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Dynamic Division of Terminal Distribution Area Based on the Front-End Warehouse Mode

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ABSTRACT

The delivery of the front position mode can effectively solve the customer's requirements for the timeliness of the order, which is an emerging distribution model. However, its management model, order distribution, path division, etc. lack scientific guidance, which will lead to an increase in end distribution costs. This article studies the dynamic division of the distribution area of the preparatory distribution staff. This problem is mainly divided into two stages for discussion. According to the total distribution capacity of the front warehouse, the demand is changed, and the use of total distribution capabilities can maximize the use of total distribution capabilities. In the first stage, the initial distribution area is divided by the K-means cluster to determine the optimal clustering number of the initial area. In the second stage, discuss the relationship between the total distribution capacity and the total demand in the initial region, and then adjust the initial area division by the path optimization. When the total distribution capacity meets the total demand, but the local distribution capacity is less than the local demand, the region is dynamically adjusted by path optimization. about. When the total distribution capacity does not meet the total demand, add third -party distribution to build a dynamic adjustment model containing third -party distribution. The adjusted third -party dynamic model is reduced by about 2%compared to the total distribution cost of non -adjusted third -party distribution. Both dynamic adjustment models are solved with ant colony algorithms. Dynamic adjustment models can reduce total distribution costs.

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KEYWORDS: *Front-warehouse, End-of-line distribution, Dynamic paths, K-means cluster*

1. INTRODUCTION

In recent years, after the global epidemic, online shopping has increased significantly, and people are more accustomed to online orders and online orders, which has brought challenges to the terminal distribution system of the logistics network. The generation of the front-end warehouse model and the optimized operation mode are very important in the end-of-line distribution, which plays an important role in improving customer satisfaction and reducing the distribution cost of enterprises. Therefore, the adaptation and optimization of the end-of-line distribution network is crucial, highlighting the importance of dynamically adapting the system-generated distribution routes within the broader distribution framework.

The diversification of consumer needs, as a whole, is the increasing number of customers who shop online, the frequency of purchases, and the quality of delivery services requested. In this case, the emergence of the pre-warehouse model has become a key node in the terminal distribution link. The ability to deliver goods to customers immediately and safely after the customer places an order is the key factor to improve the level of terminal distribution.

The development of the front warehouse is very rapid and is an important part of terminal distribution. It is very different from traditional warehouses. Front-warehouses are usually located near the community. For example, a small warehouse near a community or a community dealer is the main manifestation of a front-warehouse. This can ensure the rapid response of orders within 3-5 kilometers, and better meet the requirements of customer delivery timeliness. At present, major e-commerce companies have begun to use the front-end warehouse model to explore the development of the new retail industry in the future, which also shows that the front-warehouse will become the mainstream warehouse model of urban logistics operations in the future.

1.1. Existing front-warehouse mode

With the increase in the distribution business of the same city, the major logistics companies have gradually expanded the distribution staff of the end to make up for the problem of the faction and the backward model. There is also a big difference in the actual use of the front-warehouse. The front-warehouse model can be roughly divided into 3 categories. The first is a single front-warehouse mode for Daily You Xian and JD Grocery Shopping. The second is JDC's TDC and main station joint distribution model. The third is the integration of warehouses and stores of Hema Fresh Major e-commerce companies use the front-warehouse model. In the face of different the front-end warehouse models, its distribution method has also changed accordingly. In the fixed distribution personnel, the front-warehouse distribution model is considering maximizing the distribution efficiency of the distribution staff and the most orders completed within a certain period of time. Major e-commerce companies use the front-warehouse model to explore the future development of the retail industry, and the front-warehouse model will become the mainstream of logistics operations.

1.2. The relationship between the distribution area and path optimization

The traditional path optimization problem is optimized by allocating the delivery area first, and then the path inside the delivery area. Considering that the radiation range of the front-warehouse is small, if the delivery staff is fully driving according to the established line, the efficiency will decrease. Therefore, the division of the area is the auxiliary method, and the path optimization is the main method to dynamically adjust the area of the delivery staff. In the path optimization theory, the delivery vehicle departs from the warehouse and is distributed according to customer requirements. Taking minimal distribution costs, minimum delivery time, minimum delivery vehicles as the target function, and optimizing it. Insulting algorithms are usually used to solve such problems.

In the traditional path optimization problem, the distribution area is divided first, and then the improved algorithm is used to design the path optimization scheme within the region. Due to the small radiation range of the distribution in the front-warehouse mode, the driving efficiency is not high according to the established route. On the basis of dividing regions, this paper adopts the route optimization method to coordinate the distribution capacity in each region to dynamically adjust the initial road area, maximize the distribution efficiency, and complete more orders within a certain period of time.

The rest of the paper is structured as follows: Section 2 provides a detailed literature review and discusses the current state of research in the field of terminal distribution. Section 3 details our research methodology and the specific methods employed. Section 4 discusses the application of the dynamic adjustment model of the terminal distribution system of the front-warehouse in reality, and introduces the results of the model after operation. Finally, verse 5 concludes。

2. Literature review

In recent years, the research on the distribution network at the end of logistics, especially the terminal distribution network represented by the front-warehouse, has attracted great attention. This literature review deeply discusses the three aspects of the distribution network at the end of the front-warehouse, the clustering algorithm of the distribution area, the optimization of the vehicle routing problem, and the dynamic adjustment of the initial distribution area in the front-warehouse mode. Each of these aspects plays a vital role in improving customer satisfaction and enterprise cost control at the end of the front-warehouse.

2.1. Relevant regional cluster algorithm

The literature on regional division has always focused on the application of pre-processing of complex problems, and the current research on distribution areas is generally the initial division of regions, aiming at different research objects and different states of the same object.

The literature on regional division has always focused on the application of pre-processing of complex problems, and the current research on distribution areas is generally the initial division of regions, aiming at different research objects and different states of the same object.

Clustering is one of the most important tasks in exploratory data analysis. One of the simplest and most widely used clustering algorithms is K-means, Kazemi, A.[1] which is simple and easy to implement. Since the algorithm is very sensitive to the initial placement of clustering centers, two new non-random initialization methods of k-means algorithm are proposed.

This article is based on the background of the front-warehouse, and the area divided into consideration is the end distribution area of the front-warehouse. The commonly used cluster algorithms commonly used in related distribution areas include the following 4 categories: grid division method, Tyson polygonal theory, diagram method, search algorithm, etc. Among the many cluster algorithms, different algorithms are used in areas in different fields. according to the hydraulic simulation results of the water distribution network, Mandel, P and Maurel, M [2]used the K-means algorithm to divide the distribution area, which reduces the complexity of the distribution network and simplifies the problem solving. First, according to the customer clustering class, Wang, Y., and Ma, X L.[3]divided the distribution are through the fuzzy clustering algorithm. Then by analyzing the results of clustering, the purpose of reducing the complexity of the distribution network is achieved, and finally the optimization of the distribution path is formed. Niknam, T.[4] A designed K-mica to improve the K-means cluster algorithm to solve K-means' dependence on the initial state. Based on the above theory, the K-means cluster algorithm, which is more mature than other algorithms in the application of the logistics-end-distribution area. In the study of the VRP problem, Moradi, B[5] proposed a heuristic algorithm considering biodiversity , and constructed a new multi-objective discrete learnable evolutionary model is considering the geographical location of customers, consumption capacity in different regions, and customer needs, the second-level distribution network is found to find a model for a second-level distribution network during the distribution process, and the K-Means cluster is solved. Khoo, T.S. [6] proposed a two-stage distributed destruction-reconstruction genetic algorithm to solve VRP with time window constraints. Taking the vehicle driving distance and vehicle load as the optimization goal, Yu, M., Yue, G.J., and Lu, Z. C. [7] studied the regional division of Chinese Post in community distribution, and use the Weight-K-means clustering. The large-scale path planning problems are divided into small areas, and the two-stage K-means cluster algorithm is used to solve it.

2.2. An Optimization of Vehicle Routing Problem

With the development of online shopping, distribution as the key constituent part of it has attracted more and more attention, and the delivery efficiency directly affects customer satisfaction. The core of the tissue distribution is the vehicle road question (VRP), Dantzig et al. [8] proposed its abstract model in 1959. For actual road network constraints, algorithms that can solve large -scale distribution areas and path planning problems are more valued. Aiming at the VRP problem with time window, Osaba, E. [9], Yang, X.S. proposed to solve the problem by a discrete firefly algorithm, and obtained good results.. Yang, Z.W. [10] added the dynamic demand change to the VRP problem, and constructed the path optimization model with the smallest total cost. Molina, J.C. [11] proposed a heuristic algorithm to construct a dual-objective model with the largest total number of customers served and the smallest distance cost. Molina [12]studied the delivery of different vehicle types, and proposed a multi-cost minimized path optimization model with time windows, and finally used the ant colony algorithm to solve the problem. Shen Y[13]constructed a path optimization model with the shortest total delivery distance with a time window, and designed a hybrid intelligence algorithm for ant colony system and storm optimization to solve the problem. Real-time vehicle routing (RT-VRP) is a real-world dynamic vehicle routing problem (DVRP). The feeder vehicle routing problem (F-VRP) is made up of heterogeneous fleets. Sarbijan, MS [14] proposes a Real-Time Feeder Vehicle Routing Problem (RTFVRP) that every truck and every motorcycle can join during the freight process. After modeling RTF-VRP by hybrid integer linear programming, a dynamic inertial weighted particle swarm optimization (DIW-PSO) algorithm was proposed to solve the problem. Shen, G.J [15]analyzed the effects of the distance between the road section, the density of traffic flow, and the signal cycle on the cross -port correlation, and establish a child zone division method based on the fuzzy algorithm.

