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Research on Multi-product Order Splitting and Distribution Route Optimization Of "Multi-warehouse in One Place"

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Abstract: In recent years, large online supermarkets have become a new trend in the development of e-commerce. Due to the limited storage capacity of a single warehouse, many large online supermarkets, such as Jingdong and Tmall, often adopt the warehouse layout of "one place and multiple warehouses" to quickly respond to customer needs, and the sorting and distribution tasks of orders are completed by the warehouse. At the same time, due to the change of people's lifestyle, customer demand presents the characteristics of "one order with multiple products" and "one order with multiple quantities", which makes the split fulfillment of orders become a common phenomenon. In this paper, under the condition that the warehouse is not out of stock in the layout of one place and many warehouses, aiming at the split execution problem of multi-category orders, the split order method is based on the combination of "minimum split order rate" and "principle of proximity". An order splitting optimization model considering both category and quantity splitting is established, and a set of initial order batch splitting schemes is formed to achieve the first optimization of multi-category order splitting. Secondly, the PLBH-LNS method is used to generate a better initial distribution scheme considering the customer preset time window limit and vehicle-mounted capacity constraint. Finally, with the goal of minimizing the total order performance cost, the solution idea of two-stage method is used for reference, based on the initial order splitting scheme and distribution scheme, the improved two-stage genetic algorithm is used to generate the optimal order allocation scheme and distribution scheme from the alternative schemes, and the global optimization of the splitting and distribution process is realized. The experimental results show that compared with the order splitting strategy using simple rules in practice, the PLBH-LNS method can reduce the average order splitting cost by 12.48%, which provides a new idea and effective auxiliary decision support for the order splitting problem of large online supermarkets.

Keywords: Multiple positions in one place, Multi-product orders, Order splitting, Path optimization.

1. Introduction

With the rapid development of the Internet, online orders have occupied the vast majority of the market share of omni-channel orders, and the warehouse network layout mode of large online supermarkets "one place and multiple warehouses" and the order characteristics of customer orders "one order and multiple products",[1] make the problem of order splitting in actual operation inevitable. Often the single warehouse can not meet the reality of many order categories or a large number of orders, and multiple distribution centers are required to meet, resulting in multi-warehouse distribution problems, when customers purchase multiple categories or a large number of goods on the order, and different goods on the same order are stored in different warehouses, they face the problem of unpacking.[2] When logistics enterprises encounter the problem of unpacking, the logistics enterprise platform often performs multi-warehouse distribution according to a certain unpacking principle, which can greatly reduce distribution costs and improve customer service experience. If the order opening principle selected is unreasonable, it will face multiple warehouse pickup, multiple delivery, and multiple pickups, resulting in duplicate delivery paths and frequent customer pickups, which will seriously affect the customer service experience. Through research and combing the literature, it is found that most logistics companies use the principle of "shortest distance" when dealing with the problem of unpacking, which will increase the number of delivery vehicles, duplicate delivery routes, and packages can not all be delivered to customers on time, resulting in time window default costs, resulting in increased distribution costs, in this layout, how to split orders and select the appropriate warehouse for distribution, and design the corresponding distribution route, for the e-commerce express industry to reduce transportation costs and improve profits is of great significance.

2. Mathematical Modeling

2.1. Problem Description

The characteristics of multi-product order splitting and distribution optimization problems considered in this paper can be summarized as follows: under the "one place and multiple warehouses" storage mode, users place orders on the platform to form orders, all orders are accumulated orders in the same city generated by customers the previous day, and each order can be split into thousands of sub-packages and distributed to multiple warehouses. The platform assigns orders to warehouses for commodity picking according to certain rules, and finally each warehouse forms its own distribution route, which is delivered by several trucks of the same type in the warehouse, and the orders required by customers are delivered in the corresponding time window during the working hours of the trucks. It is known that the corresponding order distribution tasks of each warehouse corresponding to the batch splitting scheme of multi-category orders contain multiple warehouses and multiple customers, which is a many-to-many distribution problem, so in order to reduce the cost of order distribution, this paper jointly optimizes order splitting and distribution based on the order time constraint of the distribution link for multi-category orders. Customer orders will be fulfilled by multiple warehouses based on the storage of each warehouse. According to the batch split scheme collection of multi-category orders, determine the distribution tasks of each warehouse under each plan.[3]

