Selection of Distribution Center Location for Logistics Service Providers in Thailand Based on Mathematical Model

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Abstract

This research aims to apply a mathematical model to analyze the optimal location of logistics operators' distribution centers in Thailand by applying the mathematical model called Center of Gravity Technique. The model used cost information in the transportation system, which came from the lowest cost of the operators and the needs of logistics service users based on data from the 9 provinces with the highest volume of logistics services, namely Nakhon Sawan, Chiang Mai, Ubon Ratchathani, Khon Kaen, Nakhon Ratchasima, Kanchanaburi, Surat Thani, Phuket and Chonburi to analyze. In addition, qualitative factors were also taken into account, namely proper location and environment. The results showed when the Center of Gravity Technique was applied to the data of logistics operators in the 9 provinces with the volume of customer demand in 2017-2018 together with the analysis of the location and environment, there was only one location for the center of aggregate demand and supply. The suitable area for the distribution center was located at 14.44948283, 101.06126328 or 14° 26' 58.1" N 101° 3' 40.5" E or UTM 722200.217 East(X) 1598435.446 North(Y) Zone 47 Band P, which is the coordinates of Tha Maprang subdistrict, Kaeng Khoi district, Saraburi province because there were product resources, transportation routes, qualified and sufficient work resources, good attitudes of people, public services and environment in the area.

Keywords:logistics service providers, distribution center : mathematical model

1. Introduction

Distribution centers play a crucial role in the logistics service industry, contributing significantly to the management of logistics systems and supply chains. They facilitate timely, efficient responses to customer demands, possessing both capability and efficiency. Moreover, they enable businesses to control costs within budgetary constraints. Efficient management by operators is essential for generating profits.

Various transportation methods are employed today, including land, air, and sea routes. Land transport can further be divided into rail-based and road-based systems, utilizing vehicles of different types and sizes. In Thailand, road transport predominates due to its convenience, relatively short transit times, and accessibility to manufacturing sites and end customers. Consequently, most logistics operators opt to outsource transportation services to subcontractors, a key activity in the logistics system. However, this outsourcing often results in high costs and service quality issues due to subcontractors' lack of expertise in storage, handling, timely delivery, and appropriate vehicle selection.

Traditionally, transportation management relied solely on outsourcing transport services, with rates depending on fuel prices and labor costs. However, this approach leads to high transportation costs, especially in a country like Thailand, where direct deliveries without distribution centers are common. High transportation costs necessitate high service charges to customers, limiting competitiveness. Thus, establishing distribution centers within communities could reduce costs for businesses. However, a major challenge faced by logistics operators is often the inappropriate location of distribution centers, such as in congested neighborhoods, resulting in traffic congestion, inadequate space for storage, and inconvenience to customers. Moreover, they may be situated far from customers or close to competitors with more advanced and comprehensive service systems.

The process of selecting distribution center locations is typically subjective, lacking scientific principles and technological applications. Researchers recognize these challenges and propose that efficient transportation system management can be achieved by selecting suitable distribution center locations. Such a strategy could significantly reduce costs for businesses. This study aims to address high transportation costs caused by economic conditions, benefiting both small and medium-sized logistics operators, who constitute the majority of the country's logistics industry.

By employing mathematical models and Geographic Information System (GIS) data, the study analyzes transportation issues and evaluates potential distribution center locations across different regions of the country using Load Distance and Center of Gravity methods. The research team anticipates that the findings will help reduce transportation costs for small to medium-sized logistics operators, enabling them to compete with larger enterprises. This research could support the growth of the country's logistics system and serve as a guideline for future beneficial economic development studies.

2. Literature review

Several studies have explored factors influencing location selection decisions across various industries as follows.

2.1 Cam et al. (1997) selected the location for Proctor & Gamble's (P&G) distribution centers using both the Transportation Model and the Incapacitated Facility Location Model. The objective was to reduce transportation costs while meeting all requirements. The analysis resulted in a 20% reduction in the number of distribution centers, saving up to $200 million.

