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Article

The Application of Two Echelon Distribution Network Zoning in an Organic-Chemical Fertilizer Distribution: The Case Study in Northeastern Thailand

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Abstract. This research introduced the two-echelon capacitated plant location problem (2E-CPLP) to increase the efficiency of organic-chemical fertilizer distribution in Northeastern Thailand. The consequences of this unsolved problem either lead to lower productivity or increased use of less environmentally friendly fertilizers. Though centroid with equal demand zoning was previously used in this area, the unique characteristics of Northeastern Thailand cause this approach to yield less acceptable results. The introduction of the two-echelon concept is important for practitioners to adopt a better way of operating. This case-based study compared two facility location problem (FLP) approaches by using the geographical zoning and equal demand zoning methods as a baseline, then introducing the 2E-CPLP method as an alternative. The problem was solved by IBM ILOG CPLEX software and ArcGIS for Desktop 9.3 with outputs of the total cost, the maximum distance from plants to retailers, and the average distance from plants to retailers. The results showed that the 2E-CPLP method with geographical zoning outperformed equal demand zoning, with a lower total cost of 246.84 million baht or 1.05%, significantly less computational time, and lower maximum and average distances from plants to retailers.

Keywords: Two-echelon location problem, zoning, integer programming, organic-chemical fertilizer distribution, Thailand.

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1. Introduction

Recently, due to healthy consumption trends among consumers and sustainability awareness around the globe, the worldwide demand for organic fertilizer has grown exponentially. Environmental awareness has driven demand and conversion to organic farming; hence, there will be an increase in demand for organic-chemical fertilizer. More than 50% of the fertilizer consumption is chemical fertilizer and has an increasing trend [1]. However, many studies indicated that using chemical fertilizer for an extended time has a negative impact on the environment. This includes soil degradation resulting in declining soil quality. Organic-chemical fertilizer appears to reduce environmental problems [2], [3], while leftover chemical fertilizer seriously affects the quality of agricultural products and public health [4]. Besides, chemical fertilizers must be imported, at increasing cost, which is passed on to the farmers.

Organic-chemical fertilizer combines the advantages of both organic and chemical fertilizer. The use of organic-chemical fertilizer released a larger amount of organic matter, nitrogen, phosphorus, and potassium than solely using organic fertilizer or chemical fertilizers [3]. The great advantages of organic-chemical fertilizer usage for farmers were production cost reduction and production efficiency improvement. Unfortunately, the supply side of organic fertilizer is still facing many difficulties, especially in developing countries. Hence, most governments of developing countries focus upon industrialized farming. Many organic farmers are left alone to face various supply chain challenges including struggles to obtain a sufficient supply of organic fertilizers, limited infrastructure, limited subsidy programs, inefficient distribution networks, and so on. With limited governmental support for niche enterprises, local businesses need to develop a robust and self-reliant decision model to thrive.

1.1. Research Contributions: The Needs, the Research Gaps, and the New Realm to Explore The Needs

The answer to the research question of: "How can two-echelon geographical zoning help improve organic-chemical fertilizer distribution in a challenging environment" is needed to address the ongoing distribution problem of organic fertilizer supply among many underdeveloped countries. The case study approach aims to promote quick dissemination among practitioners. Within this specific case, the challenge of organic fertilizer supply is an ongoing problem for the farmers in Northeastern Thailand. The consequences of this unsolved problem led to either lower productivity or increased use of harsh chemical fertilizers.

1.2. The Existing Gap

Due to limited resources from federal and local governments, research scarcity in this region provides an opportunity to fill the localization aspect of current distribution theories. The theory gap exists due to the previous related research in this area failing to directly address this problem, within the unique challenges of this region. This study responds to the strong need for practitioner-level theory validation, which is widely discussed among supply chain researchers [5]–[7]. Theory validation in this specific context (e.g. working environment, culture, industry) helps practitioners understand how the concepts work in real life [6], [7]. As important as theory generalization, the application of theory in specific contexts helps to bridge the gap between practice and concept, and eventually strengthens theoretical concepts in the field [6]. It is important to note that local business is risk-averse and needs to see a well-proven example that already works in similar situations [5], [6]. Therefore, testing the two-echelon concept in Northeastern Thailand is important for practitioners to gain confidence with, and ultimately adopt this concept. The use of a case study approach would help fill the dissemination gap in previous research. In this case study, the step-by-step procedure was analyzed and presented to practitioners, including providing the case background, the use of applications such as common software, and financial impact analysis after implementation.