For path optimization issues, few people have adjusted dynamic adjustments to the distribution area based on the results of route optimization on the basis of considering the division of the initial distribution area. In this article, we use the K-means clustering class to initialize the distribution area, and then use path optimization methods to dynamically adjust the initial distribution area, and finally calculate the total distribution cost when the delivery is completed. First, the vehicle path problem belongs to NP-Hard, and the solution efficiency of traditional precise algorithms is low. At present, many scholars have been exploring inspiration algorithms to solve the problem of classic path optimization. In the process, they continue to expand the mode and solution of path problems. Many smart algorithms with high efficiency and ideal results have been obtained. Among them, the powerful robustness and search capabilities of Ant bacteria falling algorithms. Therefore, this article selects an Ant bacterium falling algorithm to solve the problem of distribution path optimization. First, selecting K means to divide the initial front-warehouse distribution area, and then optimize the initial area through path optimization.

2.3. Dynamic adjustment of regions

The literature on end-of-line distribution has historically focused on various aspects. From the selection of the division method of the distribution area to the adjustment of the initial area, it is all about improving the distribution efficiency and reducing the distribution cost.

In the problem of regional dynamic traffic allocation, S. F. A. Batista [16]considers the theory of limited drivers, adopts the macro basic graph and the aggregation model of regional networks, considers the travel time of preferred reliable drivers, and calculates the network balance through Monte Carlo simulation and the classical method of continuous averaging. In the real-time changing traffic network problem, Heng Ding [17] proposed a method for dynamically estimating the boundaries of sub-regions, calculated the sub-region boundary control of the dynamic change range, divided it into three aspects: entrance, exit, and pass, and then established a three-dimensional MFD surface model to determine the starting point of the congested road section. In the problem of dynamic traffic allocation in regional networks, Ludovic Leclercq[18] proposed a method for estimating the distance traveled by traffic and estimating their distance to identify traffic congestion areas and effectively relieve them. Ferrucci et al.[19, 20] modeled a dynamic demand generation model based on historical customer demand data, and designed a proactive real-time control method to deal with dynamic events in the distribution process. Thomas et al [21] argue that integrating regional customer needs in a short period of time can help improve the efficiency of vehicle scheduling. The research on D-VRP solving algorithms is the focus of scholars, and the main solving algorithms include neighborhood search algorithm [22, 23], tabu search algorithm[24, 25], genetic algorithm [26].The dynamic division of regions is mainly focused on the actual traffic network, and the terminal distribution is mainly to study the dynamic division of distribution areas of multiple distribution centers. There are few studies on the dynamic division of the terminal distribution area in the front-warehouse mode. It is closer to the front-warehouse model, which is the problem of frequent warehouse explosion at the end of the express delivery industry studied, which divides the distribution areas of different distribution points into regions, and then uses the path optimization algorithm to divide the edge points to realize the dynamic division of regions.

3. Data and algorithms Introduction

This section describes the methods and data used in the study, with a focus on the dynamic adjustment of the end-of-line distribution path. The approach includes a detailed description of the problem and the formulation of the model, followed by the process of building the model. This includes establishing relevant key assumptions and variable settings. Subsequently, it is an in-depth discussion on the dynamic adjustment of the path of the delivery vehicles in the front-warehouse when the order demand is constantly changing, and avoid the local shortage within the scope of the front-warehouse by adjusting the path. By changing the customer demand in the terminal distribution system, the driving path of the distribution vehicle is continuously adjusted, and the total distribution cost under the adjustment path is calculated. Then consider adding third-party delivery to replace the adjustment of vehicle routing, and calculate the total cost of delivery under adding third-party delivery. Compare the distribution costs of the two to obtain dynamically adjusted optimization results.

3.1. K-means Clustering algorithms

The focus of this paper is on the terminal distribution network in the front- warehouse mode, which is mainly optimized for the initial distribution area generated by the system. In the initial area, when there is a shortage of vehicles when the order demand changes, it is usually considered to add third-party distribution to meet the order demand. However, little consideration is given to dynamically adjusting the distribution path in the distribution network at the end of the front-warehouse to meet customer demand. So as to reduce the cost of dispatching vehicles in the warehouse.

The following describes the use of k-means clustering to form the initial distribution area. The K-Means cluster algorithm is a cluster analysis algorithm for iterative solution. The initial clustering center randomly selects K objects, then calculates the distance between each object and various sub-clustering centers, assigns a sample clustering center and recalculates the distance once until no objects are reassigned, or the clustering center does not change, or the sum of squares of the local error is minimized, and finally the algorithm ends[27]. S_j:the j-th cluster set; N_j: the number of data points in the j-th clustering set;Z_i, Z_j:clustering centers; X_i:data points; K:number of clusters; y:the number of iterations. Eq (1) allocates data points to each cluster center according to the principle of minimum distance. Eq(2)the new cluster center formula. eq(3)(4)convergence conditions.

$$min\{\|X - Z_i(y)\|, i = 1,2,\cdots,K\} = \|X - Z_j(y)\| = D_j(y),\ \text{else} X \in S_j \quad (1)$$

$$Z_j(y+1) = \frac{1}{N_j}\sum_{X \in S_j(y)} X,\ j = 1,2,\ldots,K \quad (2)$$

$$Z_j(y+1) \neq Z_j(y), j = 1,2,\ldots,K \text{, continue} \quad (3)$$

$$Z_j(y+1) = Z_j(y), j = 1,2,\ldots,K \text{, continue} \quad (4)$$

Based on the geometric structure of the data sample, a new evaluation index of the clustering method is designed to verify the effectiveness of the clustering method. eq(5) x_{ij} is data points, z_i is clusters.

$$M = \frac{\sum_{i=1}^{k}\sum_{j=1}^{n_i}(x_{ij}-z_i)^2}{\frac{1}{k(k-1)}\sum_{i=1}^{k}\sum_{j=1}^{k}(z_i-z_j)^2} \quad (5)$$

The numerator represents the distance from the data point to the center of the cluster, and the denominator represents the average of the sum of the distances from the center of each cluster. A smaller M means that each data point is closer to the center of the cluster, and vice versa.

3.2. Ant colony algorithm

A heuristic algorithm based on ant fidelity, which is mainly used to solve various combination optimization problems. Ant optimization process is affected by two factors: pheromone and environment. They release pheromones on the path to find food sources and release pheromone released by other ants. Ant bacteria falling algorithm is updated according to the three key mechanisms. For example, synergy mechanism, selection mechanism, and update mechanism. If the concentration of the information is the choice of the path, then the number of ants that pass through the shorter path increases, and the pheromone concentration is high, and the shortest path is formed according to the positive feedback. The implementation of ant colony algorithms is based on the following three key mechanisms:

Cooperative mechanism: It shows that the ants leave the pheromone when traversing the path and perceive the pheromone concentration of the surrounding path. These phenom play a role in information exchange between ants.

Selection mechanism: It shows that the ants are selected according to the pheromone concentration of the ants. The higher the pheromone concentration, the higher the probability of the selection.

Update mechanism: The shorter it shows the path, the more ants in the ants in the same time, the higher the pheromone concentration. Under positive feedback, the highest information concentration is the shortest path.

3.2.1. Initialization algorithm parameter

Ant number m: If the number of ants is too large, the pheromones on each path will tend to be averaged, the positive feedback effect will be weakened, and the convergence speed will be slowed down; if it too small, some paths will not be searched, and the algorithm may converge prematurely, and affect the global optimal solution. Usually set 1.5 times the number of targets.

pheromone constant Q: if it is too large, the search range will be narrowed and converge prematurely; or too small is easy to fall into a state of chaos; The value is usually between 10 and 100.

Maximum number of iterations t: if it is too large or too small, it will affect the global optimal solution; Generally, the value ranges from 100 to 500, and it is recommended to set the value to 200.

pheromone factor α: α indicates the degree of influence of pheromones accumulated on the path on ant search. Too much will weaken the randomness of the algorithm, and too small may lead to falling into local optimum. Generally, the value should be between 1 and 4.

The factor of the heuristic function β: it is easy to fall into the local optimal if it is too large; If it is too small, the randomness of the search will increase, and it is difficult to obtain the global optimum, usually with a value of 0 to 5.

Pheromone volatile factor ρ: indicates the rate at which pheromones disappear. If it is too big, it is easy to ignore the excellent path; If it is too small, the difference in pheromone content of each path is small and the convergence speed is reduced. Usually, the value is 0.2 to 0.5.

