process

Warehouse location is a strategic decision thus companies need to define the top criteria for selecting the best warehouse location based on their requirements. Multiple Criteria Decision Making (MCDM) is usually used when considering diverse categories of solutions to decision problems. The Analytical Hierarchy Process (AHP) is a method that considers a complicated multiple criteria decision-making problem as a system [18], [19]. The AHP is an effective tool for analyzing multiple criteria to support the decision-making process through a hierarchical structure that was proposed by Saaty.

This method takes into consideration both the tangible and intangible criteria by identifying the criteria and sub-criteria in a decision hierarchy and assigning rankings to the alternatives, criteria, and sub-criteria through pairwise comparison matrices in all the levels of the hierarchy [20], [21]. This analytical process can be divided into four steps: (1) structuring a hierarchy prioritization model, (2) preparing a questionnaire for collecting data from experts, (3) constructing judgment matrices in all levels, and (4) checking the hierarchical single ordering and consistency [22]. However, the key step in the AHP process is a pairwise comparison to determine the weights of the criteria and provide ratings for alternatives. The weights of the criteria and sub-criteria used in the AHP process are based on the opinions of experts and/or stakeholders who helped in analyzing the critical factors in the warehouse location selection.

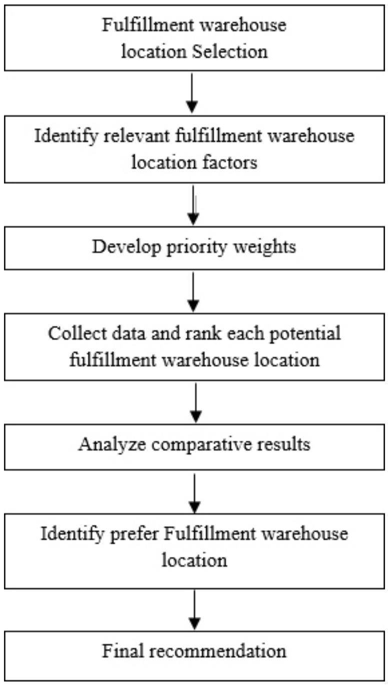

Fig. 1. Solution process of the AHP location model

III. Methodology

A. Judgment Aggregation and Rating of Decision Alternatives

Selecting a fulfillment warehouse location is a sophisticated process related to multiple locations, multiple criteria, multiple facilities, and multiple factors that can change over time due to crises such as the COVID-19 pandemic or natural disasters. No single location could be suitable under multiple criteria or factors because each location candidate may have a unique advantage in its favor. In this sense, the fulfillment warehouse placement location issue may be handled using the AHP solution technique, which is ideally suited in this case. AHP is a technique for assessing a variety of qualitative and quantitative factors. In the AHP paradigm, pairwise comparison is a crucial phase. The approach concentrates on two elements at the same time as well as their interactions. The relative significance of each element is assessed on a scale of 1 to 9, with 1 indicating that the two variables relate equally to the goal and 9 indicating that one variable is favored over the other to the greatest extent allowed [5], as seen in Table I. The creation of priority weights is a crucial stage in a pairwise comparison that is displayed as a matrix. Fig. 1 depicts the AHP fulfillment warehouse location decision model's technique. The AHP model is used in this study to examine the company's background and expectations before identifying the appropriate fulfillment warehouse location criteria. These variables are organized in a hierarchy that progresses from the overall goal to various criteria and sub-criteria in consecutive amounts [23].

B. Consistency Ratio: CR

The level to which a supposed link between components in a pairwise comparison is preserved is known as consistency. This is significant because a lack of consistency in comparisons might signal that respondents were unable to correctly calculate the impact of the items being evaluated or that they did not comprehend the distinctions between the options provided [24]. The consistency ratio (CR) is obtained by comparing the consistency index (CI) with an average random consistency index (RI), as shown in Table II [5]. The CR must be less than 0.1 to accept the computed weights. The CR is defined by using Equation (1) and the CI is determined using Equation (2).