1.3. The New Realm to Explore "The Northeastern Thailand Challenges"

Thailand provides an interesting landscape with a culture and economic background that could challenge well-established theoretical distribution concepts. A large proportion of the Thai population derives their livelihood and income from the agricultural sector. Besides, logistical conditions in Northeastern Thailand, which is vast but less populated, also provide a unique challenge to physical distribution planning. Based on our focus group, farming supply practices are outdated, and fertilizer providers struggle to keep up with an increase in demand. The focus group also emphasized that fertilizer is a necessity and major cost center of farming in this area. Agricultural practices in Northeastern Thailand provide an interesting distribution challenge due to the vast area of arid land with a seasonal farming cycle. The availability of high quality fertilizer currently plays a critical role and will continue to do so for the foreseeable future. Through the application of new approaches to the current organic fertilizer distribution practices, the agricultural output can meet this rising demand while boosting farmers' productivity and income.

2. Literature Review

2.1. Zoning Techniques

Centroid with heuristics is widely used in demand estimation due to its simplicity and speed of calculation. In Thailand, the centroid with equal demand zoning method has recently gained attention because of the GIS data available from the Department of Land of Thailand (DLT). Linear programming is widely used in facility location problem solving [8], [9]. Our focus group also indicated linear programming was a tool of choice, because of its intuitiveness. Many studies indicate the utilization of linear programming (Integer Linear Programming: ILP, Binary Integer Linear Programming: BILP, Mixed-Integer Linear Programming: MILP) allows effective solutions to complex problems [8], [10], [11]. Because of the apparent industry standard, this study utilized linear integer programming to run our Facility Location Problem (FLP) algorithm, with the assistance of IBM ILOG CPLEX software. In addition, there were applications of LP in the agro-industry [12]–[14] and in the electronic industry [15].

Among practitioners who are integrating GIS in the demand zoning approach, one issue our focus group reported was a data processing overload along with a merely mediocre result. Basically, because of the large amount of data, the GIS-based demand data was solely used to determine zoning, but plant locations were not chosen with the assistance of GIS. Because data processing limitations excluded GIS from plant location solutions, the centroid location was determined heuristically and approximately placed in the center of each zone. Unfortunately, the centroid locations often ended up in non-viable locations (e.g. in the middle of rivers, in national park reserves, or labor-scarce towns).

Logistics network design is concerned with the determination of the minimal number and location of plants and the allocation of resources to serve all customers (which is known as the set covering problem). With the current phenomenon of skyrocketing land values, it is critical to be aware of the issue of "land value of facilities" [10], [16]. In certain cases, the facilities tend to be closer to customers resulting in lower transportation costs, but higher facility costs. Therefore, it is imperative to find an optimal balance between fixed facility costs and transportation costs to solve the fixed charge facility location problem. To be efficient, these customers must be served within an acceptable distance by minimizing the total transportation cost and fixed cost. This issue is minimized with GIS by considering the land value of each location more precisely. Incorporating GIS has been able to minimize this land value issue in many industries, such as the retail site selection problem [17], [18], location of a bicycle-sharing program [19], location of automated external defibrillators in public streets [20], and the pesticide exposure model [21].

The use of GIS helps enhance zoning precision (or clustering) in previous research. GIS provides more in-depth location-related information to help make a better decision for each facility, but the disadvantage of adding geo-based level data can be burdensome for data processing. To optimize the solution from linear programming, there is a tradeoff between higher precision and largely increased processing times. This may ultimately yield a better final solution, but it may not affect at all.

2.2. The Need for a Multi-Echelon approach

The K-means approach was used to define zones for this study. K-means clustering is a popular method for grouping similar objects [22]. Many researchers utilize K-means clustering to solve grouping problems [23] such as a location model for plants that produce chromate copper arsenate (CCA) treated wood products [24]. Geographic Information Systems (ArcGIS 9.3) use two different clustering methods i.e. self-organizing maps (SOM) and K-means. The solutions obtained with both clustering methods are used to decide the best location for these plants. The advantage of K-means, compared to SOM, is significantly reduced computing time. In addition, the performance of five clustering techniques was studied: hierarchical clustering, K-means clustering algorithm, Kohonen's self-organizing maps method (SOM), K-medoids method, and K-medoids integrated with Dynamic Time Warping distance measure (DTW) method by evaluating root mean square standard deviation (RMSSTD) and r squared (RS) [25]. Previous research showed that the K-means clustering method yielded the lowest RMSSTD and highest RS for most situations. Therefore, K-means was the most suitable algorithm for clustering techniques for our zoning analysis. However, the geo-based level data from GIS remained a challenge for the K-means approach because of the excessive amount of data.

To help ease the data processing overload in zoning with GIS and increase the plant location precision, the multi-echelon approach was adopted to help systemize the clustering process by categorizing the data into different echelons and prioritizing each echelon effectively. In this case, two echelons were proposed. The first echelon is the retailer echelon, which represents the aggregated demand location, and the second echelon is the manufacturing echelon which represents the supply location.