2.2 Sequential analysis has been widely applied in location decision-making. For instance, Yang and Lee (1997) employed sequential analysis to evaluate potential locations for facilities, considering primary criteria such as market accessibility, transportation, labor force, and community factors.

2.3 Similarly, Lin et al. (2005) evaluated airports as potential locations for airport distribution centers, focusing on factors like international market location, country stability, airport services, and cargo volume. They examined Taiwan KCS Airport, Hong Kong International Airport, and Singapore Changi Airport.

2.4 In practical research applications, Chou et al. (2008) utilized Fuzzy Multi-Criteria Decision Making (FMCDM) to select hotel locations in Taiwan, considering 21 criteria. Tzeng et al. (2002) selected alternative seaport locations based on quantitative criteria and quality criteria.

2.5 Wu et al. (2005) used similar techniques to weigh the importance of different criteria according to Porter's Diamond Model to find suitable locations for setting up a hospital in Taipei.

2.6 Sharma et al. (2008) designed a distribution network from distribution centers to retail customers using sequential analysis to choose from six distribution system options. They aimed to generate satisfactory profits and meet customer demands, considering factors such as inventory management costs, transportation costs, and service quality factors like responsiveness and product variety.

2.7 Kantamon Sukkrachang (2017) conducted a study on the factors influencing the decision-making process in selecting the location of gas stations using the Analytic Hierarchy Process (AHP). The objective of the study was to examine the factors affecting the decision-making process in selecting the location of gas stations by simulating decision-makers who are managers or individuals with decision-making authority. The researchers used purposive sampling to select specific samples and developed a questionnaire based on relevant documents, articles, and research to select transportation service providers and collect relevant factors applied to gas stations. The study found that the weighted importance values of the main factors are ranked as follows: business site details (0.409), raw material sources (0.340), customer sources (0.211), and convenience facilities (0.132).

2.8 Prichat Wongpajit (2017) conducted a study on the factors influencing the selection of location according to the opinions of medium-sized industrial entrepreneurs in Nong Khai province in Thailand. The study found that factors influencing the selection of location for medium-sized industrial entrepreneurs are environmental factors, government and local policy factors, labor factors, market factors, and transportation factors. Differences in gender, marital status, and family roles lead to different opinions on environmental factors, government and local policy factors, labor factors, market factors, and transportation factors. However, there were no significant differences except for market factors and transportation factors. Age differences and educational levels also lead to different opinions on environmental factors, government and local policy factors, labor factors, and transportation factors, except for market factors.

2.9 Kittipong Rakkacharan (2014) conducted a study on transportation systems and location selection for distribution centers: a case study of a retail logistics business. Based on interview results and their summary applied to programming techniques, they served as tools in decision-making for selecting the location of a new warehouse for the case study company. Through the study of factors influencing decision-making and warehouse location, derived from relevant literature and inquiries with company experts, significant factors were identified and categorized into four main groups: 1) geographical factors, quantity of goods in various 2) transportation patterns, 3) infrastructure factors including land, and 4) business operational factors, such as the number of competitors and the specific location

In conclusion, these studies collectively highlight the diverse approaches and factors involved in location selection decisions across industries. From reducing distribution centers and saving millions to evaluating airports and sea ports, and even designing distribution networks and selecting hospital and hotel locations, each study highlights the importance of informed decision-making. By using methodologies like sequential analysis, fuzzy multi-criteria decision making, and Porter's Diamond Model, businesses can navigate complex considerations and optimize their location strategies. Furthermore, the lessons learned from these studies provide insightful direction for future initiatives, highlighting the importance of modifying strategies in response to changing stakeholder demands and market dynamics. As organizations continue to expand and innovate, understanding the complexities of location selection remains essential for achieving sustainable growth and competitive advantage in today's dynamic business landscape.

