Location Optimization Model of Regional Express Distribution Center

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Abstract

As e-business grows rapidly in recent years, express delivery industry ushered in the unprecedented opportunities for development. This also resulted in a fierce competition within the express delivery industry. How to reduce logistics cost and serve customer better has become the focus of many express companies. The importance of express distribution center and the design of its location have aroused extensive attention. Therefore, the location optimization problem of express distribution center has been paid much more attention both in industry and academic world. This paper established an optimization model of regional express distribution center location based on the reality of the road network. The Fuzzy C Means (FCM) clustering algorithm was improved to solve the model. An empirical study was implemented via a case, and it is validated that the established model and its algorithm are feasible.

Keywords: express distribution; distribution center: location optimization; FCM algorithm.

1. Introduction

As B2C and C2C e-business model have been developed rapidly in recent years. Express delivery industry ushered in the unprecedented opportunities for development. This also resulted in a fierce competition within the express delivery industry. How to reduce logistics cost and serve customer better has become the focus of many express company. The importance of express distribution center and the design of its location have aroused extensive attention.

Domestic and foreign scholars have done a lot of studies on the location of logistics distribution centers. Eiichi Taniguchi, Michihiko Noritake studied the way of selecting public logistics center’s site and concluded the best address and the best scale (Taniguchi and Noritake, 1999). Vedat Verter studied the section of the location of a variety of production distribution network (Verter, 1999). Sirisak, K used the principle of Operation Research to locate logistics centers, and put forward "layout-distribution combination model"(Sirisak, 2005). Wan Li, Huang

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Zhixiong, Li Zhiyong put forward optimized Dijkstra algorithm by adopting binary pile structure and the network storage model. Its application to locate logistics center can obtain a satisfactory location plan (Wan et al., 2007). Cao Yunzhong introduced a new locating model and used the model to design a Hopfield neural network. It provided a new method with the locating of logistics centers (Cao, 2009). The previous literatures mainly consider the location optimization problems of urban public logistics distribution centers or regional logistics centers, and there is remarkably few researches to look at the express delivery industry. Current researches about express logistics or express logistics construction are rather superficial, focusing on the macro analysis of the development of the express logistics as a whole, with the lack of an in-depth quantitative analysis. This paper proposes a model to optimize the location of regional express logistics distribution center, based upon the current industry background, combine with the characteristics of express delivery and verifies the applicability of the model by examples.

2. Description of the Problem and Parameters Processing

It is assumed that: the demand points are distributed in each place of express service area, and every demand of service has a fixed reference value; there are more than one primary express logistics distribution centers, which can supply goods for any secondary express distribution centers; there are also several secondary distribution centers, which are distributed in each place of service area and cover all demand points; there is a capacity limit of daily goods flow in each secondary distribution center, the distribution trucks in the same distribution center service range are the same model; the truck load and mileage are limited.

Due to the various kinds of express service objects, the complex distribution route conditions, and the lacked direct data of the demand of each point, it is difficult and inconvenient to establish and analyze the optimization model of regional express distribution center location. Therefore, we need to process the related parameters as follows to solve these difficulties and inconvenience:

2.1. Unit and unit normalization

In the actual logistics distribution, there are various kinds of distribution service products which have different counting units and diverse packing and physical forms. In order to make the distribution model more reasonable, we need to normalize the distribution units, and the normalized distribution unit is expressed as Unit. Supposing that one product waiting for distribution has an actual volume of V cubic decimeter and weight of G kg, then the quantity of this batch of products with the distribution unit (Unit) as the unit of measure is: \( Q = \max(V, G) \) (Unit).

2.2. Road accessibility

In the real distribution, the highway connecting any two demand points directly not always exist, even it need to take a roundabout way from one demand point to another. The distance between two points is not the linear distance between two points, so we must measure the actual distance according to the existing network conditions. The road accessibility between any two points can be described as follows:

\[
\alpha_{ij} = \begin{cases} 
1, & \text{There is a highway connecting } i \text{ and } j \text{ directly, no need to transfer, accessible} \\
0, & \text{There is not any highway connecting } i \text{ and } j \text{ directly, need to transfer, inaccessible} \end{cases}
\]
2.3. Demand calculation

The demands of all demand points were unknown before the secondary distribution centers are set up. In order to make the distribution center location more reasonable, it need to estimate and forecast the future demand of each demand point as well as make a survey of reality demand. The demand of each point is related to the local population and income level. In addition, the consumption potential of each point (especially the ascension of the local consumption level promoted by the secondary distribution center) should be evaluated. Given the comprehensive consideration of the above factors at the same time as consulting the experience demand, for demand point $j$, we set $a_j$ to be the consumption potential index of point $j$, and $D'_j$ to be the survey results of actual demand of point $j$, then the demand of point $j$ is $D_j = a_jD'_j$.