After discussions with the focus group and the management team, the two-echelon approach was introduced to help ease the zoning approach, and in turn, improve the FLP solution. In this case, the two primary parties are the retailer and the manufacturer. The retailers represent the aggregated demand facility while the mixing plants represent the supply facilities. Our research can be a strategic plan for establishing a distribution network of organic-chemical fertilizer so that the total cost is minimized while satisfying the farmers' needs. Hence, we proposed a two-echelon distribution network consisting of a set of plants and retailers as shown in Fig. 1.

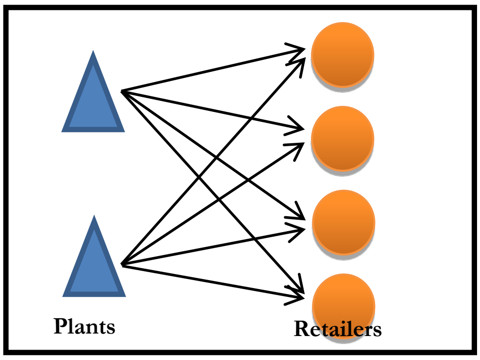

Fig. 1. Structure of a chemical-organic fertilizer logistics system.

2.3. Facility Location Problem (FLP) with GIS Application

Our study focused on the determination of the most suitable location of facilities, called the facility location problem (FLP), for organic-chemical fertilizer production. The selection of facility locations, such as plants, warehouses, distribution centers, bins and hubs is a key factor to succeed in supply chain management. Because the main concern of any company is to effectively manage costs and selecting poorly placed facilities leads to excessive costs; the facility location decision is critical to the efficient and effective operation of a supply chain and strategic logistics planning. In general, more facilities generate a higher fixed cost but tend to have higher service levels due to customer proximity, and lower outbound logistics costs from facilities to customers [26]–[28].

We proposed the use of a linear integer program to calculate the proposed facility location algorithm with the use of K-means zoning, in ArcGIS 9.3, with geo-based demand. We called this approach a Two Echelon Capacitated Distribution Network approach to solve the two-echelon capacitated plant location (2E-CPLP). It aims to reduce logistics costs in the long-term and to promote the use of organic-chemical fertilizer; leading to increased production efficiency, and creating a healthier environment. We assume that the Two Echelon approach will outperform the Equal Demand approach that is currently more commonly used among logistics practitioners.

3. Methodology

3.1. Data Collection and Preparation

Due to the benefits over pure organic and pure chemical fertilizers, identified through focus group interviews with the organic-chemical fertilizer manufacturers in the Kalasin province, an increasing trend in organic-chemical demand was confirmed. This research obtained data from a company operating several medium-sized fertilizer production plants; then, the region was zoned using two methods: equal demand zoning and geographical zoning using K-means clustering.

First, agricultural land use was obtained from ArcGIS for Desktop 9.3 (as shown in Fig. 2), along with fertilization usage rates for main crops, land price from the Department of Land, distance matrix (calculated from Geographic Information System (GIS) from location coordinates (X, Y) information kept from the Department of expressway), transportation cost, plant establishment cost and plant capacity from interviews. Second, 242 districts in Northeast Thailand were coded from 001 to 242 as shown in Fig. 3. Next, the demand for organic-chemical fertilizer in these districts was estimated by the multiplication of the land used for main crops and the fertilization usage rate of those crops in Eq. (1).

$$\sum_{i \in I} a_i x_i \tag{1}$$

where i = the index of crop type I = {rice, cassava, sugar cane, rubber and eucalyptus},

a_i = the cultivating area (rais);,

x_i = the fertilizer usage rate of crop i (ton per rai).

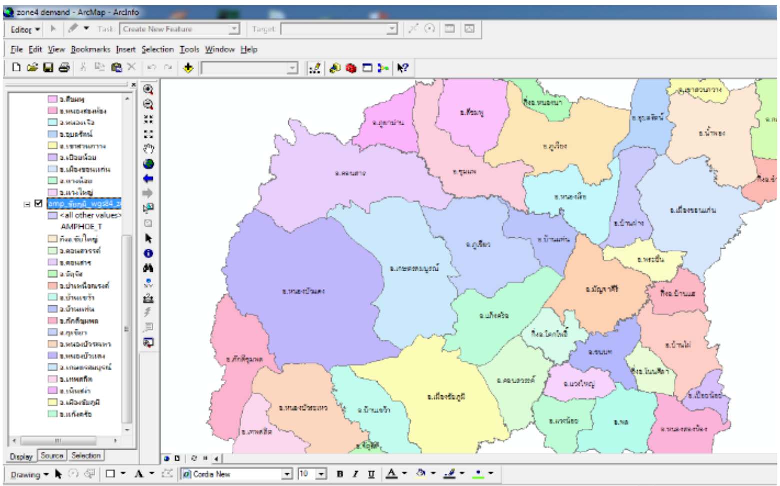

Fig. 2. Using ArcGIS for Desktop 9.3 to estimate demand.