The problem can be described as: it is known that a company has built M warehouses in a certain place to provide delivery services for orders in the region, warehouse M has mK delivery vehicles, warehouse location and quantity, working hours, number of vehicles, maximum load, and acceptable service time window for each customer, order quantity, category, weight and volume are known. The number of delivery vehicles in each warehouse can meet its order distribution needs, each distribution vehicle model is unified and has a rated load constraint, and the actual load of each delivery vehicle in order distribution shall not exceed the rated load of the vehicle; It is required that in the distribution network, based on the combination of the principle of minimum order splitting and the principle of minimum distance, the limit of vehicle loading is a constraint; Each order has a preset time window, try to provide delivery within the service time window specified by the customer, and be punished earlier or later than the delivery time window, resulting in penalty costs, and the customer enjoys door-to-door delivery service. When splitting orders, assigning orders to vehicles and planning subsequent delivery routes, it is necessary to consider the time window, vehicle volume constraints, and the quantity and category of goods, and under the premise of meeting the constraints and customer requirements for service time, an effective distribution route scheme should be formulated to reduce the number of delivery vehicles, delivery times, and customer pick-up times, so as to effectively reduce the total cost of distribution and improve customer service experience..

Therefore, the main problem to be solved in this paper is to find the optimal order batching scheme, which integrates the problem of vehicle routing arrangement, and aims to minimize the total cost composed of the time window penalty cost and distance cost, so as to realize the joint optimization of the multi-product order splitting and multi-warehouse collaborative distribution problem of online supermarket. For example, if a customer order A within the delivery range of the first distribution point purchases five products with product numbers 001, 003, 005, 012, and 015, of which goods 001 and 003 are stored in warehouses 1 and 3, product 005 is only stored in warehouse 1, product 012 is stored in warehouse 2 and 3, and product 015 is only stored in warehouse 2. It is easy to see that the use of warehouse 1, 2 or warehouse 1, 2, 3 can be used in combination to meet the demand for orders. And the former is obviously more efficient. When the number of warehouses and orders is relatively large, the selection of the optimal warehouse combination needs to comprehensively consider the split strategy of orders and the actual distribution situation.

In response to this problem, this article makes the following assumptions:

(1) The vehicle drives away from the warehouse, completes the task and returns to the warehouse, and the capacity is large enough; The opening hours of the warehouse are the service hours of the vehicle;

(2) Enterprises adopt the "one place multi-warehouse" storage model, a single warehouse cannot store all commodity SKUs, but all warehouses contain all commodity SKUs [10], which is consistent with the actual warehouse storage mode setting of JD.com;

(3) Each warehouse cannot store all types of goods, and the categories and quantities of goods stored in each warehouse are partially independent and overlapping.

(4) Each order contains one to more commodity categories, multi-category orders are splittable, and the demand for each commodity in each order is large, and the quantity can be split; Single-category orders do not need to be split, and only multi-category customer orders are considered

(5) Each warehouse operates independently and has order fulfillment functions such as order picking, packing, and distribution, and if the goods ordered in the order are in stock in a warehouse, the order can be assigned to the warehouse for fulfillment processing [4];

(6) The immediate replenishment strategy is not considered, and only the inventory situation of each warehouse at that time is considered in a period of time [14]. Because in practice, the number of orders arriving between replenishment operations is already large, and there is sufficient time and opportunity to optimize order processing; After the order is determined in batches, no new orders are inserted, that is, urgent orders are not taken into account;

(7) Each order can be split into multiple sub-orders, and the commodity category and quantity are used as small splitting units; Orders are batched according to the order batch, and the total demand for batch orders in the batch does not exceed the total inventory of the warehouse in the region.

(8) The quantity and location of the warehouse are known, the categories contained in the warehouse are known, the location of each customer point is known, and the information such as the goods, quantity, geographical location and time window on the order is known;

(9) The model of the distribution vehicle in each warehouse is unified, the number of vehicles in each warehouse can meet the distribution task, and the basic attributes of the vehicle are the same (rated load, driving speed, maximum driving distance, etc.); The actual loading capacity of each vehicle is only based on the weight of the package loaded, regardless of the package volume

(10) The order delivery time only considers the vehicle driving and waiting time, and does not consider the order preparation, packing and unloading time;

In order delivery, the vehicle always maintains a constant speed during driving, regardless of the impact of road conditions and other factors on order delivery.

$$c_2 = a_2 + b_2. \quad (1)$$

2.2. Symbol description

$I_m = \{1,2 \cdots, k, \cdots, K_m\}m$ Represents that the warehouse has a distribution vehicle, represents the collection of distribution K_m vehicles in the warehouse, I_m represents the serial number of distribution m vehicles in the warehouse;

π_2 :Transportation cost per vehicle mile;

π_3 :Single vehicle start-up cost;;