3.2.2. Construct the solution space

Place each ant in a different place at random, Calculate the next city to be visited by ant k($k \in [1, m]$)until each ant has visited all cities. During this period, the roulette method is used to select the next city to be reached, and the path selection probability is as follows

$$P_{ij}^{k} = \begin{cases} \frac{\tau_{ij}^{\alpha}(t) * \eta_{ij}^{\beta}(t)}{\sum_{s \in \text{allowed}_k} \tau_{ij}^{\alpha}(t) * \eta_{ij}^{\beta}(t)} & j \in \text{allowed}_k \\ 0 & \text{else} \end{cases} \quad (6)$$

i and j represent the start and end points of each segment of the path, τ represents the pheromone concentration from i to j at time, η is equal to the reciprocal of the path length d, $allowed_k$ represents the set of nodes that have not been visited.

3.2.3. Update pheromones

Calculating the length of the path traveled by each ant as L, and then recording the shortest path in the current number of iterations. According to eq. (7), updating the pheromone concentrations of the pathways connecting the cities.

$$\tau_{ij}(t+1) = \tau_{ij}(t) * (1-\rho) + \Delta\tau_{ij}, 0 < \rho < 1, \ \Delta\tau_{ij} = \sum_{k=1}^{m} \Delta\tau_{ij}^k \quad (7)$$

The pheromone content of cities i to j after the t+1 cycle is equal to the pheromone content on cities i to j after the t cycle multiplied by the pheromone residue coefficient plus the new pheromones. And the new pheromones are the sum of the pheromones left by all ants on cities i to j. The new pheromone content can be divided into the following three models according to different rules: ant circumference model, ant volume model, and ant density model

- Ant week model:

$$\Delta\tau_{ij}^k = \begin{cases} \frac{Q}{L_k} & \text{ant k from i to j} \\ 0, & \text{otherwise} \end{cases} \quad (8)$$

- ant quantity model:

$$\Delta\tau_{ij}^k = \begin{cases} \frac{Q}{d_{ij}} & \text{ant k from i to } j \\ 0, & \text{otherwise} \end{cases} \quad (9)$$

- ant density model:

$$\Delta\tau_{ij}^k = \begin{cases} Q & \text{ant k from i to } j \\ 0, & \text{otherwise} \end{cases} \quad (10)$$

4. A dynamic model of distribution of construction

4.1. Problem description

Traditional route optimization is to cluster orders within each time period and then randomly assign them to a delivery person. When increasing the demand for an order, this article discusses the change in the relationship between total fulfillment capacity and total demand. Cross-regional distribution is formed by adjusting the regional distribution path, and finally the dynamic adjustment of the region is realized.[18] When the total distribution capacity and the distribution capacity of each internal area meet the demand, it is not a dynamic adjustment. First, when the total distribution capacity meets the total demand but the local demand exceeds the distribution capacity of the region, and the distribution capacity of other regions is surplus. First, when the total distribution capacity meets the total demand but the local demand exceeds the distribution capacity of the region, and the distribution capacity of other regions is surplus, then the dynamic adjustment is formed by adjusting the global situation or directly adding a third-party distribution in the local area, and then comparing the total distribution cost of the two. Second, when the total distribution capacity cannot meet the total demand, the demand of more local areas exceeds the distribution capacity of the region, assuming that outsourcing and timeout are allowed, and then comparing the model of directly adding third-party distribution in each local area and the model of making overall dynamic adjustment after adding a third party. Initial zones are divided by analyzing the demand for each distribution area, and then the delivery route is adjusted. Optimize the total cost of distribution by matching areas with areas with excess distribution capacity in the surrounding areas

4.2. Basic assumptions and parameter definitions

In order to simplify the model and make it more in line with the realities of the front-warehouse distribution network. We make the following assumptions about the dynamic adjustment model of the terminal distribution network:

- The customer's position in the front-warehouse and the delivery note are known.
- The distribution vehicle is the same, and equipped with positioning equipment, and the goods are not abnormal, and can be transported in the same car.
- The dealer is responsible for one car and one service path at a time, which cannot be strung together; A point of demand can only be delivered by one vehicle, and one vehicle can serve multiple customers.
- The distance of the distribution route is less than or equal to the maximum driving distance of the transport vehicle.
- The unit distance cost from the front-warehouse to each demand point is known.
- The vehicle departs from the front-warehouse and must return to the front warehouse after completing the delivery task.
- Set the demand of one customer to 1, if the demand exceeds 1, it means that there are different customers at the demand point, and the delivery time needs to be superimposed.
- During transportation, the vehicle can only deliver goods and cannot collect goods.

- Front-warehouse is connected with each demand point, and the demand point is also connected
- The first travel time of the delivery vehicle is reset to zero, and there is a time window limit during the delivery process.

4.3. Variable settings

O: A collection of order demand point i,即 $i,j \in O = \{1,2,3,4,\dots,O\}$

q^i: The amount of demand at the point of demand i.

$x_{i,j}^p$: $x_{i,j}^p = 1$ Representing the delivery person from point i to j, else $x_{i,j}^p = 0$.

$d_{i,j}$: The delivery distance of the point i to j.

B_i^p: The time when the delivery person arrives at point i, If the delivery personnel do not participate in the delivery, it will be 0.

T_i: The estimated delivery time of the front-warehouse to point i. T: The time limit required to complete a single delivery.

M_0: Total number of people delivered.

L: The delivery time required for each quantity demanded.

q^p: The maximum load capacity of a courier at one time.

V_0: Average driving speed.

C: Cost per delivery route..

c_1: The cost per unit of timeout within the specified timeout range of the front-loaded position.

c_2: The cost of the unit timeout time that exceeds the specified range.

c_3: The delivery commission for each order of the delivery personnel.

c_4: A fixed salary for a delivery person.

c_5: The cost of third-party fulfillment of an order. A: Start-up fees for third parties.

4.4. Objective function

Time cost: Overtime penalty cost w, The cost of not completing the delivery on time, which is the delivery vehicle is later than the estimated time of arrival Te. Through literature review and field research, Through literature review and field research, the satisfaction reduction caused by overtime was divided into two stages. If the timeout is less than 15 minutes or more than 15 minutes, the time penalty function is the time:

$$w = \sum_{p=1}^{M_0} \sum_{i=1}^{O} [c_1 \max(B_i^p T_e, 0) + c_2 max(B_i^p - T_e - 15, 0)] \quad (11)$$

Transportation cost: Electric vehicles are the main mode of terminal distribution, using vehicle power consumption as transportation costs, based on the standard mileage of the vehicle, and at the same time, the problem of weak tram batteries is not considered:

$$C \sum_{p=1}^{M_0} \sum_{i=0}^{O} \sum_{j=o}^{O} (x_{i,j}^p d_{i,j}^p) \quad (12)$$

Fixed costs of personnel: The fixed costs of the front-warehouse mainly include warehouse rent, hiring workers, purchasing vehicles, facilities and equipment, etc. In this paper, the fixed cost of distribution personnel mainly includes the basic salary of distribution personnel:.$c_4 p$, The commission of each order of the distributor is c_3; The order quantity: $(c_4 p + c_3 x_{i,j}^p)$. The function is expressed as follows:

$$\sum_{p=1}^{M_0} \sum_{i=0}^{O} \sum_{j=o}^{O} (c_4 p + c_3 x_{i,j}^p) \quad (13)$$

Third-party delivery cost: The third-party delivery cost is added on the basis of model 1, including the fixed cost of starting the third-party A, the income of the third-party delivery person per order c_5, The number of orders that cannot be fulfilled by self-operated delivery personnel $z_{i,j}^p$.

$$\sum_{p=1}^{M_0} \sum_{i=0}^{O} \sum_{j=o}^{O} (c_5 z_{i,j}^p) + A \quad (14)$$

5. Dynamically adjust the model of the region

5.1. Considering the dynamic adjustment model of the region when the total distribution capacity is fixed

When the total distribution capacity meets the total demand, the objective function of model 1:

$$f(x) = \min \left\{ \begin{array}{c} C \sum_{p=1}^{M_0} \sum_{i=0}^{O} \sum_{j=o}^{O} (x_{i,j}^p d_{i,j}^p) + \\ \sum_{p=1}^{M_0} \sum_{i=1}^{O} [c_1 \max(B_i^p T_i, 0) + \max(B_i^p - T_j - 15, 0)] + \\ \sum_{p=1}^{M_0} \sum_{i=0}^{O} \sum_{j=o}^{O} (c_4 p + c_3 x_{i,j}^p) \end{array} \right. \quad (15)$$