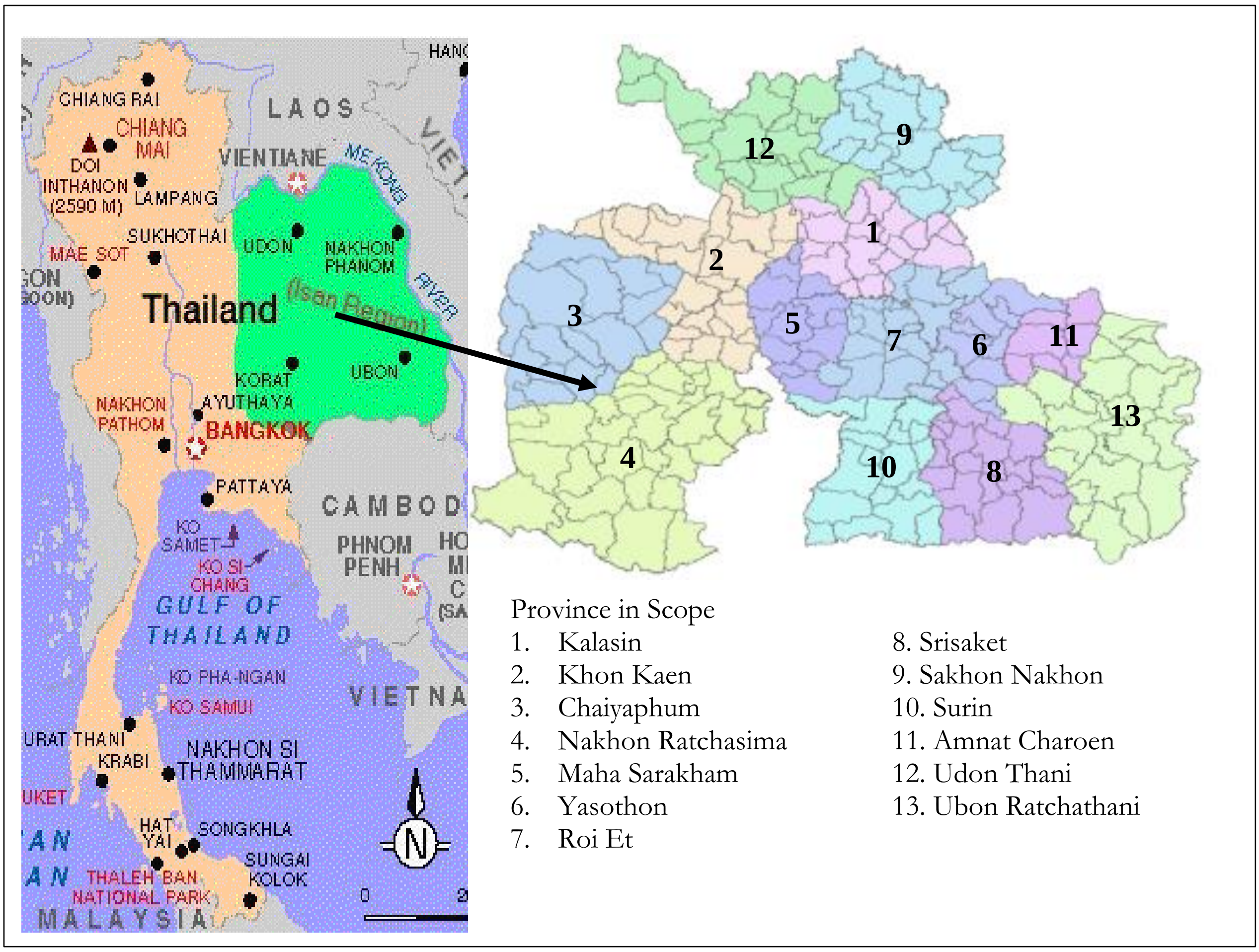

Fig. 3. Scope of the geographical area for this research.

The data from ArcGIS for Desktop 9.3 was converted to a spreadsheet to calculate demand. The main agricultural land uses for rice, cassava, sugar cane, rubber, and eucalyptus were chosen since they are suitable crops for Northeastern Thailand. Though the actual rate of fertilizer usage for each crop is not equal and is dependent upon location, type of crop, moisture level, and fertility of the soil; we assumed the rate to be constant. This information was derived using the expected value supported by the historical usage rate [29]–[32]. The fertilizer demand calculation of three districts in the Kalasin province is shown in Table 1.

Table 1. Calculating fertilizer demand of 3 districts at Kalasin province.