3. Location Optimization Model

Sign convention, as follows: $a_{ij}$: Accessibility variability. If $a_{ij} = 1$, it exists directly connected road between point $i$ and point $j$; if $a_{ij} = 0$, it doesn’t exist directly connected road between $i$ and $j$; $b_{kij}$: If $b_{kij} = 1$, it’s the shortest path from $k$ to level 2 express distribution center $s$, if $b_{kij} = 0$, it isn’t the shortest path; $c_{ij}$: Unit price from level 1 express distribution center $i$ to level 2 express distribution center $j$; $d_{ij}$: Direct distance from point $i$ to point $j$; $D_j$ : Requirement of point $j$; $F_i$: Fixed costs of alternative level 2 express distribution center (include capital investment and fixed operating costs); $g_i$: Circulation unit price of level 2 express distribution center $i$ (management fees and storage costs of one unit flow amount); $h$: Distribution price from point $i$ to point $j$; $L_{ij}$: The distance from level 1 express distribution center $i$ to level 2 express distribution center $j$; $\text{Len}$: The maximum mileage restrictions from level 2 express distribution center to demand point directly; $m$: Alternative places number of level 2 express distribution center; $M_i$: Design capacity of alternative level 2 express distribution center $i$; $n$: The number of demand points; $p$: The maximum number that level 2 express distribution center can be built; $r$: The number of level 1 express distribution center; $X_{ks}$: The transport volume from level 2 express distribution center $s$ to demand point $k$; $W_{ij}$: The transport volume from level 1 express distribution center $i$ to level 2 express distribution center $j$; $z_i$: Variable of level 2 express distribution center location, if $z_i = 1$, demand point $i$ is level 2 express distribution center, if $z_i = 0$, demand point $i$ isn’t level 2 express distribution center; $\text{Cost}$: The total cost of distribution network.

On the basis of previous description of the problem and processing parameters, this paper is to establish the following mixed integer programming model of regional express distribution center location optimization:

$$\text{min Cost} = \sum_{i=1}^{r} \sum_{j=1}^{m} c_{ij} W_{ij} L_{ij} + \sum_{s=1}^{m} \sum_{k=1}^{n} \sum_{j=1}^{n} h_j a_j b_{kij} X_{ks} z_s + \sum_{i=1}^{r} \sum_{j=1}^{m} g_i W_{ij} + \sum_{i=1}^{m} F_i z_i$$  \hspace{1cm} (1)

Subject to:

$$\sum_{i=1}^{m} W_{ij} \leq M_j z_j \quad j = 1, 2, 3, \ldots, m$$  \hspace{1cm} (2)
$$\sum_{i=1}^{m} X_{ij} \geq D_j \quad j = 1, 2, 3, \ldots, n$$  \hspace{1cm} (3)
$$\sum_{i=1}^{m} z_i \leq p$$  \hspace{1cm} (4)
$$\sum_{i=1}^{m} \sum_{j=1}^{n} X_{ij} \leq \sum_{k=1}^{n} \sum_{s=1}^{m} X_{ks}$$  \hspace{1cm} (5)
$$a_{ij} = \begin{cases} 0 & \text{can't access directly between } i \text{ and } j \\ 1 & \text{access directly between } i \text{ and } j \end{cases} \quad i, j = 1, 2, 3, \ldots, n$$  \hspace{1cm} (6)
\[
\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} b_{ij} d_{ij} \leq \text{Len, } k=1,2,3,\ldots,n, s=1,2,3,\ldots,p
\] (7)

\[
b_{ij} = \begin{cases} 1 & \text{shortest path from } k \text{ to } s \quad i,j,k = 1,2,3,\ldots,n \\ 0 & \text{else} \quad s=1,2,3,\ldots,p; \end{cases}
\] (8)

\[
z_i = \begin{cases} 1 & \text{i is second class distribution center} \\ 0 & \text{else} \quad i=1,2,3,\ldots,m; \end{cases}
\] (9)

\[
X_{ij} \geq 0, W_s \geq 0, \rho \geq 1, g_i > 0, d_{ij} > 0, \quad s, \quad j = 1,\ldots,n;
\] (10)

\(W_s, h_i, a_{ij}, b_{ij}\) are decision variables. The remaining variables. \(m, n, p, \text{Len}\) are integer and greater than zero.