Equation (1);

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

Equation (2);

$$CI = \frac{\lambda\text{max} - \text{n}}{n - 1}$$

where λmax = maximal eigenvalue

TABLE I
FUNDAMENTAL SCALES FOR PAIRWISE COMPARISONS

Scales	Degree of Preferences	Descriptions
1	Equally	Two activities contribute equally to the objective.
3	Moderately	Experience and judgment slightly or moderately favor one activity over another.
5	Strongly	Experience and judgment strongly or essentially favor one activity over another.
7	Very strongly	An activity is strongly favored over another and its dominance is showed in practice.
9	Extremely	The evidence of favoring one activity over another is of the highest degree possible of an affirmation.
2, 4, 6, 8	Intermediate values	Used to represent compromises between the preferences in weights 1, 3, 5, 7 and 9.

Source: Saaty [20]

TABLE II
RANDOM INDES (RI) TABLE

N (number of factors)	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

C. *Criteria and Sub-Criteria*

To help with criteria selection, the researcher compiled the typical criteria and priority weights from past studies regarding warehouse location selection. Literature analysis and managerial conclusions were used to get the sub-criteria in this study.

There are five potential fulfillment warehouses proposed for location consideration. The reason for selecting these locations is because all of them passed the pre-requirements regarding the distance from the company to the candidate warehouses and the three key location criteria that are most relevant to fulfillment warehouse location [25]-[27]. Each of the key criteria is disaggregated into three major sub-criteria, which are based on company policy. The three key criteria and nine sub-criteria (two levels) are structured into a decision hierarchy, as shown in Fig. 2 and Table III.

The appropriateness of the decision order may be verified by a process that begins with small group meetings to establish research goals and outline the major criteria, sub-criteria, and alternatives in the decision model. The meeting is attended by a group of five assessors, comprising executives and staff from the company's warehouse department. The evaluators remarked on the model's suitability for selecting fulfillment warehouse locations.

Table III shows if the parameters are qualitative or quantitative. The nine site criteria are utilized as a decision matrix, and the AHP model requires the decision makers' evaluations for each site. The priority weights of each site criterion are calculated by comparing each parameter at a given level using pairwise comparisons.

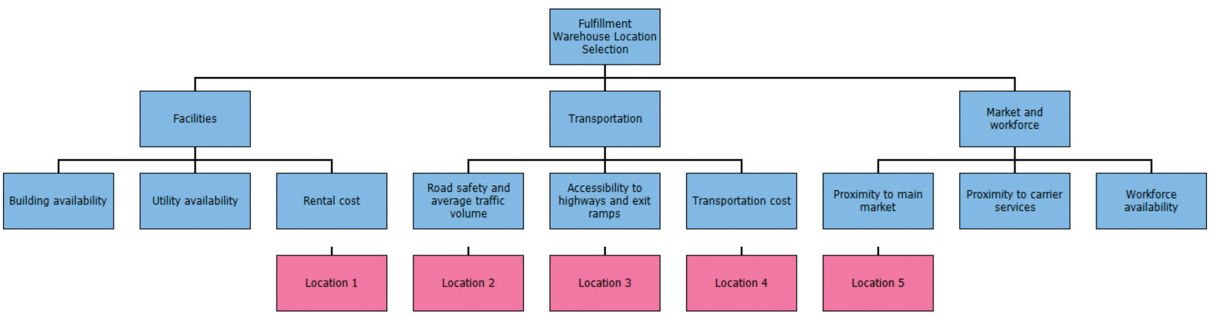

Fig. 2. Hierarchy structure

TABLE III
LOCATION CRITERIA AND SUB-CRITERIA TYPES

Criteria	Type
A. Facilities	
A1- Building availability	Qualitative
A2- Utility availability	Qualitative
A3- Rental cost	Quantitative
B. Transportation	
B1- Road safety and average traffic volume	Qualitative
B2- Accessibility to highways and exit ramps	Qualitative
B3- Transportation cost	Quantitative
C. Market and workforce	
C1- Proximity to main market	Qualitative
C2- Proximity to carrier services	Qualitative
C3- Workforce availability	Qualitative

D. Location Candidates

There are five potential fulfillment warehouses proposed for location consideration based on company criteria and policy. Location 1 is located in Pak Kret; location 2 is located in Muang Thong Thani; location 3 is located in Lat Phrao; location 4 is located in Ngamwongwan; and location 5 is located in Chatuchak.