Crop Types	Fertilizer Usage Rate (ton/rai)	Cultivating Area (rais)			Demand for Fertilizer (tons/month)		
		Khong Chai	Somdet	Na Mon	Khong Chai	Somdet	Na Mon
Rice	0.06	84,887.50	82,006.25	74,887.50	424.44	410.03	374.44
Cassava	0.05	1,931.25	5,956.25	12,512.50	8.05	24.82	52.14
Rubber	0.10	-	756.25	1,893.75	-	6.30	15.78
Eucalyptus	0.02	1,212.50	562.50	5,200.00	2.43	1.13	10.40
Sugar cane	0.15	-	1,618.75	19,943.75	-	20.23	249.30
Total	0.38				434.91	462.51	702.05

3.2. Service Zoning

The problem size of 242 districts is too large to be optimally solved in a short time. Hence, it can be reduced by considering two zoning methods: equal demand zoning and geographical zoning. The number of zones was determined by considering the lowest root mean square standard deviation (RMSSTD) of distance from one district to another as in Eq. (2). Utilizing this method, the optimal result is obtained with 14 clusters, as shown in Table 2.

$$RMSSTD = \sqrt{\frac{\sum_{i=1}^{k}\sum_{j=1}^{p}\sum_{a=1}^{n_{ij}}(x_a-\bar{x}_{ij})^2}{\sum_{i=1}^{k}\sum_{j=1}^{p}(n_{ij}-1)}} \quad (2)$$

where *k* is the number of clusters,

p is the number of independent variables in the dataset,

x_{ij} is the data in variable *j* and cluster *i*,

$\bar{x}_{ij}$ is the mean of data in variable *j* and cluster *i*, and

n_{ij} is the number of data which are in variable *p* and cluster *k*

Table 2. Result of RMSSTD for a suitable number of cluster selection.

No. of Clusters	8	9	10	11	12	13	14
RMSSTD	37,185	34,612	33,127	31,644	29,996	28,713	**28,274**

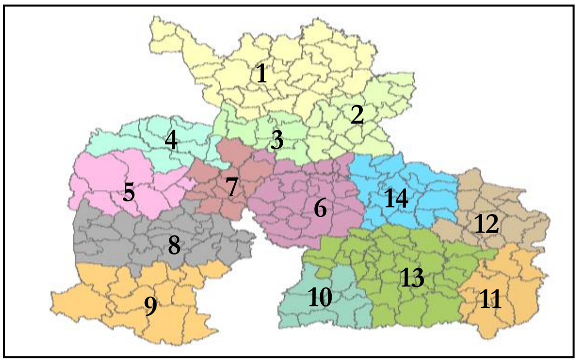

Fig. 4. The equal demand zoning method result

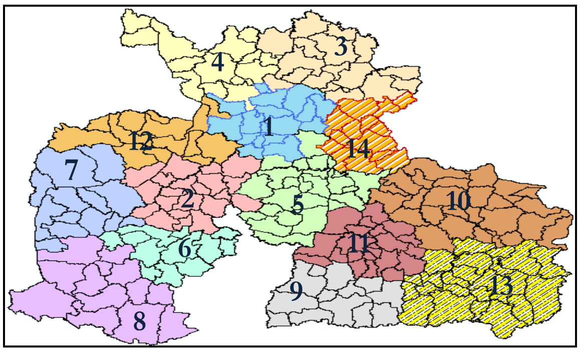

Fig. 5. The geographical zoning method result.

3.2.1. Equal Demand Zoning

Equal demand zoning considers the proximity of districts, in the same zone, which has approximately equal total demand. We used two-step clustering to separate the data and measured the difference within each group by calculating the root mean square standard deviation (RMSSTD). For this purpose, lower RMSSTD scores are better, though factory capacity must also be considered for certain cases. The equal demand zoning results showed an optimized solution of 14 zones as shown in Fig. 4.

3.2.2. Geographical Zoning

Geographical zoning is accomplished using K-means clustering with SPSS 16.0. Zones are first defined with X coordinates (Longitude) and Y coordinates (Latitude), obtained from ArcGIS for Desktop 9.3. Then, a distance matrix from a district to a similar district in each zone is computed using a geographic information system (GIS), provided by the Department of Highways. The result is shown in Fig. 5.

Next, we formulated an integer program using the two-echelon approach and solved the location problem using CPLEX version 12.4. Finally, we compared the solutions derived from each of the two zoning methods.