Q: The rated load of the vehicle;;
v : Vehicle speed;
α: Commodity weight coefficient (provided that the unit weight of each commodity is the same;
β_1: Penalty cost coefficient of vehicle arrival time earlier than time window;
β_2: Penalty cost coefficient of vehicle arrival time later than time window;;
d_{ij} : The distance between the order (customer i) and the order (customer j),$d_{ij} = d_{ji}$;
P_m^{ih} : The warehouse m gives the order i (customer) the quantity of $h$goods delivered;
T_i^{mk} : If the vehicle k,departs from the warehouse m, the moment of arrival of the order (customer);
Tt: Delivery service time of orders (customers) (set up to be consistent with the delivery service time of each customer);
t_i^{mk}:In case of departing vehicles K from the warehouse m , the waiting time for the order (customer).i
$[ET_i, LT_i]$:Order (customer)i time window, ET_iwhich is the earliest arrival time and the latest arrival timeET_i;
y_i^{mk}: Variable, if the vehicle k departing from the warehouse m is delivered to the order (customer)i , the value is 1, otherwise the value is 0;
x_{ij}^{mk}: variable, if the vehicle k departing from the warehouse m is delivered from the order (customer)i to the order (customer)j, the value is 1, otherwise the value is 0;
Q:Maximum cargo capacity of the vehicle;;
Zijm:the loading volume of the vehicle n from customer I point to customer j point;;
L:the maximum distance traveled by the vehicle;;
d_{ij} :The distance between customer i and customer J, i∈v,j ∈v, $d_{ii}=\infty$
x_{ijk} :If vehicle kgoes from customer i to customer j,then w_{ijk} =1, otherwise w_{ijk} =0 x=d_{ij}
Fcn: Vehicle fixed costs
Cn: The cost per kilometer traveled by the vehicle n, which is the variable cost;
F:Unit transportation costs for e vehicles
E: vehicle start-up fee
W: Vehicle transportation costs
Z: Total cost of delivery

capsulated PostScript (EPS), or Tagged Image File Format (TIFF), sizes them, and adjusts the resolution settings. If you created your source files in one of the following you will be able to submit the graphics without converting to a PS, EPS, or TIFF file: Microsoft Word, Microsoft PowerPoint, Microsoft Excel, or Portable Document Format (PDF).

Figure 1. Google Scholar

2.3. Model Building

The essence of multi-category order splitting is to split a single order into multiple sub-orders according to the category and quantity of goods, that is, multiple packages are handed over to multi-warehouse joint distribution, so as to meet the demand of orders, and finally realize that the same order is delivered to customers through multiple parcels through multiple delivery, and the order splitting leads to an increase in the number of order delivery tasks, which increases the delivery cost of the enterprise and increases the waiting time of the customer. This article splits a single order into multiple sub-orders, that is, multiple packages, according to the category and quantity of goods, and studies the splitting problem of a single multi-product order with the goal of minimizing order fulfillment. As the first link of order fulfillment, the quality of the order splitting process affects the subsequent processes, including picking, packing, distribution and other major order fulfillment operations. The order fulfillment cost under the order splitting decision mainly includes: picking cost, packaging cost, and distribution cost [4]. The previous assumption is that SKUs and warehouse storage specifications are similar, and the internal facilities of the warehouse are the same, so regardless of the picker proficiency, the picking cost is the same regardless of which warehouse the order is assigned to and in which warehouse the picking is completed. Therefore, the order fulfillment costs in this section only consider packaging costs and shipping costs. The packaging cost is related to the number of unfolds and can be expressed as

$$C^{pack} = \sum_{j=1}^{J} \sum_{k=1}^{K} C_1^{pack} y_{jk}$$

This article does not consider the specific situation of the parcel passing through the distribution station, assuming that the parcel is delivered directly to the customer from the warehouse. Each departure has a fixed start-up cost for transportation C_2^{fxed} and distance-related variable costs $C_2^{rariable}$,Therefore, the fulfillment cost can be expressed as:$C^{ship} = \sum_{k=1}^{K} \sum_{j=1}^{J} \left(C_2^{fixd} + C_2^{variable} di_{kj}\right) y_{jk}$

The integer programming model for this problem is described as follows:

$$\min FC = \sum_{j=1}^{J} \sum_{k=1}^{K} C_1^{pac} y_{jk} + \sum_{k=1}^{K} \sum_{j=1}^{J} \left(C_2^{fred} + C_2^{ararabl} dis_{kj}\right) y_{jk} \quad (1)$$