3. Method

This research aims to study suitable locations for the distribution centers of logistics operators using mathematical models; investigate logistics systems and supply chains using mathematical models; and develop knowledge for further utilization in advancing logistics systems. The study employed an initial problem-solving approach to transportation using mathematical models such as transportation models. It combined field survey data (topographic data) with geographic data (from government agencies and private organizations) to study location determination and site selection. Mathematical models were then used to analyze decision-making in selecting distribution center locations based on optimization principles to find the most suitable values for management. The study steps are as follows:

- This research study begins by reviewing relevant theories, research works, and geographic information data. It also examines the application of geographic information data to establish the foundation for constructing a research model. The study then explores the initial problem-solving approach to transportation using mathematical models such as transportation models. It integrates field survey data (topographic data) and geographic data (from government and private organizations) to study location determination and site selection. Mathematical models are utilized to analyze decision-making in selecting distribution center locations based on optimization principles to find the most suitable values for management.

- The study gathers and consolidates data on various factors influencing logistics and supply chain management in the country to identify suitable locations for distribution centers.

- Location analysis involves evaluating potential distribution center locations using the method of evaluation location alternatives. This method combines quantitative and qualitative data using appropriate criteria to assess location alternatives numerically and create mathematical models. Techniques such as the Center of Gravity Method and the Load-distance Technique are employed to quantify location options. Additionally, data is collected, categorized, analyzed, synthesized, and summarized.

3.1.Tools

Selecting the location for a distribution center is crucial for business operations to quickly meet customer demands. There are various methods for location selection, but in this research, two mathematical techniques were used as follows:

- Center of Gravity Technique: This method determines the center point of product distribution, allowing operators to optimize transportation costs. It involves finding the center of gravity, a mathematical technique used to identify the most optimal location for distributing goods across multiple destinations. Sometimes referred to as the centroid method or pivot point method, this approach calculates the weighted average coordinates to pinpoint the ideal location, resembling the overall center of distribution in the area. This is illustrated in Figure 1.

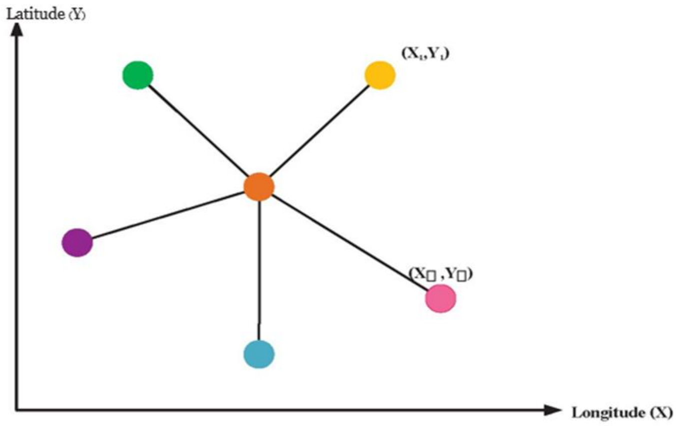

Figure 1 illustrates the coordinates for finding the center of gravity of the distribution within the area.

Using geographical principles, the location is determined by applying calculations based on distance and the weight of the goods to be transported. The center of gravity point (XCG, YCG) represents the position of the weighted average of the factors originating from multiple sources (systems). In cases where the system consists of numerous factor origins, the center of gravity point is considered along the X-axis and the Y-axis as follows.

$$X_{CG} = \frac{\sum(m_i X_i)}{\sum m_i}$$

$$Y_{CG} = \frac{\sum(m_i Y_i)}{\sum m_i} \qquad (1)$$

Where:

XCG = Geographic coordinate X of the center of gravity point

YCG = Geographic coordinate Y of the center of gravity point

Xi = Geographic coordinate X at position i

Yi = Geographic coordinate Y at position i

Mi = Weight value at different geographic coordinates

i = 1,2,3,...,n

The calculation process is as follows: 1) Identify the coordinates of the data points used in the study. 2) Multiply the coordinates of each position by the corresponding weight value, such as transportation volume, product size, shipping cost, etc. 3) Calculate the dispersion of the weight distribution. 4) Plot or specify the coordinates obtained from the calculation on the map.