ST:

$$\sum_{p=1}^{M_0}\sum_{j=0}^{O} X_{ij}^{p}=1,\quad (i\neq j, i=1,2,3,\cdots,O) \tag{16}$$

$$\sum_{p=1}^{M_0}\sum_{i=0}^{O} X_{ij}^{p}=1,\quad (i\neq j, j=1,2,3,\cdots O) \tag{17}$$

$$\sum_{p=1}^{M_0} Y_i^{p}=1,\quad (i=1,2,3\ldots,p) \tag{18}$$

$$\sum_{p=1}^{M_0}\sum_{j=0}^{O} X_{i,j}^{p}=\sum_{p=1}^{M_0}\sum_{j=0}^{O} X_{j,i}^{p}\leqslant 1,\quad (i\neq j, i=0,1,2,O) \tag{19}$$

$$\sum_{i=1}^{O} q^{i} Y_i^{p}\leq q^{p},\quad (p=1,2,3,\ldots,M_0,\ i=1,2,3,\ldots,O) \tag{20}$$

$$B_j^{p}=B_i^{p}+\frac{d_{i,j}}{v}+q^{i}L,\quad (p=1,2,3,\ldots,M_0,\ x_{i,j}^{p}=1,\ (i,j=1,2,3,\ldots,O) \tag{21}$$

$$B_i^{p}=0,\quad (\forall p\in M_0,\ i=0) \tag{22}$$

$$x_{i,j}^{p}=\begin{cases}1, & delivery\ person\ p\ from\ i\ to\ j\ for\ delivery\\ 0, & otherwise\end{cases} \tag{23}$$

$$Y_i^{p}=\begin{cases}1, & delivery\ person\ p\ delivered\ at\ point\ i\\ 0, & otherwise\end{cases} \tag{24}$$

eq(16), (17)Each demand point is delivered by one courier at a time; eq(18)In the process of order allocation, the delivery staff delivers one demand point at a time ; eq(19)All delivery staff set off from the front position, and return to the front position after completing the order; eq(20)Maximum cargo capacity; eq(21)The time of the delivery staff p arrives at point j; eq(22)The delivery time starts from 0, and the total distribution time set in the model does not exceed 120min; eq(23), (24)Model decision variable.

5.2. Considering the regional dynamic adjustment model with changes in distribution capabilities

When the total demand exceeds the total distribution capacity, the outsourcing cost of the third -party distribution is added. Model 2 assumptions are the same as the hypothesis of Model 1. The target function of Model 2:

$$f(x)=\min\left\{\begin{array}{c} C\sum_{p=1}^{M_0}\sum_{i=0}^{O}\sum_{j=o}^{O}(x_{i,j}^{p}d_{i,j}^{p})+\sum_{p=1}^{M_0}\sum_{i=0}^{O}\sum_{j=o}^{O}(c_4p+c_3x_{i,j}^{p})+\\ \sum_{p=1}^{M_0}\sum_{i=0}^{O}\sum_{j=o}^{O}(c_5z_{i,j}^{p})+\\ \sum_{p=1}^{M_0}\sum_{i=1}^{O}\left[c_1\max\left(B_i^{p}T_i,0\right)+c_2max\left(B_i^{p}-T_i-15,0\right)\right]+A\end{array}\right\} \tag{25}$$

On the basis of Model 1, the model two increases the constraint(26):

$$z_{i,j}^{p}=\begin{cases}1, & Y_j^{p}=0\ \text{or}\ B_j^{p}\geq T_j+10\\ 0, & \text{otherwise}\end{cases} \tag{26}$$

6. Simulation verification and results analysis

This section details the process and results of a simulation analysis of the dynamic adjustment of the initial distribution area in the terminal distribution network of the front-warehouse. Combined with the k-means clustering algorithm to solve the division problem of the initial distribution area, and on this basis, the ant colony algorithm is used to solve the dynamic adjustment problem of the path. The following subsections describe the results from data collection to the specific application of the method and the final dynamic adjustment.

6.1. Data point collection and processing

Investigating a front position of an e -commerce company in Beijing, it was found that the front positions were mainly daily necessities and freshness. Their transactions were usually inside the community. The distribution range is 5 kilometers, from the north to the East Sanqi Hotel, the south to the K Cool Fashion Plaza, the west to the Taoyuan Community, and the east to the Oriental Star Golf Course, as shown in Figure 2. The situation in the warehouse is described below. The average daily order volume is 1500 orders. The working hours are from 7 am to 9 pm, the average distribution is 1 time on average, 7 times a day, and the average total distribution is 214. If everyone sends 10 orders, 22 -bit riders. In the actual warehouse, there are about 39 riders. Each distributor only needs to distribute 6 orders, and the total distribution ability meets the total needs. Assuming the average order volume is D, the peak period is not considered. It is divided into 6 periods per day, the average order volume of two hours is d. and then the relative range of the demand for division around d. Table 1 is community information for research.

$$d_i = D/6 \tag{27}$$

Study each point of the front-warehouse to obtain the community's population density. Population density is Z, community area S, community population R。

$$Z = R/S \tag{28}$$

Table 1 community information table

<table>
<tr><th>Community name</th><th>community area/10^4m^2</th><th>building numbers</th><th>population density// 10^4m^2</th><th>Community name</th><th>community area / 10^4m^2</th><th>building numbers</th><th>population density栋 / 10^4m^2</th></tr>
<tr><td>Yancheng Court</td><td>30</td><td>26</td><td>0.86</td><td>Run ze Yuexi</td><td rowspan="3">61</td><td rowspan="3">70</td><td rowspan="3">1.14</td></tr>
<tr><td>Urban Fang yuan</td><td>50</td><td>109</td><td>2.18</td><td>Shi hua Park County</td></tr>
<tr><td>Jiu tai Manor</td><td>18</td><td>17</td><td>0.94</td><td>Hua mao City</td></tr>
<tr><td>Tian tong Xi yuan</td><td rowspan="4">201</td><td rowspan="4">228</td><td rowspan="4">1.13</td><td>Times Manor</td><td rowspan="5">100</td><td rowspan="5">172</td><td rowspan="5">1.72</td></tr>
<tr><td>obei North</td><td>Winning Autumn Court</td></tr>
<tr><td>Beijing North</td><td>Lai Chun Yuan</td></tr>
<tr><td>Hop Cube</td><td>Guanghua Residence</td></tr>
<tr><td>Tian tong North Court</td><td>120</td><td>142</td><td>1.18</td><td>Yunshiyuan</td></tr>
<tr><td>Tian tong Middle Court</td><td>48</td><td>65</td><td>1.35</td><td>Jasmine Garden</td><td rowspan="4">58</td><td rowspan="4">38</td><td rowspan="4">0.65</td></tr>
<tr><td>Tian tong East Court</td><td>120</td><td>134</td><td>1.11</td><td>Shing Kam Court</td></tr>
<tr><td>Tian tong yuan</td><td>90</td><td>130</td><td>1.44</td><td>Jiaxing Garden</td></tr>
<tr><td>Run ze Manor</td><td rowspan="4">105</td><td rowspan="4">192</td><td rowspan="4">1.82</td><td>Chuk Wah Nin</td></tr>
<tr><td>Run ze Mansion</td><td>Tian ju yuan</td><td rowspan="3">40</td><td rowspan="3">40</td><td rowspan="3">1</td></tr>
<tr><td>Run jing Ming yuan</td><td>Tin Lok Yuen</td></tr>
<tr><td>China Railway Construction International City</td><td>Ping An Garden</td></tr>
<tr><td>Jia Yun Garden</td><td rowspan="3">63</td><td rowspan="3">105</td><td rowspan="3">1.66</td><td rowspan="3">Shimao Aolin</td><td rowspan="3">24</td><td rowspan="3">15</td><td rowspan="3">0.62</td></tr>
<tr><td>Jia Cheng Garden</td></tr>
<tr><td>Dong chen District</td></tr>
</table>

Using K-means clustering to obtain 5 areas and 5 groups of delivery personnel. Each group of delivery personnel has about 4 persons, and the total number of people does not exceed 20. The total order volume is set to a fixed value. Taking the total order volume as the standard, the total order volume is adjusted according to population density, and the adjustment range is set to 10. First, the specific order volume is generated based on the simulated demand points of each community, and then the coordinates of the simulated demand points in the corresponding area are generated. The total order volume = 48 * the number of areas. It can be seen from the population density of the above table. The ratio between each other is: 0.86: 2.18: 0.94: 1.13: 1.18: 1.35: 1.11: 1.44: 1.82: 1.14: 1.72: 0.65: 1: 0.62: 1.66. Each delivery area is initially set to 48 orders. According to the population density ratio of each community in Table 1, the order quantity for each community is divided as follows: 2, 5, 2, 3, 3, 3, 3, 4, 5, 3, 4, 2, 3, 2, 4. The total order quantity is fixed. According to the population density ratio in Table 1, the regional order quantity is randomly added with a value of plus or minus 3 to simulate the specific order quantity of each community. When the total order quantity is 170, according to and the specific order quantity of each community demand point, the coordinates of 170 specific demand points and the number of orders corresponding to the demand points are randomly simulated. only shows 29 simulated data.