3.3. Model Formulation

3.3.1. Assumption of the Model

The assumptions of our model were as follows: Plant capacity is 150 tons/day which obtained through interviews with a manufacturer, total area is approximately 8 rais (3.16 acres), transportation cost – 2 THB/ton-km, plant establishment cost is 15 Million THB, land cost is estimated from the Department of Lands, distance matrix used GIS data from Department of Highways, organic-chemical fertilizer estimated demand is based on land usage from Department of Land in ArcGIS format, and retailers may receive products from more than one plant. The construction cost was assumed to be the same in all districts. The assumptions were then used to define the sets and indices, parameters, decision variables, and model formulation as follows:

3.3.2. Indices and Sets

i is a plant index, *I* is a set of fertilizer plants where $I = \{1\ldots,m\}$

j is a customer index, *J* is a set of retailers where $J = \{1,\ldots,n\}$

3.3.3. Parameters

m = Number of plants
n = Number of retailers
F_i = Fixed cost of plant *i* (THB)
C_{ij} = Transportation cost per ton from *i* to *j* (THB/ton/km)
A_i = Capacity of plant *i* (ton/month)
Q_j = Demand for fertilizer of retailer *i* (ton/month)
D_{ij} = Distance from plant *i* to customer *j* (km)

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S = Maximum distance where S = 250 km. (based on the customer coverage level which is set by the factory)

3.3.4. Decision Variables

$$x_i = \begin{cases} 1 & if \quad plant \quad i \quad is \quad opened \\ 0 & otherwise \end{cases}$$

y_{ij} = Amount of fertilizer from plant i to customer j (tons)

3.3.5. Objective Function and Constraints of an Integer Program

The problem can be formulated as follows:

Minimize $\sum_{i=1}^{m} F_i x_i + \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij} D_{ij} y_{ij}$

Subject to

$$\sum_{i=1}^{m} y_{ij} \geq Q_j, \ \forall j \in J \quad (3)$$

$$\sum_{j=1}^{n} y_{ij} \leq A_i x_i, \ \ \forall i \in I \quad (4)$$

$$D_{ij} x_i \ \leq S, \forall i \in I, \forall j \in J \quad (5)$$

$$x_i \ = binary, \forall \text{ i} \in \text{I},$$

$$y_{ij} \geq 0, \forall \text{ i} \in \text{I}, \forall \text{ j} \in \text{J} \quad (6)$$

The objective function aims to minimize the total cost of establishing an organic-chemical fertilizer plant and transportation cost from the plant to retailers. Equation (3) requires that the amount of organic-chemical fertilizer demand must be satisfied. Equation (4) requires that the total organic-chemical fertilizer distribution to retailers, from one plant, may not exceed the plant's capacity. Equation (5) limits the total distance from any plant to any retailer to a maximum of 250 kilometers. Finally, Eq. (6) specifies that decision variables x are binary and y are positive real numbers.

4. Results

4.1. Equal Demand Zoning and Geographical Zoning

To compare the performance of both zoning methods, we consider the number of districts, the total demand for fertilizers, as well as maximum and average distances from a plant to a retailer as the performance indices in each zone. Next, calculate the minimum, maximum, average, and standard deviation of these values as shown in Table 3. The 242 districts in Northeastern Thailand were divided into 14 zones. Equal demand zoning divided the proximity districts in each zone with approximately 12,420-13,502 tons/month whereas geographical zoning considered the proximity of retailers rather than the demand; hence, the total demand fluctuated between 233-26,318 tons/month. Geographical zoning had a lower maximum number of retailers than that of equal demand zoning, which was more inclusive, efficient, and cost-effective than the equal demand approach. Shorter distances between plants and retailers resulted in faster delivery of organic-chemical fertilizer while decreasing transportation costs.

4.2. Solution Comparison of Two Zoning Methods

First, we designed a model to ensure the fertilizer demands were met for each zone while simultaneously minimizing the total cost of meeting those demands. We then solved the 2E-CPLP for two zoning methods using an optimization package. The number of plants required in zones 1 through 4 and the allocation of fertilizer from the respective plants to retailers are shown in Table 4. Samples of plant/retailer allocation, from both zoning methods, were shown in Fig. 6 and 7.

We observed that geographic zoning allowed a variable number of customers per plant and a variable number of plants while equal demand zoning required a fixed number of plants; in this case, four plants in all zones.

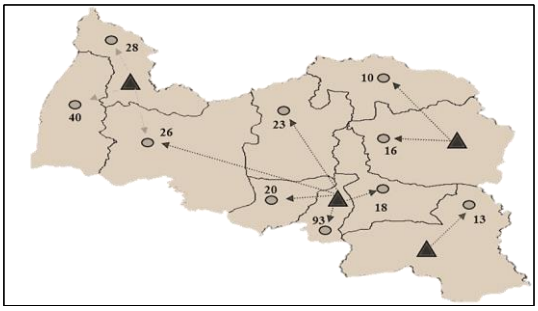

Fig. 6. The optimal logistics network by equal demand zoning in zone 3.

Considering the total cost of 14 zones, we found that geographical zoning outperformed equal demand zoning. Most notably, geographical zoning was able to reduce the total cost over the equal demand method by 2.58 million baht, a reduction of 1.05%.