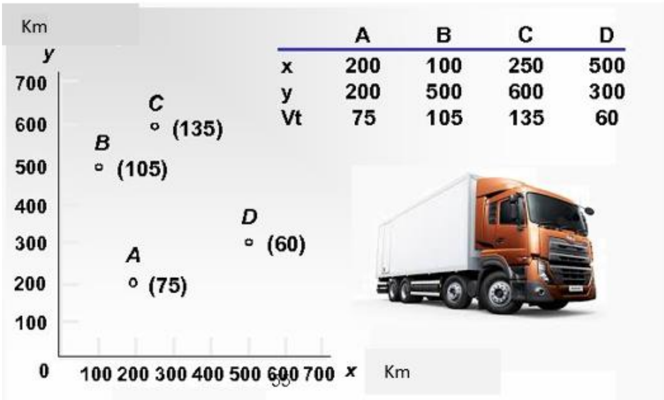

Figure 2: Example of Analysis Using the Center of Gravity Technique

The Load Distance Technique is a method used to select the most suitable location for a center from multiple proposed locations by calculating the distance and transportation cost of each location. This technique involves evaluating alternatives based on the distance measured in straight lines from the shipping source to the target customers, proximity to suppliers, proximity to the workforce, or other conveniences such as main roads. These factors are taken into account to make decisions. The objective of this technique is to choose the center location for distributing goods by analyzing the total weight to be transported between locations within a given travel time to minimize the total quantity. Distances can be represented by equations and compared by calculating the weight and distance of each potential center location, as shown in Equation (1)

$$\text{Load Distance Technique} = \Sigma(LAB * DAB) \qquad (1)$$

Where:

LAB = Weight of goods transported between center locations A and B

DAB = Distance between center locations A and B

From Equation 1, it can be observed that the total quantity of weight and distance for each potential location of the distribution center can be calculated by multiplying the weight of goods transported between center locations (LAB) with the distance (DAB). The sum of all these multiplications for every potential location of the distribution center is calculated, with the objective of achieving the minimum total quantity. This is done to reduce travel costs by minimizing the weight burden from locations with heavier cargo. The sequential steps involved in calculating the total weight and distance used for decision-making to select the center location are as follows:

- Distance Calculation Process: This involves determining the distance between the positions of various distribution center locations. Measurement of transportation distance is done in a straight line. The removal distance is the shortest distance between the positions of the distribution center locations. Travel distance measurement is done in the north-south or east-west direction. The distance between distribution center locations in this straight-line manner is designated as coordinates shown on the map and used to evaluate the distance between distribution center locations.

- Calculation of Distance and Transportation Costs: The distance between distribution center locations is calculated as the sum of the absolute differences between the distribution center locations, as calculated in Equation 2.

$$DAB = |XA-XB| + |YA-YB| \quad (2)$$

When defined as:

DAB = Distance between the locations of distribution centers A and B

XA = X-axis coordinate value of distribution center A

XB = X-axis coordinate value of distribution center B

YA = Y-axis coordinate value of distribution center A

YB = Y-axis coordinate value of distribution center B

Furthermore, the Load Distance Technique can also be calculated using another method, as shown in Equation 3.

$$d_{AB} = \sqrt{(X_A - X_B)^2 + (Y_A - Y_B)^2} \quad (3)$$

When defined as:

dAB = Distance between the locations of distribution centers A and B

XA = X-axis coordinate value of distribution center A

XB = X-axis coordinate value of distribution center B

YA = Y-axis coordinate value of distribution center A

YB = Y-axis coordinate value of distribution center B

Additionally, the calculation of the load distance score multiplied by the distance between distribution centers and other factors, for example transportation rates, number of trips, or quantity of goods, affecting overall transportation costs can be determined. It is found that the farther the distance of transportation tends to increase overall transportation costs. This can be calculated as shown in Equation 4.

$$LD = \sum_{i=1}^{n} d_i l_i \quad (4)$$

When defined as:

li = transportation rate or number of trips or quantity of goods

di = distance between the locations of distribution centers

The process of assigning weights to the transported goods: Once the calculation of straight-line distances is successfully completed, the next step is to specify the total weight of all goods to be transported between the locations of one distribution center. The resulting value from the calculation is LAB.