$$1 \le \sum_{k=1}^{K} y_{jk} \le M, \forall j \quad (2)$$

$$\sum_{j=1}^{J} x_{ijk} \le S_{ki}, \forall i, k \quad (3)$$

$$\sum_{k=1}^{K} x_{ijk} \ge D_{ji}, \forall i, j \quad (4)$$

$$x_{ijk} \le y_{jk} D_{ji}, \forall i, j, k \quad (5)$$

$$x_{ijk} \in N^+, \forall i, j, k \quad (6)$$

$$y_{jk} \in \{0,1\}, \forall i, j, k \quad (7)$$

The objective function (1) represents minimizing order fulfillment costs FC; Constraint (2) indicates the order opening constraint, that is, the customer order j is fulfilled by at least one warehouse and at most by M warehouses; Constraint (3) indicates a supply constraint, that is, the demand for SKUi in each warehouse k is less than or equal to its inventory at that time; Constraint (4) indicates a demand constraint, that is, it ensures that the demand for each SKUi in order j can be satisfied; Constraint (5) indicates a conditional constraint, that is, if and only if there is transportation from warehouse k to order j, goods can be shipped from warehouse k to meet the demand for SKUi in order j jiD; Constraints (6) and (7) represent the value range of the decision variable. The above order splitting optimization problem belongs to the NP-difficult problem, and its optimal solution cannot be solved quickly in polynomial time. In order to overcome the problem that the order splitting and fulfillment optimization decision solution space is huge and the timeliness of the split decision is high, and the approximate optimal solution can be obtained in a short time, it is necessary to construct a fast heuristic search algorithm based on the characteristics of the problem to efficiently find the optimal order splitting scheme

Multi-category order distribution mainly includes two aspects: one is to assign orders to delivery vehicles, determine the delivery tasks and task volume of each vehicle; The second is to plan a reasonable distribution path for the vehicle according to the tasks assigned by the delivery vehicle. Based on the collection of multi-category order batch splitting schemes obtained after the first split optimization of multi-category orders, this paper optimizes the multi-category order distribution problem, which can be classified as the optimal scheduling problem of delivery vehicles from multi-distribution center to multi-order, while considering the rated load limit of the vehicle and the delivery time window, and constructs a multi-category order distribution optimization model with the goal of minimizing the order delivery cost, and the order distribution cost includes three parts: vehicle start-up cost, transportation cost and time window penalty cost, and its model is established as follows:

(1) Vehicle start-up cost

The start-up cost of each vehicle refers to the fixed cost that needs to be paid once it is used, regardless of the length of the vehicle delivery route or the travel time, and the starting cost of the vehicle in the order distribution is only related to the number of vehicles participating in the delivery task. The vehicle start-up cost expression is as follows: $C_1 = \pi_3 \sum_{m\in\Delta} \sum_{k\in I_m} \sum_{i\in O} y_i^{mk}$

(2) Vehicle transportation costs

The transportation cost of each vehicle refers to the cost incurred during transportation, which is generally positively correlated with the length of the vehicle without considering the influence of road conditions and other factors. The cost of vehicle transportation during the order fulfillment process is the transportation cost of all vehicles involved in the delivery task. The vehicle transportation cost expression is as follows:

$$C_2 = \pi_2 \sum_{m\in\Delta} \sum_{k\in I_m} \sum_{i\in O} \sum_{j\in O, i\neq j} d_{ij} x_{ij}^{mk} \qquad (8)$$

(3) Time window penalty costs

For orders with a set delivery window, enterprises need to deliver orders to customers within the time window, and if the delivery cannot be achieved within the time window, it will affect the customer's delivery service experience and incur additional costs. Time windows are generally divided into hard time windows and soft time windows, this article considers the order delivery in the case of soft time windows, and stipulates that when the actual delivery time is not within the time window set by the customer, that is, the actual delivery time is earlier than or later than the delivery time window, the enterprise will be punished in the form of adding penalty costs. For customers, the delivery time is earlier or later than the time window will have an impact on their satisfaction, but generally early delivery has a relatively small impact on customers than late delivery, so set . The time window penalty cost expression is as follows:

$$C_3 = \sum_{m\in\Delta k\in I_m i\in O} \sum_{O} \left(\beta_1 \times \max\left[0, \left(ET_i - T_i^{mk}\right)\right] + \beta_2 \times \max\left[\left(T_i^{mk} - LT_i\right), 0\right]\right) \qquad (9)$$

Based on the above analysis, the order delivery model is established as follows

$$\min C = C_1 + C_2 + C_3$$

$$\min C = \sum_{m\in\Delta k\in I_m i\in O} \sum_{i} y_i^{mk} + \sum_{m\in\Delta k\in I_m i\in O} \sum_{j\in O, i\neq j} d_{ij} m_{ij}^{mk} + \sum_{m\in\Delta k\in I_m i\in O} \left(\begin{matrix} \beta_1 \times \max\left[0, \left(ET_i - T_i^{mk}\right)\right] + \\ \beta_2 \times \max\left[T_i^{mk} - LT_i\right), 0 \end{matrix}\right]\right) \qquad (10)$$