G. Data Collecting and Analyzing

The company is expected to provide judgment data from decision-makers, company's management team, with knowledge, competence, and experience in logistics and warehouse services. The pairwise comparisons data were collected using the on-site questionnaire. There were 13 pairwise comparison matrices; 3 for the main criteria, 9 for the sub-criteria, and 1 for the alternatives. The aggregated pairwise comparison judgment is computed by the weighted geometric mean method. The researcher entered the data from the surveys into the Expert Choice software to calculate the Consistency Ratio for each person. The researcher scheduled another meeting with the assessor until the CR value was within an appropriate range if the value did not satisfy the requirements. The AHP approach was employed in this study, and the Expert Choice software was used in the assessment procedure.

IV. RESULTS

There are three key criteria in this research: (A) Facilities, (B) Transportation, and (C) Market and workforce. The nine sub-criteria are (A1) Building availability, (A2) Utility availability, (A3) Rental cost, (B1) Road safety and average traffic volume, (B2) Accessibility to highways and exit ramps, (B3) Transportation cost (C1) Proximity to main market, (C2) Proximity to carrier services and (C3) Workforce availability. Among the nine sub-criteria, two are quantifiable, but the others are not. The study was based on a pairwise evaluation of all of the sites concerning all criteria and sub-criteria.

The eigenvalue in the associated eigenvector of each matrix represents the priority weight of each condition. This eigenvector is graded with the greater element's weight, which is utilized as the pairwise comparison criteria. The weights of the sub-criteria are multiplied by the weight of the factor immediately in the hierarchy to get the composite weights of the location criteria. The results of the analysis of the composite weight are shown in Table IV.

TABLE IV
LOCATION CRITERION WEIGHT

Criteria	A	B	C
A. Facilities	**0.376**		
A1- Building availability	0.230		
A2- Utility availability	0.235		
A3- Rental cost	0.535		
B. Transportation		**0.417**	
B1- Road safety and average traffic volume		0.293	
B2- Accessibility to highways and exit ramps		0.262	
B3- Transportation cost		0.445	
C. Market and workforce			**0.207**
C1- Proximity to main market			0.389
C2- Proximity to carrier services			0.468
C3- Workforce availability			0.142

The results are shown in Table IV, and, with regard to the fulfillment warehouse location selection, transportation is the highest priority (0.417). The subsequent priorities are assigned to facilities (0.376) and market and workforce (0.207) according to the obtained weights. For the facilities criteria, the rental cost is the first priority sub-criteria (0.535), regarding the transportation criteria, transportation cost is the first priority sub-criteria (0.445), and for the market and workforce, proximity to carrier services is the first priority (0.468).

The total priority score for each site option is determined by multiplying the site's rating score for each provided criterion by the associated criterion's priority weight. The final results consist of the derived criteria weights and the class ratings, which are calculated using the consistency ration (CR). The CR of this model is less than 0.1, so the computed weights are accepted. As the results seen in Table V show, location 2 is the preferred location because it has the highest score (0.246) among the five candidate locations. The subsequent priorities are assigned to location 1 (0.212), location 5 (0.198), location 4 (0.174) and location 3 (0.168), according to the obtained weights.