Calculating the total quantity of goods and distances from each distribution center location can be achieved by multiplying the distance between centers by the weight of the transported goods. The process of selecting the location of the distribution center involves choosing the site that offers the lowest total weight quantity and the shortest distance.

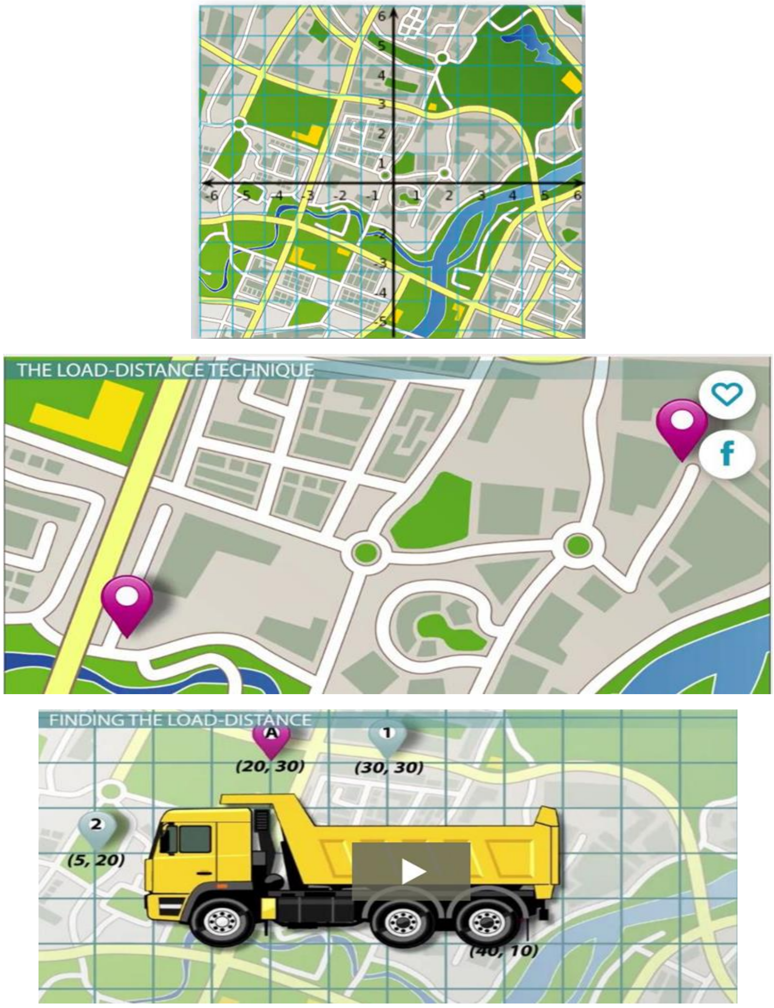

Figure 3 : Example of Calculation Results Using the Method load distance

3.2. Data Collection and Analysis

The process of analyzing data to solve transportation system problems and select distribution center locations can be divided into the following steps:

- Distribute information for analyzing cost expenses. Expenses in the transportation system arise from management costs, fuel costs, transportation labor costs, and vehicle rental costs.
- Distribute information on road conditions and customer locations to determine distances and transportation times.
- Analyze suitable site locations using mathematical models such as the Center of Gravity Technique and the Load Distance Technique.
- Compare the results of selecting site locations using both methods to analyze the most suitable solution for the given problem.
- Compare the solutions for transportation problem-solving and site selection obtained from the research with the current company's transportation system. This comparison will utilize indicators derived from the research, including: transportation system costs, transportation distances from receiving fuel at the Rayong depot to delivering to customers and transportation times from the origin to customers. This analysis aims to determine whether selecting distribution center locations in each region or outsourcing transportation management to another company yields the shortest transportation distances, shortest transportation times, and lowest destination costs.