Formula (1) is the objective function. The first part of the objective function is freight of goods transported from the level 1 express distribution center to level 2 express distribution center. The second part of the objective function is distribution costs based on the shortest route. The third part of the objective function is inventory circulation management costs of transit goods at the level 2 express distribution center. The forth part of the objective function is the capital investment and fixed operating costs of the level 2 express distribution center. Formula (2) is capacity constraints of express distribution center. Formula (3) is that the distribution volume should satisfy demand. Formula (4) is the constraints of the number of express distribution center. Formula (5) is that the distribution volume of level 2 express distribution center should not be greater than the supply of level 1 express distribution center. Formula (6) is the constraints of accessibility of road transport system between two points. Formula (7) is the constraints of total distribution distance. Formula (8) represents whether it’s the shortest path. Formula (9) considers whether the distribution center is selected. Formula (10) is the requirement of non-negative. Formula (11) is the requirement of non-negative integer.

4. Solution Algorithm

Regarding the above model, in order to reach the lowest cost and to guarantee an overall optimality, the paper applied FCM (Fuzzy C Means) clustering algorithm to optimize the location of express distribution center. The paper also improved the FCM clustering algorithm. FCM is a typical algorithm to realize fuzzy clustering. It updates the membership by minimizing within-class distance. Once the membership of a sample point is determined, the sample will be assigned to the class with the highest degree of membership according to the principle of maximizing membership. FCM algorithm is an effective solution to the errors generated and remained as a result of the initialization process in the traditional algorithm. The main part of the improvement regarding FCM is using shortest path algorithm Dijkstra to calculate the shortest distance between two points, and using gravity method to calculate clustering center, considering the effect of the values of various demand points on clusters in a comprehensive way.

The problem regarding regional Express distribution center location optimization can be solved with improved FCM clustering algorithm. The process is described as follows:

Input: the number of clusters \(c\), sample data set contains \(n\) objects; Output: \(c\) clusters;

Step1: Initialize the cluster centers. The number of clusters \(c\) is given, set iteration stopping threshold. Initialize center vector matrix . Set iteration counter.

Step2: Update the partition matrix.

Step3: Update the cluster center vector matrix.

Step4: According to the previous division, calculate the new cluster center through Dijkstra algorithm and gravity method. Return to step2 until result is stable.
5. Case Study

In order to verify the applicability of the model and the algorithm, this paper analyses the case of an express company. The company adopts the traditional method to operate logistics, and regional division is based on administrative division, which is of low efficiency and resource-wasting.

The study selects 212 demand points from a region as distribution points. Each point is given a number and a demand points table is made. The table contains the demands at each point, the respective sides of the information connected to each point, and the coordinates of each point value. Find out all roads with distribution driving conditions in the area where the points are connected (total 416), and make a route table as distribution points contains length and numbers of connected points of each road. Assume that the fixed costs and design capacity of 212 optional distribution centers are all the same. Total demand (10.4 million U) is divided by the designed capacity (1.4 million U) of each distribution center. Using normalization method to handle the quotient could get the result of the distribution centers’ number (8). Simulate the geographic information of certain area by using MapInfo software as Figure 1.

According to conditions given above, by programming in Matlab software, it can solve the problem of 212 demand points, 461 optional roads, and 8 undetermined express distribution center. The clustering result is shown in table 1

![Fig.1 The simulation of geography information](image)

Analyze data for Clustering results in Table 1. Clustering result is shown in Figure 2.

It can be seen from Table 1 that the number served by each express distribution center is almost the same and the total demand within the scope of each express distribution center are within the service capabilities and utilization of distribution center is relatively high. As can be seen from Figure 2, the layout of the express distribution center is reasonable. The optimization result is very satisfactory.

| Range of services (number of demand point) | The total demand (UNIT) | Utilization of express distribution center capacity |
|-------------------------------------------|-------------------------|---------------------------------------------------|
|                                           |                         |                                                   |
6. Summary

The research scope of this article was defined in the express logistics process from level 1 express distribution center to level 2 express distribution centers, then to demand points eventually. Problem of express delivery location optimization based on the real road network was put forward, and a mathematic model was established. In addition, the FCM clustering algorithm was improved and applied to express delivery problems. Through a simulation analysis of a certain express company within region A, it is verified that the proposed model can well describe the problem and improved FCM clustering algorithm can solve such problems. The model and algorithms have important practical significance.

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