The constraints are as follows:

$$\sum_{m\in\Delta k\in I_m} y_i^{mk} \geq 1, \forall i \in O \qquad (11)$$

The constrained formula (11)means that the same order (customer) can be delivered by multiple vehicles, that is, receive multiple delivery services.

$$\sum_{i\in O} y_i^{mk} \leq 1, \forall m \in \Delta; \forall k \in I_m \qquad (12)$$

The constrained formula (12) means that the same vehicle can access the same customer point at most once, avoiding invalid paths.

$$\sum_{k\in I_m} \sum_{i\in O} \sum_{j\in O, i\neq j} x_{ij}^{mk} \leq K_m, \forall m \in \Delta \qquad (13)$$

means that the same vehicle can access the same customer point at most once, avoiding invalid paths

$$\alpha \sum_{i\in O} \sum_{k\in C} y_i^{mk} P_m^{ik} \leq Q, \forall m \in \Delta; \forall k \in I_m \qquad (14)$$

Constrained means that the number of vehicles actually performing distribution tasks in each warehouse does not exceed the number of vehicles owned by the warehouse.

$$t_i^{mk} \begin{cases} ET_i - T_{mk}^i, T_{mk}^i < ET_i \\ 0, T_{mk}^i > ET_i \end{cases}, \forall i \in O; \forall m \in \Delta; \forall k \in I_m (15)$$

indicates the vehicle departing from the warehouse, the waiting time in the order (customer),

$$T_j^{mk} = T_i^{mk} + t_i^{mk} + tt, \forall i, j \in O; \forall k \in I_m; \forall m \in \Delta \qquad (16)$$

Represents the moment when the vehicle departing from the warehouse arrives at the order (customer), which is equal to the cumulative sum of the moment the vehicle arrives at the previous order (customer) and the vehicle's service time and waiting time on the order (customer).

2.4. Algorithm designt

Next, in response to this paper, it is proposed that the traditional genetic algorithm will be improved by combining the two-side exchange algorithm, and the following is the specific operation process:

First, the first stage, under the principle of minimum order splitting, solve the problem of order vehicle allocation, determine which distribution center each vehicle departs from, which goods of which orders are transported and their quantity, that is, determine the number of vehicles, the number of distribution centers, the order number, the product type and its quantity.

(1) Encode and decode

The chromosome adopts the natural number coding method, and its structure is: virtual distribution center code + (actual departure distribution center code) + vehicle code + order code + product type situation + actual returned distribution center code + virtual distribution center code. Among them, 0 represents the virtual distribution center code, 1,2,...,M represents the actual distribution center code, 1,2,...,K represents the vehicle code, and the order number and product type are coded in a combination way, that is, the order code + "[]" + the quantity of each product shipped, 0, 1,...,N represents the order code, and the quantity of each order product is connected with &.

(2) Population initialization

All order numbers and vehicle numbers are encoded, which are natural numbers, generated by random method, and the order codes are randomly arranged, so the initial population is a randomly generated chromosome coding string, and the scale is not too large or too small.

(3) Select Actions

The basic idea is to inherit the better individual selection to the next generation, and the roulette strategy is adopted at this stage, the steps of which are as follows: 1 counts the fitness of chromosome I; chromosomal fitness accumulation, as shown in ;$F = \sum f_i$

To calculate the chromosome selection probability, the formula is shown in$p_i = f_i/F$

Each operation randomly generates a value, according to the size of the chromosomal fitness function value, to determine whether to choose, set a suitable threshold, if , choose to retain, otherwise do not choose retention, that is, the higher the fitness value, the greater the chance of being selected to retain.

(4) Cross operation

Using a partially matched crossover, as shown in Figure 4-3, the crossover operation is performed according to the following steps:

Step1: Randomly select two parent chromosomes R1 and R2;

Step2: Two intersections a and b are randomly selected on the parent chromosomes R1 and R2, and the region between these two points is used as the matching region;

Step3: Cross the two parent chromosome matching regions to obtain offspring chromosomes A1 and B1;

Step4: Conflict detection of daughter chromosomes A1 and B1 yielded two new daughter chromosomes A2 and B2;

Step5: Check whether the daughter chromosomes A2 and B2 meet the minimum order splitting principle and vehicle load constraints, and delete them if they are not; If satisfied, it is retained, generating an order-vehicle allocation feasible set;

Step6: Repeat Step1-Step5 to update the feasible set of order vehicle allocation.

(5) Mutation operationUsing the two-point cross mutation (as shown in Figure 4-4), one chromosome P1 was randomly selected from the feasible set of order vehicle allocation, two mutation points x and y were randomly generated, and the two mutation points were exchanged to form a new chromosome P2, and the chromosome that met the minimum order splitting principle and vehicle loading constraint was preserved, and the feasible set of order vehicle allocation was updated.