Table 2 Coordinates of simulated demand points and corresponding number of orders

number	location	longitude and latitude	Number of orders
1	Yancheng Court number 15	116.443564,40.093302	1
2	Yancheng Court number 8	116.44475,40.092177	1
3	Yancheng Court number 14	116.443597,40.093009	2
4	Yancheng Court number 1	116.444315,40.091029	2
5	Yancheng Court number 30	116.445663,40.094072	1
6	Lai Wu Court number 5	116.4024,40.08643	3
7	Lai Wu Court number 8	116.403083,40.087341	1
8	Jia hu Court number 22	116.399535,40.086879	1
9	Jing hu Court number 5	116.397325,40.089211	1
10	Jing hu Court number 4	116.395591,40.089549	1
11	City Garden number 37	116.396894,40.08672	1
12	Jia hu Court number 19	116.39869,40.086851	1
13	Hopwood Lodge number M4	116.393651,40.087417	1
14	City Garden number U12	116.393519,40.088907	2
15	City Garden number 6	116.395585,40.088589	1
16	City Garden number 33	116.399996,40.086637	1
17	Jiu tai Manor number 5	116.400325,40.082552	1
18	Jiu tai Manor number1	116.398529,40.081662	1
19	Jiu tai Manor number 17	116.393902,40.083277	2
20	Jiu tai Manor number 5	116.396319,40.082676	1
21	Jiu tai Manor number 3	116.400005,40.081482	2
22	Pacific Home number 25	116.413683,40.076707	1
23	Pacific Home number 12	116.417204,40.075762	1
24	Community number 2	116.417645,40.066079	1
25	Community number 1	116.417645,40.066079	1
26	Tian tong West Court number 47	116.413953,40.070772	1
27	Tian tong West Court number 8	116.413225,40.07189	1
28	Tian tong West Court number 21	116.41666,40.082752	1
29	Tian tong North Court number 27	116.442725,40.082863	1

6.2. k-means initial area clustering k-means

K-means was used to cluster the 170 simulated demand points, and the initial end distribution area was set to different cluster centers, such as 2, 3, 4, 5, 6 and 7 clusters. The evaluation values of different clustering centers were calculated as follows: $M_2=40.7533$, $M_3=24.5706$, $M_4=10.6438$, $M_5=7.3435$, $M_6=5.8243$, $M_7=6.0258$. shows the clustering effect of k=5, k=6, and k=7, and it can be observed that the M value increases when clustering into class 7, and the clustering center of 6 evaluates the best clustering effect.

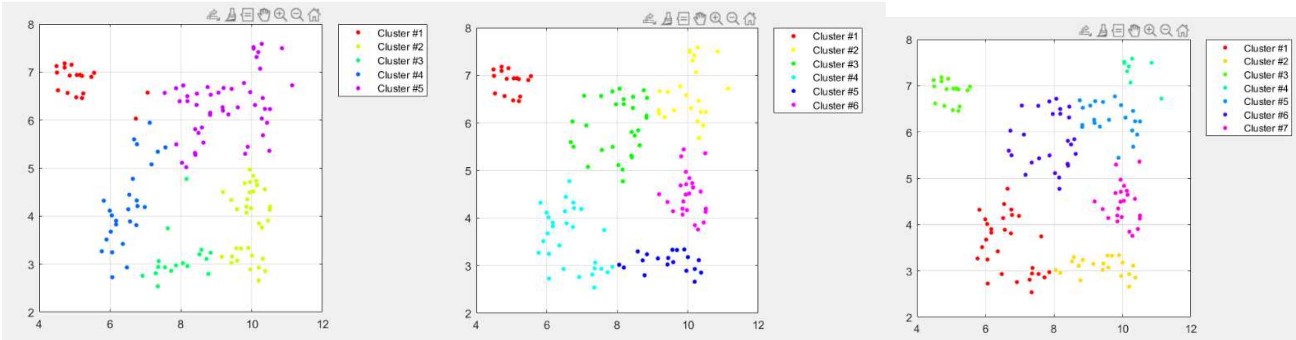

Figure 1Results of clustering center of 5,6,7

After the clustering was run for many times, the results of different clustering algorithms k=6 were displayed to observe the clustering effect. The minimum distance method, density clustering method, and k-means clustering method were followed in order. When k=6 was calculated by the evaluation formula, the index evaluation values of different clustering methods were M_density=22.2568, M_distance=7.4438, and M_K-means=5.82433. It can be seen that the results of the density peak algorithm are not ideal, and the maximum and minimum distances can achieve better results, and the K-means clustering method is more effective. initially divides the region into six categories, and shows the result plots with a cluster center of 6 for different clustering methods.

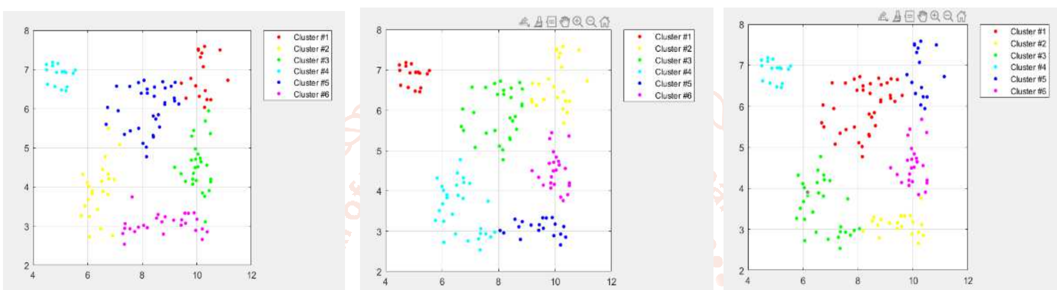

Figure 2 Results of different clustering algorithms with clustering center of 6

Due to the better effect of the K-means clustering method, the clustering results of the k-means algorithm were finally selected as the results of the distribution area initialization score. Subsequent experiments will verify the results of dynamic adjustment on the basis of this clustering. The initial division area is shown in Figure 3

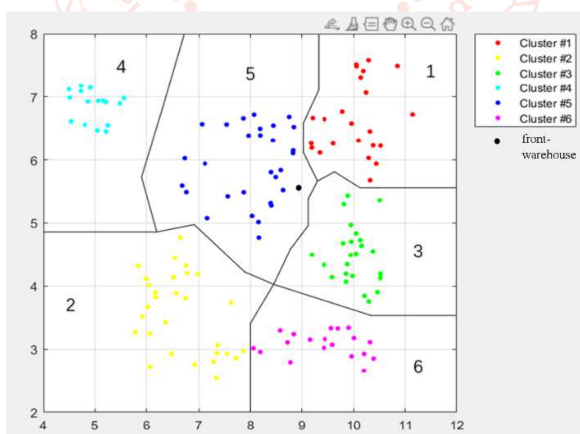

Figure 3The initial area of division of 170

In , when the K-means algorithm cluster center is 6, the result of the region division when the total demand is 70 is as follows: region 1: 3 people, region 2: 4 people, region 3: 3 people, region 4: 2 people, region 5: 4 people, region 6: 3 people. The parameters of the algorithm are shown in Table 3. When the order quantity is increased to 170, 180, 190, and the order quantity is 200, it shows that the total distribution capacity cannot meet the total demand.

Table 3 Parameter information table

parametric	Parameter name	value	parametric	Parameter name	value
M_0	Number of distributors	19	c_2	Unit overtime cost for exceeding the specified overtime range	0.4
L	Time spent at each point of demand	5	c_3	Fixed delivery commission per order for delivery staff	5
V_0	Average driving speed	8	c_4	Basic salary of delivery staff	1
c_0	Unit route cost	0.5	c_5	Commission per order for third party delivery staff	10
c_1	Unit time cost of overtime within the specified timeout range of the front position	0.2	A	The cost when starting a third party	50
T_i	Prescribed delivery time to point i	120			

6.3. Model solving and results analysis

The simulation results are discussed in three aspects:

When the total distribution capacity can meet the total demand, the dynamic adjustment result of the total demand of 170 is selected for display in this section.

If the total distribution capacity is enough to meet the total demand, and the distribution capacity is insufficient in the local area, the dynamic adjustment result of the total demand of 180 is selected for display. Compare the direct use of a third party without adjustment and the elimination of local delivery capacity through dynamic adjustment.

When the total distribution capacity cannot meet the total demand, the distribution network will start the third-party distribution. The results selected for this section are 200 orders. The contrast is between the use of a third party to meet the needs and the use of a third party on the basis of dynamic adjustments.