4. Result

We applied mathematical modeling using the Load Distance Technique, incorporating management cost data from logistics operators as well as service usage data from customers. We defined sets, parameters, decision variables in the objective function, and constraints equations. Then, we processed the data using the Excel solver program to find the optimal distribution center locations that minimize costs. The process proceeded as follows:

4.1 Set:

i = Distribution centers of logistics operators, as shown in Table 1.

Table 1 Distribution Center Selection Locations

Location Options for Distribution Centers	Area
1	Nakhon Sawan
2	Chiang Mai
3	Ubon Ratchathani
4	Khon Kaen
5	Nakhon Ratchasima
6	Kanchanaburi
7	Surat Thani
8	Phuket
9	Chonburi

4.2 Parameter

Cij represents the transportation cost from distribution center i to the customer.

Table 2 Average Transportation Costs from Distribution Centers (Baht per Box)

Representative / Distribution center	Nakhon Sawan	Chiang Mai	Ubon Ratchathani	Khon Kaen	Nakhon Ratchasima	Kanchanaburi	Surat Thani	Phuket	Chonburi
Nakhon Sawan	4.358	5.656	6.644	6.587	5.998	5.882	7.424	8.804	7.640
Chiang Mai	5.656	5.022	6.986	7.044	6.002	6.688	7.982	8.968	7.984
Ubon Ratchathani	6.644	6.996	4.026	5.984	6.006	7.090	8.224	8.985	8.042
Khon Kaen	6.587	7.003	5.996	4.442	5.889	6.988	8.990	9.007	7.864
Nakhon Ratchasima	5.998	7.226	6.024	6.662	6.201	7.324	8.996	9.208	8.368
Kanchanaburi	5.882	7.004	7.865	7.445	6.889	3.996	8.660	9.038	8.990
Surat Thani	7.424	8.995	8.886	8.644	8.996	8.067	4.008	6.660	9.008
Phuket	8.804	9.442	8.981	8.880	8.994	9.898	6.989	4.882	9.223
Chonburi	7.640	8.859	7.990	8.446	8.883	8.544	7.990	9.698	5.002

Dj = Customer demand volume in each province, using the average demand of service users for the two years, fiscal year 2018-2019, as shown in Table 3.
Table 3 Average Customer Demand per Year (2018-2019)

Area	Service Demand (Pieces)
Nakhon Sawan	1,888,784
Chiang Mai	2,450,885
Ubon Ratchathani	2,320640
Khon Kaen	2,466,882
Nakhon Ratchasima	2,320,422
Kanchanaburi	868,994
Surat Thani	1,220,410
Phuket	1,562,220
Chonburi	2,324,680

Fi = Warehouse Rent and Management Costs in Each Area (Data on rental prices referenced from market prices cited by logistics operators in each area)
Table 4 Warehouse Rent and Management Costs

Area	Warehouse Rent / Year (Baht)	Management Cost (Baht / Year)	F_i
Nakhon Sawan	2,800,000	1,400,000	4,200,000
Chiang Mai	3,600,000	1,900,000	5,500,000
Ubon Ratchathani	2,900,000	1,950,000	4,850,000
Khon Kaen	2,750,000	1,880,000	4,630,000
Nakhon Ratchasima	2,680,000	1,900,000	4,580,000
Kanchanaburi	1,200,000	900,000	2,100,000
Surat Thani	1,900,000	1,400,000	3,300,000
Phuket	3,000,000	2,400,000	5,400,000
Chonburi	2,900,000	2,200,000	5,100,000

Si = Logistics service provider's capability in storing goods

Decision Variables:

Xi € {0,1} where Xi = 1 if selecting the distribution center in that area and 0 otherwise.

YiJ € {0,1} where YiJ = 1 if there is a delivery from distribution center i to customer j, and 0 otherwise.