Second, in the second stage, solve the route problem, take the feasible set of the result order vehicle allocation obtained in the first stage as the initial solution input of the second stage of route optimization, consider the time window and loading capacity constraints, carry out the distribution route planning, and achieve the goal of the smallest total distribution cost on the basis of the first stage, so as to obtain the optimal solution of the distribution route planning.

2.5. Case analysist

According to the model and algorithm designed in this paper, the traditional order fulfillment strategy and the globally optimized order splitting and distribution scheme are compared and analyzed. Since the problem studied in this paper is raised in a real-world scenario, this paper applies the aforementioned model and improved algorithm to the verification of actual distribution data. Therefore, in this chapter, we use Company Y as a real-world example. Company Y was founded in 2015, is a comprehensive e-commerce company, known to use the "one place multi-warehouse" storage type, the enterprise sells 5 categories of goods, recorded as SP1, SP2, SP3, SP4, SP5, Y company due to the lack of experience in warehousing, logistics, often appear long order fulfillment, high logistics distribution costs and other related problems. In order to improve the timeliness of order response, increase the robustness of warehouse distribution and the efficiency of coordination, Company Y has formulated a logistics service improvement strategy internally, including the distribution of orders and the distribution of orders.

The company has built a total of 3 warehouses to meet all the order needs in the region, each warehouse is mainly used to provide commodity storage, order picking and distribution services, warehouse number is recorded 1-3, Its latitude and longitude are shown in Table 5.1 below, each warehouse is affected by the consumption level of the region and its building space restrictions and other factors, can not store all types of goods, each warehouse distribution vehicle model is uniform, the actual load of each distribution vehicle shall not exceed the rated load of the vehicle, and the number of vehicles owned can meet the order distribution needs, each warehouse has a fixed delivery time range [08:00-20:00], in order to ensure the effectiveness of order delivery, The delivery time window set by each order is within the limit of the warehouse delivery time range, and on working days, each delivery vehicle departs according to the earliest delivery time of the warehouse according to the planned delivery route and the assigned order, and then delivers the order in turn according to the delivery route and delivery time window. Select the orders that Company Y must deliver to the customer point on a certain day, and conduct a split matching study on the 20% of the orders that need to be opened, and the rest of the orders that are not split are used as the delivery points, and only consider the order delivery problem in the stage of generating the delivery route.

The daily order quantity of the enterprise is huge, the order presents the characteristics of multiple batches, and the demand for the order goods oriented by the enterprise is large, the demand for each commodity in each order can not be met by a single warehouse, so consider the category order and the quantity of the two situations, and considering the complexity of the problem studied in this paper, take the 50 orders received in a batch of the enterprise as the research object, the batch contains both single-category orders and multi-category orders, and the order number is extended on the basis of the warehouse number, and MATLAB is used in this paper The software performs simulation verification on the study.

The basic information of the study is as follows:

(1) Basic information of the warehouse

The basic information of the warehouse mainly includes the location of the warehouse, the number of delivery vehicles and its commodity inventory information, which provides necessary data for subsequent calculation. The warehouse numbers are W1, W2, W3

Warehouse point	Longitude	Latitude
W1	103.45	28.27
W2	105.26	31.04
W3	102.91	29.13

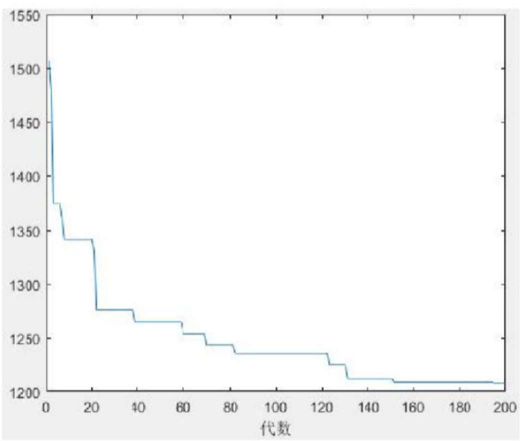
(2) Warehouse and customer distribution

In order to make the warehouse location and the location of each order (customer) and their distribution more intuitively displayed, the distribution of some warehouses and customers is as follows:

The study shown in this article involves a total of 50 orders (customers) and 3 warehouses, and since there are many data values for the distance between warehouses and orders (customers), it will not be shown here, and the actual distance information table of the two is included in the appendix

According to the collection of multi-category order batch splitting schemes obtained after multi-category order splitting, the delivery of multi-category orders is optimized. Based on the multi-category order distribution optimization model, under the delivery time window of each order and the rated load constraint of the vehicle, the improved genetic algorithm simulation and optimization are used to obtain the global optimal multi-category order distribution scheme, as shown in Table 2-2:

		Multi-category order splitting and distribution optimization solutions and results		
Warehouse number	vehicle	Shipping route	Number of packages/ piece	Fulfillment cost/RMB
1	1	1-41-39-31-14-45-49-1	12	721
1	2	1-17-11-24-20-15-5-1	17	569
1	3	1-38-23-10-43-19-30-1	15	684
2	1	2-34-6-49-1245-2	9	588
2	2	2-41-39-31-14-45-49-2	6	615
2	3	2-28-27-21-35-33-2	18	712
3	1	3-41-44-14-52-3	21	693
3	2	3-27-21-24-20-25-37-47-3	29	601
3	3	3-28-6-40-46-8-35-11-3	12	529
total			139	5712



Final result: In the global optimal order splitting scheme, a total of 21 orders are split, and the largest is split into two sub-orders, a total of 84 packages are generated, the order opening rate is 41%, the order opening cost is 15 yuan, the number of delivery vehicles is 11, and the delivery cost of the corresponding order distribution scheme is 5712, with a total cost of 5903 yuan.

The objective function in this paper minimizes the total cost of order fulfillment, including the order splitting cost, vehicle start-up cost, vehicle distance travel cost, and penalty cost components for violating the time window. The algorithm converges after 200 iterations, and the algorithm iterative convergence graph is shown in Figure 5-8, and the optimal value of the objective function is 1536 yuan.

In order to verify the effectiveness of this study, the results of multi-category order splitting and order distribution in the traditional order fulfillment process are compared. In the traditional order fulfillment process, the principle of shortest distance is mostly selected, and the orders are split in real time according to the order order, and then the order distribution problem corresponding to the order splitting result is transformed into the order distribution problem of multiple single warehouses to multiple orders, and the distribution optimization is carried out in each warehouse in turn. Therefore, this paper uses the same example to apply the traditional order fulfillment method.

Split scenario	Number of packages	Split rate	Split cost/yuan	Fulfillment costs	The total cost of order fulfillment
Traditional scenarios	92	61%	56	7728	7510
Improvement scenarios	75	47%	29	5094	6831

According to the comparative analysis of simulation results, compared with the traditional method, the solution method proposed in this paper has a certain degree of optimization, for the 50 orders in the study, the number of packages after order splitting is reduced from 76 to 58, and the order opening rate is reduced from 61% to 29%, and the decrease rate is 21%, which effectively reduces the order opening rate and the cost of unpacking. At the same time, the order delivery cost was reduced from 7,621 yuan to 5,183 yuan, an increase of 18.3%, realizing the optimization of order distribution costs; The total cost of order fulfillment decreased by 20.6%, so the method proposed in this article can effectively reduce business costs and increase business revenue while improving the level of distribution services.

2.6. Acknowledgment

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3. Literature References

Order splitting means that retailers split customer orders (one order and multiple products) containing multiple SKUs [2] into multiple sub-orders according to the inventory of goods in multiple warehouses in the same region (multiple warehouses in one place), and assign them to the corresponding warehouses to complete subsequent fulfillment operations including order picking, packaging, and distribution. The calculation scale of the order splitting problem is very large, and the specific number of order splitting schemes mainly depends on the number of combination schemes of suborders that may be generated by each order, which belongs to a complex combinatorial optimization problem [3]. According to the online supermarket customer order fulfillment process, from the beginning of the online customer order to the end of the offline customer receipt, the front-end online order splitting processing is the first link in the subsequent order offline fulfillment process, once the order is split by one or one split will increase the corresponding sorting, packaging and distribution and other operation costs [4-6]. The serious problem of unpacking has brought about the phenomAt present, the issue of order splitting has attracted widespread attention and interest from scholars. The existing research results mainly focus on how to reduce the splitting problem of "one order and multiple products" orders, with the goal of reducing the number of orders or reducing the cost of order fulfillment. On the one hand, some scholars indirectly explore the operation optimization of related links related to order splitting from the perspectives of "prevention before opening orders" and "adjustment after order opening", in order to achiev the goal of reducing the number of split orders. Catalan et al. [8] efirst proposed and proved the problem of allocation storage of SKUs in multiple warehouses with the goal of minimizing the number of split orders in this paper, and proposed several useful heuristic methods to optimize the selection allocation strategy with store 1 as the actual background. Zhu et al. [9] aimed at reducing the number of split orders, established an integer programming model, and designed a fast K-links heuristic clustering algorithm to solve the problem of commodity allocation and placement among multiple warehouses by analyzing the correlation of commodity categories. Li Jianbin et al.[10] aimed at minimizing the order splitting rate, formulated a multi-warehouse SKU allocation strategy, adopted an improved hot-selling product algorithm, and designed a ring algorithm to solve the order splitting problem. Based on the inventory of goods in the given warehouse, some scholars focus on the real-time order allocation of customer orders, and directly explore how to better split and fulfill orders "when split", and reduce the related order fulfillment costs by reducing the number of orders. Xu et al. [11] proposed the first model of online retail order fulfillment, which uses delayed picking and distribution of orders to minimize the number of deliveries, builds a mixed integer programming model, designs a neighborhood search algorithm, and performs order splitting optimization and redistribution. Acimovic et al. [12,13] simultaneously consider multiple delivery time modes for order fulfillment, with the goal of minimizing the sum of the logistics and distribution costs of current orders and predicted orders, optimizing how orders are split and distributing them between warehouses. Torabi et al. [14] make full use of the decision window of online retailers to process orders, comprehensively consider the decisions of order allocation, inventory transfer, and virtual transfer, and establish a mixed integer programming model for order processing. Mahar and Wright[18] propose a dynamic order allocation strategy for the order fulfillment process of dual-channel (online-offline) online retailers by considering expected inventory costs, distribution costs, and customer waiting costs.