6.3.1. Consider dynamic regional adjustments with fixed total distribution capacity

In model 1, with an order volume of 170, discusses the dynamic area adjustment model and path optimization results. As in Figure 4

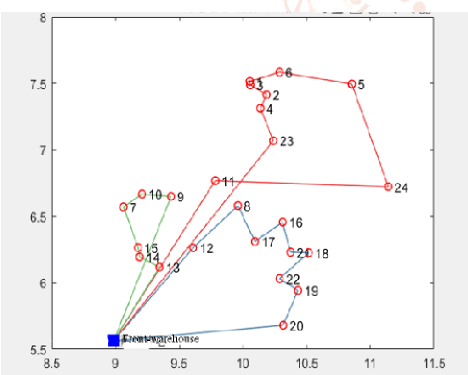

Figure 4 (1) Zone 1 of 170

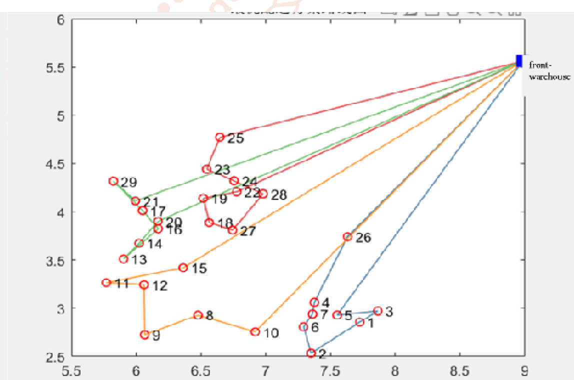

Figure 4 (2) Zone 2 of 170

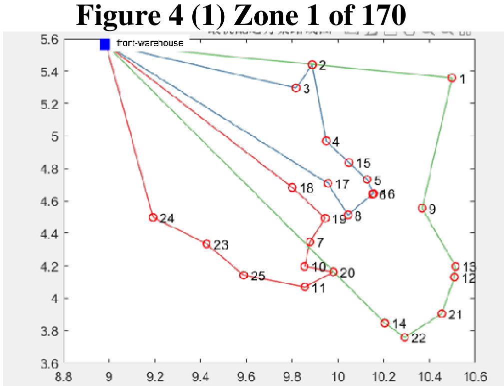

Figure 4 (3) Zone 3of 170

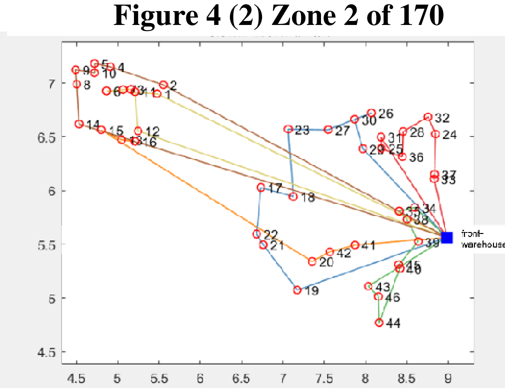

Figure 4 (4) Zone 4of 170

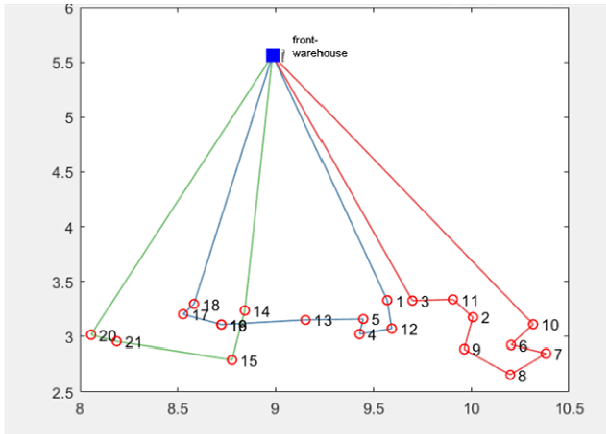

Figure 4 (5) Zone 5 of 170

Figure 4 The optimal distribution route diagram of order volume of 170

shows the dynamic adjustment path for each region when the total demand is 170. shows the initial zone division results, and Figure 4 shows the zone dynamic adjustment results. The principle of adjustment is: if the distribution capacity of the existing local area is less than the demand, and there is a surplus distribution capacity in the surrounding area, the two areas will be combined for joint planning. Based on the total demand of 170, the distribution capacity of zone 4 is insufficient, and it is combined with the nearest zone 5 to form an optimization scheme of 6 distribution routes. The demand points involved in the two routes in the upper left corner of are divided into region 4. The remaining demand points are divided into zone 5. Finally, the distribution scheme in is formed. The total cost of delivery is 806.4407.

Table 4 The result of a dynamic adjustment of the total demand of 170

Delivery zones of 170	routes	Point of Demand
(1) the specific route is:	route1	0->12->8->17->16->21->18->22->19->20->0
	route2	0->23->4->2->3->1->6->5->24->11->0
	route3	0->9->10->7->15->14->13->0
(2) the specific route is:	route1	0->26->4->7->6->2->1->3->5->0
	route2	0->22->19->18->27->28->24->23->25->0
	route3	0->21->29->17->16->13->14->20->0
	route4	0->15->11->12->9->8->10->0
(3) the specific route is:	route1	0->3->2->4->15->5->16->6->8->17->0
	route2	0->18->19->7->10->20->11->25->23->24->0
	route3	0->14->22->21->12->13->9->1->0
(4) the specific route is:	route1	0->33->37->24->32->28->36->25->31->0
	route2	0->29->30->26->27->23->18->17->22->21->19
	route3	0->43->46->44->40->45->39->38->35->34->0
	route4	0->41->42->20->15->13->16->0
	route5	0->12->11->3->7->6->1->0
	route6	0->2->4->5->10->9->8->14->0
(5) the specific route is:	route1	0->18->17->19->16->13->5->4->12->1->0
	route2	0->3->11->2->9->8->7->6->10->0
	route3	0->14->15->21->20->0

The path optimization of each partitioned region on the initial region is carried out to obtain the distribution path and total allocation cost of the corresponding region. shows the results of the dynamic adjustment of the region. At 180 orders, Zone 1 has 4 distribution paths; Zone 2 has 4 distribution paths; Zone 3 has 3 distribution paths; Region 4 has 6 distribution paths; Region 5 has 3 distribution paths. The principle of adjustment is to jointly plan the local areas where the existing distribution capacity is insufficient and the surrounding areas with the remaining distribution capacity. The total distribution cost is 862.0843.

Table 5 The result of a dynamic adjustment of the total demand of 180

Delivery zones of 180	routes	Point of Demand
Zone_1 the specific route is:	route1	0->13->14->15->7->10->9->11->8->17->0
	route2	0->23->4->2->3->1->6->25->5->24->0
	route3	0->18->21->22->19->20->16->12->0
Zone_2 the specific route is:	route1	0->26->4->7->6->2->5->1->3->0
	route2	0->10->8->9->12->15->31->0
	route3	0->18->27->19->24->22->28->23->25->0
	route4	0->21->17->20->16->14->13->11->30->29->0
Zone_3 the specific route is:	route1	0->3->2->4->15->5->16->6->8->17->0
	route2	0->18->19->7->10->20->11->25->23->24->0
	route3	0->26->14->22->21->12->13->9->1->0
Zone_4 the specific route is:	route1	0->37->32->36->33->43->38->44->41->42->0
	route2	0->39->40->18->17->47->12->50->15->0
	route3	0->49->16->20->19->21->25->28->48->26->34->0
	route4	0->23->29->27->24->30->22->35->31->0
	route5	0->2->1->11->3->7->14->4->10->0
	route6	0->6->5->9->8->13->45->46->0
Zone_5 the specific route is:	route1	0->18->17->19->16->13->5->4->12->1->0
	route2	0->11->2->10->6->7->8->22->9->3->0
	route3	0->13->23->15->21->20->0

In the same way, the clustering results of 190 and 200 orders are discussed, and then the path optimization is carried out for each segmented region, and finally the distribution route and total distribution cost of the corresponding region are obtained.

At a total demand of 190, zone 1 has 6 delivery routes: zone 2 has 2 delivery routes; Zone 3 has 11 delivery routes; The total distribution cost is: 914.676.

Zone 1:route_1: 0->, 28->, 29->30->, 53->, 41->, 31->, 42->, 32->34->0; route_2: 0->45->33->36->37->51->49->50->44->43->0; route_3: 0->35->39->38->47->40->48->46->52->0; route_4: 0->27->20->26->19->22->21->18->16->17->0; route_5: 0->, 8->, 11->, 9->, 10->, 7->, 15->, 14->, 13->, 12->0; route_6: 0->, 23->, 4->, 2->, 3->, 1->, 6->, 25->, 5->, 24->0

Zone 2: route_1: 0->, 12->, 15->, 6->, 7->, 3->, 11->, 1->, 2->0; route_2: 0->14->4->10->5->9->8->13->0

Zone 3: route_1: 0->56->55->52->63->60->61->69->57->62->0; route_2: 0->58->59->37->35->67->34->68->39->38->0; route_3: 0->36->, 25->, 23->, 24->, 22->, 18->, 27->, 31->, 19->0; routes_4: 0->, 14->, 13->, 15->, 33->, 16->, 20->, 17->, 21->30->0; route_5: 0->84->89->86->93->83->75->74->82->71->0; route_6: 0->, 73->, 81->, 72->, 79->, 92->, 78->, 94->, 77->, 95->0; route_7: 0->, 80->, 76->, 85->, 87->, 88->, 91->, 90->, 3->, 4->0; route_8: 0->, 7->, 6->, 2->, 5->, 32->, 28->, 51->0; route_9:0->70->50->54->41->49->45->66->53->46->0; route_10:0->48->42->43->47->44->40->65->64->0; route_11:0->29->11->12->9->8->10->1->26->0. The total cost is: 914.676.