In this study, the researchers utilized Excel Solver program for processing, with the objective function defined as:

$$MinZ = \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij} D_j Y_{ij} + L_i X_i \quad (5)$$

From the formula (SUMPRODUCT(B3:J3,B14:J 14, B17:J17)+M3*S3)+(SUMPRODUCT(B4:J4,B14: J14,B18:J18)+M4*S4)+(SUMPRODUCT(B5:J5,B19:J19,B14:J14)+M5*S5))+(SUMPRODUCT (B6:J6,B20:J20,B14:J14)+M6*S6)+(SUMPRODUCT(B7:J7,B21:J21,B14:J14))+M7*S7)+(SUMPRODUCT (B8:J8,B22:J22,B14:J14)+M8*S8)+(SUMPRODUCT(B9:J9,B14:J14,B23:J23)+M9*S9)+(SUMPRODUCT(B 10:J 10,B14:J14,B24:J24)+M10*S 10)+(SUMPRODUCT(B1 1:J11,B14:J14,B25:125)-M11*S11)

The processing of the mathematical model by applying the Load Distance Technique with Excel Solver involves using data on service usage quantities from logistics operators, distances, and average transportation costs between 2020-2021, including management costs, to find the solution of the mathematical model for determining the suitable location for the logistics center. The results of the processing with Excel Solver are as follows:

Table 5 Results: Xij Values from Processing with Excel Solver Program

X_{ij}	Nakhon Sawan
Nakhon Sawan	0
Chiang Mai	0
Ubon Ratchathani	0
Khon Kaen	0
Nakhon Ratchasima	1
Kanchanaburi	0
Surat Thani	0
Phuket	0
Chonburi	0

Table 6 Results: Yij Values from Processing with Excel Solver Program

Y_{ij}	Nakhon Sawan	Chiang Mai	Ubon Ratchathani	Khon Kaen	Nakhon Ratchasima	Kanchanaburi	Surat Thani	Phuket	Chonburi
Nakhon Sawan	0	0	0	0	0	0	0	0	0
Chiang Mai	0	0	0	0	0	0	0	0	0
Ubon Ratchathani	0	0	0	0	0	0	0	0	0
Khon Kaen	0	0	0	0	0	0	0	0	0
Nakhon Ratchasima	1	1	1	1	1	1	1	1	1
Kanchanaburi	0	0	0	0	0	0	0	0	0
Surat Thani	0	0	0	0	0	0	0	0	0
Phuket	0	0	0	0	0	0	0	0	0
Chonburi	0	0	0	0	0	0	0	0	0

From Table 5, it is found that the value of Xij for Nakhon Ratchasima province is equal to 1, and from Table 6, it is found that the value of Yij for Nakhon Ratchasima province is also equal to 1. This indicates that Nakhon Ratchasima is suitable for establishing the distribution center for logistics operators, as revealed by mathematical modeling analysis.

The application of the Center of Gravity Technique to the data of logistics operators in various provinces is another method used. This technique involves finding the location of the distribution center as the single position that serves as the center of aggregate demand and aggregate supply, based on economic principles. In determining the coordinates of each representative area, geographic information system data from the Department of Highways is integrated with the customer service demand data for the fiscal year 2018-2019 to calculate the location using the Center of Gravity Technique.

Table 7: Geographic Coordinates, Latitude, Longitude, and Logistics Service Demand Quantity

Area	Service Demand Quantity (Pieces)	Latitude	Longitude	Coordinates X (XD_j)	Coordinates Y (YD_j)
Nakhon Sawan	1,888,784	15.6833824	100.0693846	614599.2949055188	1734202.535342942
Chiang Mai	2,450,885	18.7510764	98.9294344	492562.00269710796	2073286.4457145547
Ubon Ratchathani	2,320,640	15.3397894	104.6279516	460065.6368471739	1695943.0722102104
Khon Kaen	2,466,882	16.4007017	102.7455027	259221.801327609	1814597.6333166664
Nakhon Ratchasima	2,320,422	14.9779867	102.0903586	187042.4933747782	1657946.2505086819
Kanchanaburi	868,994	13.9755317	97.3942449	326554.73239311983	1545607.3244544
Surat Thani	1,220,410	13.7984477	90.5987911	240399.37195327462	1526733.7947835294
Phuket	1,562,220	7.9643888	98.2823387	420905.45805463084	880429.6186463949
Chonburi	2,324,680	13.0906705	100.9683358	713409.1893281671	1447993.1659666079
Sum	17,423,917	14.723384	101.9986745	822919.8563482116	1629880.4975572042