TABLE V
OVERALL RATING OF FIVE LOCATIONS

Criteria	Location 1	Location 2	Location 3	Location 4	Location 5	CR
A. Facilities						
A1- Building availability	0.148	0.281	0.094	0.342	0.135	0.031
A2- Utility availability	0.114	0.281	0.087	0.380	0.138	0.036
A3- Rental cost	0.373	0.288	0.172	0.056	0.111	0.079
B. Transportation						
B1- Road safety and average traffic volume	0.227	0.300	0.137	0.159	0.177	0.068
B2- Accessibility to highways and exit ramps	0.151	0.370	0.136	0.126	0.217	0.018
B3- Transportation cost	0.140	0.098	0.264	0.202	0.296	0.045
C. Market and workforce						
C1- Proximity to main market	0.204	0.134	0.230	0.161	0.271	0.051
C2- Proximity to carrier services	0.229	0.321	0.125	0.119	0.206	0.029
C3- Workforce availability	0.265	0.326	0.140	0.148	0.121	0.009
Score	**0.212**	**0.246**	**0.168**	**0.174**	**0.198**	**0.045**

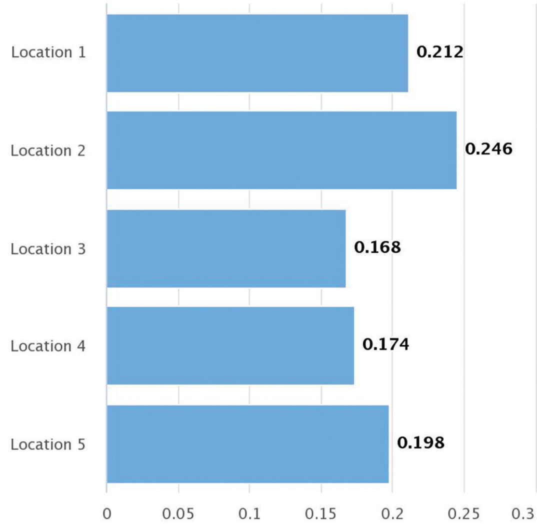

Fig. 3. Priorities with respect to fulfillment warehouse location selection

V. Summary and Managerial Implications

In the process of the optimization of a logistics system in 3PL and 4PL, the selection of the proper location for a fulfillment warehouse has always been considered as one of the most strategic and important challenges to overcome. Making good decisions is extremely important for startup companies because it is costly and difficult to reverse them and they give rise to long-term commitments [28]. Many quantitative and qualitative criteria affect the selection of the warehouse location as a long-term decision, such as markets, transportation, labor, and utilities [14]. The keys to the success of a fulfillment warehouse are speed and accuracy in responsiveness to customer demands [3], [4], [29]. This paper presents an Analytic Hierarchy Process (AHP) location decision model for the startup company seeking a location for expansion of their business. The main criteria consist of facilities, transportation, and market and workforce. Moreover, the nine sub-criteria are building availability, utility availability, rental cost, road safety and average traffic volume, accessibility to highways and exit ramps, transportation cost, proximity to main market, proximity to carrier services, and workforce availability. The highest priority criterion is transportation. The subsequent priorities are assigned to facilities, and market and workforce, respectively. Transportation is an important consideration factor because transportation costs are high and vary with distance and traffic conditions. Therefore, a location where transportation time, as well as transportation costs, can be reduced should be selected, which will increase transportation efficiency and facilitate a quick response to the needs of customers, in accordance with previous research [9], [30]. The operational goal of fulfillment warehouse is fast fulfillment. Proximity to key roadway is a key criteria when selecting the new warehouse location, according to previous research [3]. Based on the results of this research, it was found that fulfillment warehouse location 2 (Muang Thong Thani) is the first priority. The subsequent priorities are assigned to location 1, location 5, location 4, and location 3, respectively.

In this research, the analytical hierarchy process was applied to the fulfillment warehouse location selection, which allows decision-makers to compare the importance of the criteria and sub-criteria affecting the process when a decision is made. Furthermore, it can logically inform them about the importance of each of the location candidates in terms of the various criteria. In addition, the analytic hierarchy process can verify the inconsistency of the comparisons and analyze the accuracy of the information. However, Analytic Hierarchy Process cannot make decisions on behalf of humans; hence, the knowledge, experience, and expertise of the decision-makers will be the key factor in their decision making. These research outcomes can help a company's management to identify the important factors to consider when selecting the best fulfillment warehouse location. For further research, additional criteria related to warehouse management systems should be included in future studies.

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