As discussed earlier, the total demand was 170, and the distribution demand in a small number of local areas was insufficient. There are few demand points for adjustment in the region, and the dynamic adjustment of the initial area is not obvious. As the demand increases to 180, the number of adjustment demand points in the region increases, and the overall initial number of zones does not change. When the total demand increases to 190, the overall initial number of zones is changed from 6 to 3 after dynamic adjustment.

When the order volume is 200, the total demand within the overall area is greater than the total delivery capacity. In this case, the comparison is to increase the total cost of third-party distribution by directly adding third-party distribution and dynamically adjusting it. See **Error! Reference source not found.**.

Table 6 The result of a dynamic adjustment of the total demand of 200

delivery zones of 200	routes	Point of demand	Third-Party delivery
Zone_1 the specific route	route1	0->28->20->26->19->22->21->18->16->17->0	24
	route2	0->8->11->27->9->10->7->15->14->13->0	
	route3	0->12->23->4->2->3->1->25->6->5->0	
Zone_2 the specific route	route1	0->32->33->35->34->23->22->20->16->0	7/9/10
	route2	0->25->31->13->11->12->28->15->19->0	
	route3	0->27->18->14->29->17->21->26->30->0	
	route4	0->24->1->3->5->4->2->8->6->0	
Zone_3 the specific route	route1	0->27->1->2->15->5->4->14->26->3->0	25
	route2	0->16->18->7->6->9->10->24->22->23->0	
	route3	0->17->19->13->21->20->11->12->8->0	
Zone_4 the specific route	route1	0->3->7->6->10->5->4->14->11->2->0	1
	route2	0->12->15->13->8->9->16->0	
Zone_5 the specific route	route1	0->23->24->32->2->1->33->5->4->3->0	29/30
	route2	0->25->28->36->26->37->38->34->22->27->0	
	route3	0->21->20->17->8->14->31->11->18->35->0	
	route4	0->19->16->7->15->9->13->12->6->10->0	
Zone_6 the specific route	route1	0->29->10->25->7->24->8->28->9->22->0	15
	route2	0->6->2->11->3->1->5->4->12->13->0	
	route3	0->23->16->19->14->18->17->21->20->27->26->0	

The area 1 has 3 distribution paths and enables the third party to complete the distribution of demand point 24; the area 2 has 4 distribution paths and enables third -party to complete the demand point 10, 9, and 7 distributions; There are 3 distribution paths in the area 3 and enable the third party to complete the distribution of demand point 25; the area 4 has 2 distribution paths and enables the third party to complete the distribution of demand point 1. 30 and 29 distributions; the area 6 has 3 distribution paths and enables third parties to complete the distribution of demand point 15; the total cost is: 1045.1805.

shows the dynamic adjustment results for different scenarios from 170 to 190 total demand. From the figure, it can be found that the demand points in the adjustment area are more evenly distributed and the distribution efficiency is higher.

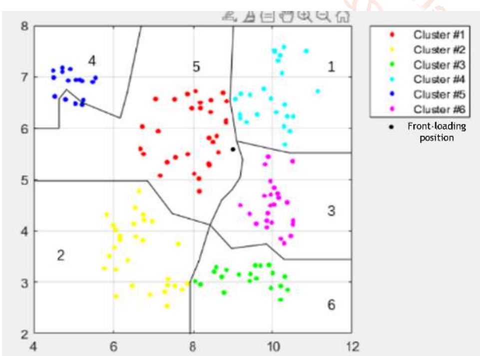

Figure 5 (1) Dynamic adjustment of order 170

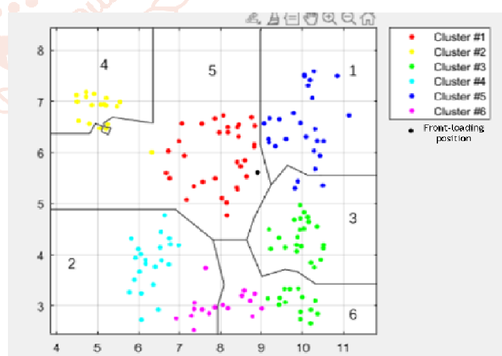

Figure 6 (2) Dynamic adjustment of order 180

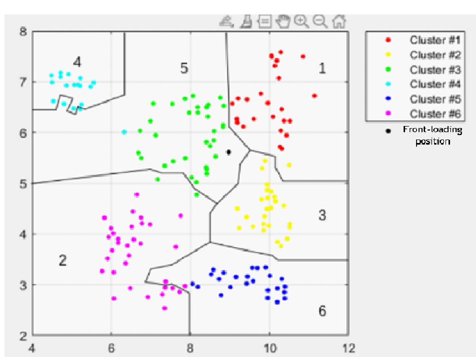

Figure 7 (3) Dynamic adjustment of order 190

6.3.2. Fixed distribution areas that take into account changes in distribution capacity

The change in fulfillment capacity represents the addition of third-party fulfillment, which is Model 2. The following shows how to add a third-party distribution without considering dynamic adjustments when the total demand is 170 to 200.

In the When order volume is 170, which divided into 6 regions, region 1 has 3 distribution paths; region 2 has 4 distribution paths; region 3 has 3 distribution paths; region 4 has 2 distribution paths, demand points 8, 9, 14, 15 by the third-party distribution; region 5 has 4 distribution paths; region 6 has 3 distribution paths; the total cost of distribution is: 870.4502.

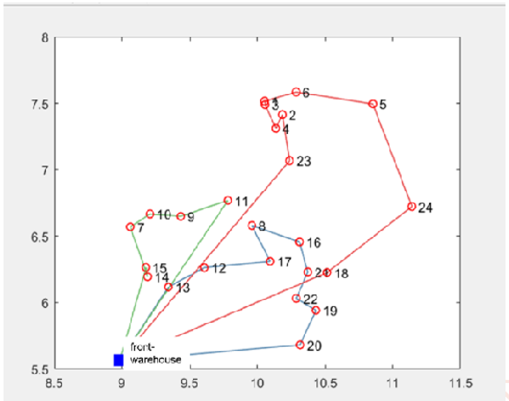

Figure 6 (1) static areas of 170

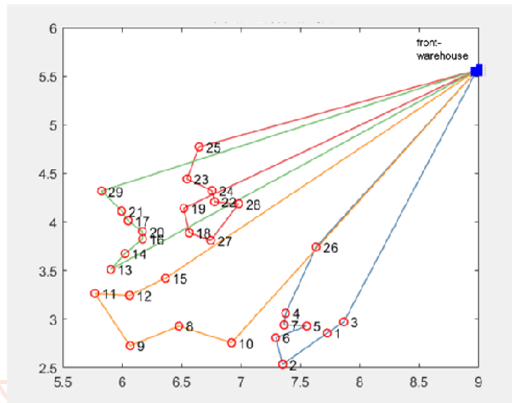

Figure 6 (1) static areas of 170

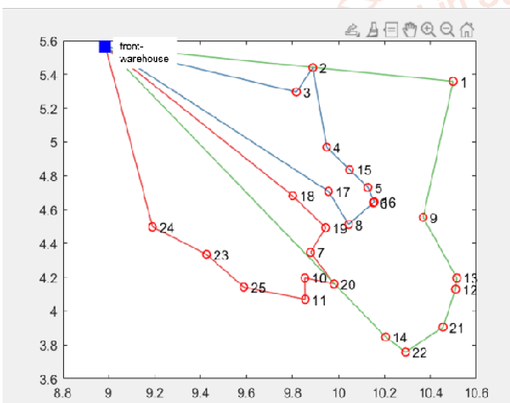

Figure 6 (3) static areas of 170

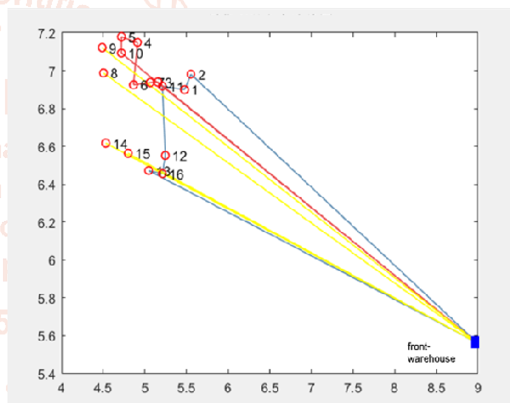

Figure 6 (4) static areas of 170

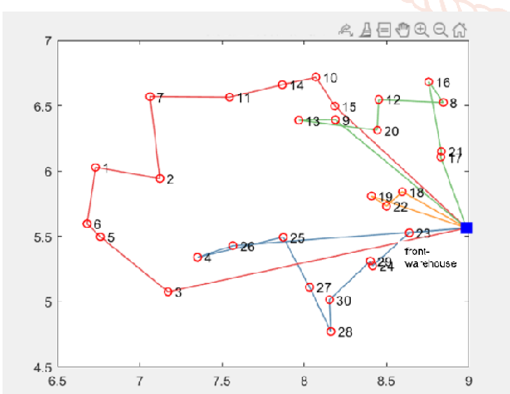

Figure 6 (5) static areas of 170

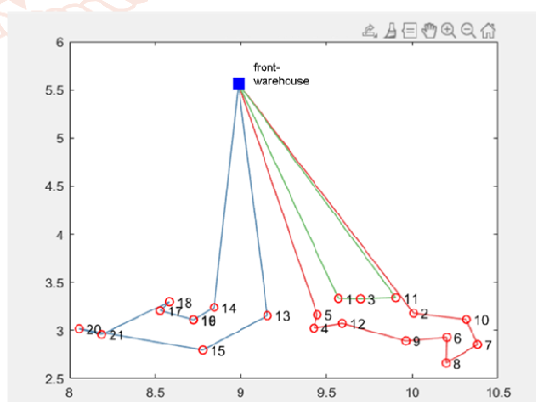

Figure 6 (6) static areas of 170

Similarly, the clustering results for order volume 180 are discussed. It is divided into 6 zones, and the number of delivery routes in each zone is 3, 4, 3, 2, 4, 3. and enable 2 third-party fulfillments. Table 7 shows the results for the initial regional distribution with a total demand of 180. When the local regional delivery capacity is lower than the local demand, the third-party delivery is directly added. Its total cost is 926.7906. In Table 7.