From applying the centroid method...

$$X_{CG} = \frac{\sum(m_i X_i)}{\sum m_i} \qquad Y_{CG} = \frac{\sum(m_i Y_i)}{\sum m_i} \quad (6)$$

XCG = Geographic coordinate X of the centroid
YCG = Geographic coordinate Y of the centroid
Xi = Geographic coordinate X at position i
Yi = Geographic coordinate Y at position i
Mi = Weight value at different geographic coordinates
i = 1,2,3,…,n

The coordinates obtained are X = 822919.8563482116 and Y = 1629880.4975572042.

The study found that the suitable area for establishing the distribution center is located at coordinates (822919.8563482116, 1629880.4975572042), approximately at:

14°43'24.2"N 101°59'55.2"E

14.723384, 101.998674

Address: Ban Han Tai, Tambon Takhoo, Pak Thong Chai District, Nakhon Ratchasima 30150

Figure 4: Suitable Coordinates for Establishing a Distribution Center - Nakhon Ratchasima Province
Source
:https://www.google.co.th/maps/place/14%C2%B043'24.2%22N+101%C2%B059'55.2%22E/@14.723384,101.9964805,808m/data=!3m2!1e3!4b1!4m5!3m4!1s0x0:0x0!8m2!3d14.723384!4d101.9986745

5. Discussion and Recommendations

The utilization of mathematical modeling techniques, particularly the Load Distance Technique, in conjunction with Excel Solver, offers a systematic approach to determining optimal distribution center locations for logistics operators. By integrating management cost data from logistics operators, customer service usage data, and transportation cost data, the model provides a comprehensive analysis to minimize costs effectively.

The results of the mathematical modeling analysis, as shown in Tables 5 and 6, reveal Nakhon Ratchasima as the most suitable location for establishing the distribution center. This finding emphasizes the importance of considering various parameters such as transportation costs, customer demand volumes, and warehouse rent and management costs in decision-making processes.

Furthermore, the application of the Center of Gravity Technique provides an additional method to validate the results. By integrating geographic information system data with customer service demand data, the centroid method identifies the optimal location for the distribution center. The obtained coordinates (822919.8563482116, 1629880.4975572042) confirm Nakhon Ratchasima as the preferred location, aligning with the findings from the Load Distance Technique.

Recommendations:

Validation and Sensitivity Analysis: While the mathematical models provide valuable insights, it's essential to conduct validation and sensitivity analyses to assess the robustness of the results. Sensitivity analyses can explore the impact of variations in parameters such as transportation costs or customer demand volumes on the optimal location determination.

Stakeholder Engagement: Engaging stakeholders, including logistics operators, customers, and local authorities, is crucial in the decision-making process. Collaborative discussions can provide additional insights into factors affecting distribution center locations, ensuring alignment with business objectives and regulatory requirements.

Long-term Planning: Considering the dynamic nature of business environments, it's essential to adopt a long-term perspective in distribution center location decisions. Anticipating future changes in customer demand patterns, infrastructure development, and regulatory frameworks can enhance the sustainability and adaptability of distribution networks.

Technology Integration: Utilizing advancements in technology, such as geographic information systems (GIS) and predictive analytics, can enhance the accuracy and efficiency of distribution center location analyses. Integrating real-time data sources and predictive modeling capabilities can enable proactive decision-making in response to changing market conditions.

Continuous Improvement: Distribution center location decisions should be viewed as iterative processes, subject to continuous improvement based on feedback and evolving business requirements. Regular reviews and updates to the mathematical models can ensure alignment with organizational goals and market dynamics.

By incorporating these recommendations into the decision-making process, logistics operators can optimize distribution center locations to enhance operational efficiency, reduce costs, and better serve customer needs in dynamic business environments.

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