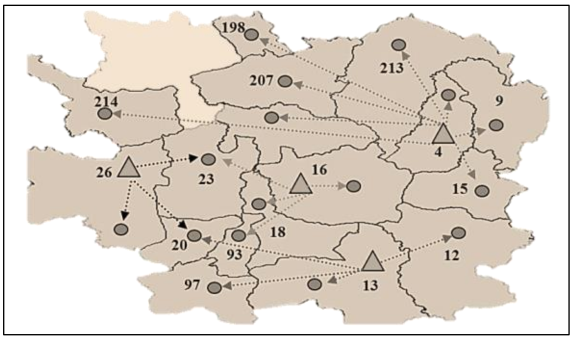

Fig. 7. The optimal logistics network by geographical zoning in zone 1

Besides, geographical zoning required four fewer plants than the equal demand zoning method, a 7.69% reduction (shown in Tables 5 –6). Furthermore, the average distances given by geographical zoning are slightly shorter than those of equal demand zoning, even though the geographical method required fewer plants.

Geographical zoning also had lower maximum distances (46.41% less) than equal demand zoning and lower variance of maximum distance. Thus, there was a lower variability in distances between plants and retailers in each zone, ultimately translating to a better customer service level. Equal demand zoning outperformed the geographical method when considering the variance of the total cost, implying that the equal demand method better balanced the total cost of each zone. Considering the other benefits attained with the geographical method, it outperformed.

Table 3. The results of demand and district in each zone from zoning.

Zone	Equal Demand Zoning				Geographical Zoning			
	# of Districts	Demand (tons/month)	Max. Distances (km)	Average Distances (km)	# of Districts	Demand (ton/month)	Max. Distances (km)	Average Distances (km)
1	31	12,419.93	311.4	95.61	17	15,546.21	166.71	64.76
2	18	12,740.77	360.94	72.46	21	17,024.52	137.26	60.40
3	10	12,750.66	111.33	48.66	17	15,444.95	150.48	66.05
4	11	12,702.39	107.95	53.04	14	233.91	166.67	73.32
5	9	12,515.09	143.75	58.53	24	10,734.92	158.99	62.88
6	27	12,777.64	195.46	66.56	12	4,438.49	144	60.37
7	12	12,726.58	122.28	44.96	13	15,378.47	161.46	65.62
8	25	12,902.59	226	82.81	13	13,001.96	152.36	65.20
9	13	12,806.17	157.15	67.22	13	13,379.89	127.07	56.31
10	9	12,797.22	108.48	46.35	26	26,318.11	200.75	79.03
11	9	12,891.72	125.8	57.91	22	6,765.33	121.55	53.06
12	14	12,771.53	147.39	60.46	14	16,757.04	159.58	66.42
13	37	12,757.44	194.07	77.53	22	16,568.54	171.46	70.96
14	17	13,501.61	144.74	62.19	14	7,468.92	142.72	59.72
Average	17	12790.09	175.48	63.88	17	12790.10	154.36	64.58
Maximum	37	13501.61	360.94	95.61	26	26318.11	200.75	79.03
Minimum	9	12419.93	107.95	44.96	12	233.91	121.55	53.06
St.Dev.	9.14	241.70	77.31	14.51	4.76	6498.11	20.04	6.77

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Table 4. Samples of the retailer allocation in each plant of zone 1-4.

Zone	Equal Demand Zoning		Geographical Zoning	
	Plant	Clustered Customers	Plant	Clustered Customers
1	163	211,163,158	4	4,9,10,15,23,198,213,214,207
	160	208,210,215,217,169,160,171	16	16,18,23,93
	172	205,206,209,201,212,200	13	12,13,20,97
	164	204,198,199,202,203,207,213, 214,216,217,171,172,170,162 173,164,165	26	20,23,26
2	161	159,161,166,167,168,157	31	22,31,36,24,21,29,96
	4	156,9,4,15	42	33,42,81,61,98
	7	167,3,8,17,7	38	39,33,38,47,66,79,65
	2	5,11,2,12	46	36,19,46,47
			96	92,96
3	16	10,16	163	163,158,169,208
	18	16,23,18,26,20,93	160	169,160,171,172,203
	28	26,28,40	165	173,165,164,172,170,162
	13	13	168	173,157,168,166,156
4	25	48,34,25,43	11	205,209,211,215,206,210, 204,212,201,217,200,199, 202,216
	27	43,27,35		
	30	30,41,53,32		
	56	53,56		

Table 5. The comparison of the number of plants, customer allocation, total cost, and maximum distances service in each zone between two zoning methods.