Table 7 The result of initial regional distribution of the total demand of 180

Delivery zones of 180	routes	Point of Demand	Third-Party delivery point
Zone_1 the specific route	route1	0->13->12->17->16->18->21->22->19->20->0	0
	route2	0->1->3->6->25->2->4->23->5->24->0	
	route3	0->8->11->9->10->7->15->14->0	
Zone_2 the specific route	route1	0->26->4->7->6->2->5->1->3->0	13
	route2	0->30->17->21->29->23->24->22->28->0	
	route3	0->19->18->27->31->20->16->14->25->0	
	route4	0->15->12->11->9->8->10->0	
Zone_3the specific route	route1	0->18->17->6->16->5->15->4->3->2->0	0
	route2	0->8->19->7->10->20->11->25->23->24->0	
	route3	0->26->22->14->21->12->13->9->1->0	
Zone_4 the specific route	route1	0->2->1->11->3->12->16->13->0	8/9/14/15
	route2	0->17->7->6->5->10->4->0	
Zone_5 the specific route	route1	0->23->22->19->18->21->17->8->16->0	0
	route2	0->12->31->20->9->15->13->11->14->10->0	
	route3	0->7->32->2->1->33->6->5->3->4->26->0	
	route4	0->25->27->30->28->24->29->0	

When the order volume is 190, it is divided into 6 regions, and the number of distribution routes in each region is 3, 4, 3, 2, 4, 3, and 3 third-party deliveries are enabled, and the total distribution cost is 988.4487. The results show that even with good initial clustering results, once the order volume increases, there will always be a local distribution area where the demand exceeds the distribution capacity of that area. If the dynamic adjustment of the region is not carried out, it will inevitably lead to overtime or third-party distribution, which will cause the total distribution cost to increase. In .

Table 8 The result of initial regional distribution of the total demand of 190

Delivery zones of 190	routes	Point of Demand	Third-Party delivery
Zone_1 the specific route	route1	0->13->17->16->18->21->22->19->26->20->0	-
	route2	0->24->5->25->6->2->1->3->4->23->0	
	route3	0->8->11->9->10->7->15->14->12->0	
Zone_2 the specific route	route1	0->28->22->24->23->30->17->21->29->0	11/25
	route2	0->20->16->33->15->18->31->27->32->0	
	route3	0->26->4->7->6->2->5->1->3->0	
	route4	0->10->8->9->12->13->14->19->0	
Zone_3 the specific route	route1	0->3->2->4->27->15->16->6->5->17->0	1
	route2	0->8->19->7->10->11->25->23->26->24->0	
	route3	0->18->20->14->22->21->12->13->9->0	
Zone_4 the specific route	route1	0->2->1->11->3->7->17->0	8/9/5/10/14
	route2	0->4->6->15->13->16->12->0	
Zone_5 the specific route	route1	0->25->23->24->22->27->18->31->33->32->0	9/11
	route2	0->26->4->7->6->2->5->1->3->0	
	route3	0->10->8->15->12->13->14->0	
	route4	0->16->20->17->21->29->30->19->28->0	
Zone_6 the specific route	route1	0->19->16->14->18->17->21->20->15->23->0	-
	route2	0->9->22->8->24->7->25->6->10->2->0	
	route3	0->11->3->1->12->5->4->13->0	

When the order volume is 200, it is divided into 6 regions, and the number of delivery lines in each region is3, 4, 3, 2, 4, and 3 in order, and 4 third-party deliveries are enabled, and the total delivery cost is 1047.0443. In .

Table 9 The result of initial regional distribution of the total demand of 200

Delivery zones of 200	routes	Point of Demand	Third-Party delivery
Zone_1 the specific route	route1	0->13->8->11->27->9->10->7->15->14->0	-
	route2	0->26->20->19->22->21->18->16->17->12->0	
	route3	0->23->4->2->1->3->6->25->5->24->0	
Zone_2 the specific route	route1	0->32->35->34->23->25->24->22->28->0	8/9/1
	route2	0->27->18->31->17->30->21->29->19->0	
	route3	0->3->5->7->4->6->2->10->26->0	
	route4	0->33->15->12->11->13->14->20->16->0	
Zone_3 the specific route	route1	0->28->3->2->1->6->16->5->15->27->0	9
	route2	0->4->13->12->21->14->22->20->10->11->24->0	
	route3	0->23->26->25->7->19->8->17->18->0	
Zone_4 the specific route	route1	0->2->1->11->3->7->17->18->0	8/9/13/14/15
	route2	0->16->12->6->5->10->4->0	
Zone_5 the specific route	route1	0->36->30->27->37->38->28->34->24->29->0	25/33
	route2	0->23->20->31->12->16->8->21->17->35->0	
	route3	0->18->22->19->9->15->13->14->10->0	
	route4	0->11->7->32->1->2->6->5->3->4->26->0	
Zone_6 the specific route	route1	0->27->2->11->3->1->5->12->4->13->0	-
	route2	0->23->15->19->16->14->17->18->21->20->0	
	route3	0->9->26->22->8->24->7->25->6->10->0	

Conclusions and prospects

Table 10 Comparative analysis of the results

Number of orders Distribution routes	170		180		190		200	
	third-party delivery	Dynamic adjustment without third-party distribution	third-party delivery	Dynamic adjustment without third-party distribution	third-party delivery	Dynamic adjustment without third-party distribution	third-party delivery	Dynamic adjustment without third-party distribution
Region 1	3	3	3	3	3	6	3	3
Region 2	4	4	4	4	4	2	4	4
Region 3	3	3	3	3	3	11	3	3
Region 4	2	4	2	6	2	-	2	2
Region 5	4	3	4	3	4	-	4	4
Region 6	3	-	3	-	3	-	3	3
Demand Points for Third Party Distribution	8, 9, 14, 15;	-	8, 9, 14, 15; 13;	-	11, 25; 1; 5, 8, 9, 10, 14; 9, 11;	-	1, 8, 9; 9; 8, 9, 13, 14, 15; 25, 33;	24; 7, 9, 10; 25; 1; 29, 30; 15
TDC	870.4502	806.4407	926.7906	862.0843	988.4487	914.676	1047.0443	1045.1805

In. This paper illustrates the dynamic adjustment relationship between the delivery agent and the delivery area. Table 4, when the order quantity is 170, 180, and 190. A semicolon indicates that third-party distribution is not used directly at the initial time. Instead, dynamic adjustment is performed on the initial distribution road area, indicating that dynamic adjustment avoids enabling third-party distribution. It can be concluded that dynamic adjustment reduces the total distribution cost by roughly 7% compared to local direct third-party delivery. When the order exceeds 200, the total demand exceeds the total distribution capacity, and the total demand cannot be met by inter-area adjustment; at this time, a third party is added to the distribution, and dynamic adjustment at this time reduces the total distribution cost by 2 per cent compared with no adjustment. Dynamically adjusted total distribution costs are lower when total distribution capacity is not saturated for the same amount of demand. When the total distribution capacity is saturated, enabling a third party and dynamically adjusting the third party's distribution area also reduces the total distribution cost compared to no adjustment. In conclusion, the dynamic adjustment model can significantly reduce the total distribution cost by using regional consolidation when the overall distribution capacity is surplus and the local distribution capacity is less than the demand. When the overall distribution capacity is insufficient, enabling a third party and adjusting the overall region can also reduce the cost to a certain extent. In this paper, we simulate a front-warehouse distribution system and verify that the total distribution cost can be optimized in the dynamic case.

During the study, it is assumed that some demand points are fixed, and the initial distribution area is divided. Then change the order quantity for each demand point. In fact, the emergence of demand points is random. In the empirical analysis part, due to the relationship with customer information, it is difficult to obtain some demand point data, and the coordinates of the demand point and the number of orders at the point can only be randomly generated in the corresponding area.

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