The study of order distribution problems can be classified as logistics distribution vehicle optimization scheduling problems [15]. Delivery is an important part of order fulfillment, as well as an important part of physical delivery in customer shopping, which has a direct relationship with customers and occupies a large share in the customer's shopping experience. Based on customer needs, consider the logistics activities carried out by customers for the category, quantity and delivery time of goods. In different order backgrounds, the goals, constraints and parameters set for order delivery are different. Yu Mengqi et al. established a multi-warehouse and multi-warehouse joint distribution model with the lowest delivery cost under the constraint of time window for the delivery of "one single and multiple products" orders in online pharmacies under the classification and storage of drugs[16]. Zeng Qingcheng et al. established a mathematical model with time window constraints and vehicle load for the problem of order delivery in the mixed mode of online catering order booking and real-time ordering, aiming at the lowest delivery cost [17]. Li Min et al. clustered based on order time, space and delivery objects, constructed order neighborhoods as distribution routes to initialize the population, and reasonably planned delivery routes with the lowest delivery cost as the goal [18]. In view of the problem of perishable food distribution, Li Chang et al. comprehensively considered the delivery cost and food freshness, and established a multi-objective distribution model with time window constraint and vehicle load constraint [19] It can be seen from the literature analysis that the order distribution problem mainly considers the delivery time window, vehicle load limit, whether the product has special attributes and other factors, mostly with the minimum cost or the shortest time target, or set up a multi-objective model, should be combined with the specific analysis of the actual problem, to determine the order delivery target, constraints and parameters.

In summary, the existing research on order splitting mostly only considers category and quantity splitting, most of which are carried out from a single delivery distance (shortest distance principle) or order split rate (minimum order splitting rate principle), and the research on order splitting and distribution is mostly transformed into two completely independent stages, ignoring the correlation between the two, resulting in limited order distribution and unable to achieve comprehensive optimization of order splitting and distribution. Based on the existing literature, this paper considers category and quantity splitting, uses the principle of "minimum order opening rate" and "shortest distance", and considers the customer order time window, comprehensively considers the cost of order splitting and distribution links, and realizes the joint optimization of order splitting and distribution links.

4. Conclusion

This paper studies the order splitting and order distribution of self-operated large-scale online supermarket e-commerce platforms with self-built warehouses in China. Combined with the characteristics of large order scale and multiple items of a single order of large online supermarkets, this paper builds a model of multi-product order splitting optimization and distribution problems in view of the problem of order splitting and fulfillment with high order opening rate and global optimization of the distribution process under the layout of "multiple warehouses in one place", aiming at reducing the total order fulfillment cost. The main contributions of this paper are as follows:

1. Based on the characteristics of multi-category orders, with the optimization goal of reducing the number of customer pick-ups and reducing delivery costs, a new order splitting method is adopted - an order splitting method that combines the idea of "minimum unpacking rate" and "shortest delivery distance principle". From the perspective of reducing the amount of enterprise distribution tasks and customer pick-up times, and improving the level of distribution services, combined with the actual demand for orders and the characteristics of the "multi-warehouse in one place" storage mode, a multi-category order splitting optimization model was constructed for a batch of orders in the same batch, and a nonlinear integer programming model was established to characterize the problem of unpacking and distribution by considering the time window and vehicle volume factors of the distribution link.

2. Drawing on the solution idea of the two-stage method, the set coverage problem is used to solve the "minimum decomposition singular" of the first stage, and then the solution result of the first stage is used as the search range generated by the second stage path, and the update strategy is improved, so that the convergence speed of the algorithm is accelerated and a better solution is found.

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