Zone	Equal Demand Zoning			Geographical Zoning		
	No. of Plants	Total Cost (million baht)	Max. Distances	No. of Plants	Total cost (million baht)	Max. Distances
1	4	16.98	197.07	4	17.04	92.41
2	4	17.32	71.28	5	21.26	49.38
3	4	16.32	48.37	4	18.66	59.07
4	4	16.68	41.16	1	3.45	134.6
5	4	16.58	57.8	3	16.09	107.35
6	4	17.28	75.01	2	8.49	62.42
7	4	17.31	50.66	4	18.07	101.7
8	4	19.56	100.11	4	17.13	48.48
9	4	24.67	69.13	4	34.92	85.41
10	4	16.77	44.41	7	29.98	41.26
11	4	18.06	69.61	2	9.49	72.1
12	4	17.12	45.16	5	20.15	48.93
13	4	17.3	118.04	5	21.85	99.03
14	4	17.47	109.19	2	10.26	71.07
Total	56	249.42	1097	52	246.84	1073.21
Average	4	17.82	78.37	3.71	17.63	76.65
S.D.	0	2.05	40.57	1.53	8.01	26.55

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4.3. Discussions, Managerial Implication, and Future Research

Based on our results, the two-echelon logistics network outperformed equal demand zoning, considering the following criteria: optimal plant locations, total cost, the maximum distance from plants to retailers, and the average distance from plants to retailers. The greatest improvement is in the area of maximum distance from plants to retailers. The two-echelon method yielded significantly lower maximum distances than the equal demand method by 46.41%. The reduced maximum distance could translate into fewer retailers falling outside the optimum service zone and fewer of them left behind. For a vast and less populated land area, such as Kalasin, this is a great improvement in customer service. The second-best improvement is in optimal plant locations. The two-echelon method helped to define the optimal location more effectively; therefore, it utilized four fewer plants in the network; 7.69% less than the result obtained from the equal demand method. The smaller number of plant locations results in less fixed assets, less labor, and less operating expenses and administration work for businesses. The third improvement is in the average distance between the plant and retailers, where the two-echelon system yielded a 2.24% lower distance than the equal demand zoning method. In general, the average shorter distance could not only lead to faster transit times but also a more responsive customer service experience for all retailers in the network. The fourth significant improvement is in the area of the total cost. The two-echelon method helped to save 1.05%, or 2.58 million baht, over the result of the equal demand zoning method. It is important to note that the computation time for both methods was not significantly different.

Table 6. Comparison of the total cost, computational time, and service level between two zoning methods.

Index	Zoning Method		% Difference	Outperforming Method
	Equal Demand	Geographical		
Total plants established	56	52	7.69%	Geographical
Total cost (million baht)	249.42	246.84	1.05%	Geographical
Computational time (sec)	57.94	58.37	-0.74%	Not significantly different
Max. distances from plant to retailers (km)	197.07	134.60	46.41%	Geographical
Average distances from plant to retailers (km)	78.37	76.65	2.24%	Geographical

For the managerial implications, this more effective distribution network helped more farmers gain access to organic-chemical fertilizer and helped to decrease the use of chemical fertilizers; a major import deficit of Thailand. This method showed rapid benefits since it can be executed by local businesses, without the assistance of governmental programs. Increased usage of organic-chemical fertilizer also can reduce production costs and yield higher farming production efficiency. In addition, the organic-chemical fertilizer will yield long-term positive benefits for the environment. The socio-economic characteristics of this area are very challenging since this landlocked region has limited infrastructure, is less populated, receives less rainfall, has a lower per-capita income, lacks appropriate equipment/tools, receives limited support from the government sector, and so on. However, this rural condition is common among developing countries of the subtropical/tropical areas, which may allow this research to apply to other developing countries with similar issues.

For future research, as a part of practitioner level theory validation, the concept should be studied in every stage of the product life cycle. From the industry viewpoint, the relative infancy of the chemical-organic fertilizer industry in Northeastern Thailand adds unique insight for demand-supply integration, offering this opportunity. The maturation of the introduction stage into the growth stage of the PLC (product life cycle) is a more challenging time to study than the maturity and the declining stages. Therefore, the uncertainties of the early adoption stage, as well as the geo-socio-economic factors in this area and industry, provide a supply chain context to challenge the robustness of well-established network concepts, such as equal zoning and two-echelon zoning.

5. Conclusion

By comparing the two-echelon capacitated plant location problem between using the geographical zoning and the equal demand zoning methods, the geographical zoning yielded a smaller number of plants to meet the potential demand for fertilizers. Additionally, this method provides for more suitable locations for plant establishment, simplifying distribution network design. Moreover, it produced a more efficient organic-chemical fertilizer distribution network, reducing long-term transportation costs and increasing service levels to customers. This study helped to validate the efficacy of the two-echelon geographical zoning method in challenging contexts, such as Kalasin, Thailand. The findings in this specific context also help to bridge the gap between theory and practice. Practitioners facing similar problems should feel more confident adopting this technique to make positive and immediate improvements to their business, without waiting for the realization of long-term governmental infrastructure improvement projects.

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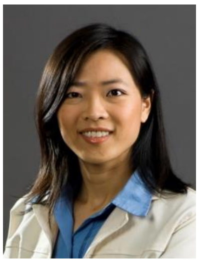

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