Research on Optimization of Supermarket Chain Distribution Routes Under O2O Model

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Abstract
Dealing with the store distribution problems in transformation and upgrading of supermarket chains under Online-to-Offline (O2O) e-commerce model and considering the factors that affect the distribution cost and customer satisfaction, such as distribution distance, number of distribution vehicles, and delivery time, an O2O store distribution optimization model has been constructed with the purpose of minimizing total distribution cost. Moreover, a two-stage heuristic algorithm for ordering nearest distribution and mileage saving planning has been designed. The applicability and effectiveness of the model and method have been verified by enterprise case data collected. The results have shown that the total cost of distribution is obviously reduced compared with the accounting results of related models, which is suitable for supermarket chains or single-store retail enterprises with low probability of order splitting and distribution due to the shortage of certain products.

Keywords O2O · Chain stores · Optimization model for distribution · Mileage saving method

Introduction
With the rapid development of China’s e-commerce, online shopping has gradually become one of the main shopping methods for consumers. Especially with the “COVID-19 epidemic,” the measures of “home isolation” have further promoted consumers’ recognition of online shopping methods for fresh department stores and accelerated the popularization and application of O2O e-commerce model. The increasingly mature O2O e-commerce model has become the preferred path for traditional retail enterprises to transform and upgrade. The so-called O2O e-commerce model is essentially an operation mode that connects offline real business with online users. The offline real economy can tap and attract consumer traffic online, and consumers can place orders online or experience in physical stores. The development of O2O e-commerce model has brought a new strategic decision direction for the operation upgrade of supermarket chains. With the help of digital technologies such as network information technology, cloud computing, and big data, traditional supermarket chains implement O2O e-commerce mode, build new sales channels, and expand consumer markets. However, if traditional large supermarket chains want to give full play to the advantages of O2O e-commerce mode, they must create a good shopping experience for consumers. According to the investigation of five large supermarket chains implementing O2O e-commerce mode, one of the key factors affecting consumers’ shopping experience is the delivery time of goods. Whether the goods can be delivered within the time expected by consumers depends on two logistics links: sorting and distribution, while the “last mile” instant distribution problem is more difficult to control and optimize. The “last mile” instant delivery problem is a “stuck neck” problem that restricts the rapid development of O2O e-commerce mode. According to the high sensitivity of consumers to the delivery time of goods, the distribution problem of supermarket chains in online to offline can be attributed to VRPTW (Vehicle Routing Problem with Time Windows). For supermarket chains, it can effectively solve the “last mile” instant delivery problem, which can enhance the decision-making effectiveness of traditional retail enterprises in implementing O2O e-commerce mode.
Material and Methods

On the Solution of VRPTW Problem  Clark and Wright proposed Clark-Wright algorithm (C-W cost saving method) in 1964, which was used to solve VRPTW problem. Mester et al. (2007) put forward the multi-parametric evolution strategies algorithm, which is mainly used to solve the vehicle routing problem of VRPTW and CVRP. Yang et al. (2006) improved the simulated annealing algorithm to solve VRPTW problem, and introduced the representation method of solutions arranged directly by customers, which improved the solution efficiency. Meng et al. (2014) proposed the HPBIL algorithm (Hybrid Population-based in Cremental Learning Algorithm) for the VRPTW problem, which can minimize the total driving distance and the number of vehicles at the same time.

Research on Vehicle Routing Problem Under Online to Offline  On the one hand, it studies the distribution of supermarket stores. On the basis of considering the constraints of time window, Yao (2014) analyzed the various costs in the distribution process of fresh products in supermarket chains, establishes a model of minimizing the total distribution cost, and optimizes the distribution vehicle route by using the mileage saving method. In order to minimize the travel time of vehicles in the distribution process, Wu et al. (2015) established an uncertain opportunity constraint model. On the other hand, it is the study of customer (consumer) distribution. According to the characteristics of online to offline (O2O) fresh take-out orders with high dynamics and strong timeliness of distribution services, Li and Chen (2020) established an O2O fresh take-out instant distribution path optimization model with a hard time window. In order to reduce the distribution cost of fresh food distribution enterprises, Wu et al. (2015) the improved NSGA II (Non-Dominated Sorting Genetic Algorithm II) to solve the model. Yao (2014) etc., considering the factors such as commodity types, inventory capacity, and customer returns, put forward the order splitting strategy of splitting only by commodity types rather than quantity, and set up an O2O store distribution optimization model based on order splitting with the goal of minimizing the total distribution cost.

To sum up, there is a lack of research on the optimization of distribution path for large supermarket chains to implement online to offline. Therefore, this paper will mainly focus on the real-time distribution of supermarket chains in online to offline, investigate the logistics operation data of a supermarket chain, and explore the model of real-time distribution path optimization, hoping to provide reference for retail enterprises in implementing O2O e-commerce model.

Construction of Distribution Optimization Model Based on O2O Stores

Problem Description and Hypothesis

Company A, a supermarket chain enterprise, is using the e-commerce platform to implement online to offline and give full play to the advantages of online traffic. After the customer of company A places an order through the e-commerce platform, the system will automatically assign the order to the nearest store according to the customer’s location, and the store will organize personnel to pick and distribute the goods, with the distribution distance of the store being 3–5 km. The main products consumed by customers belong to fresh department stores, and the order quantity is generally small, but there are many varieties, which are usually packaged into several parcels for delivery to customers. Because customers have higher requirements on delivery time, the timely delivery of goods is the key factor to improve online traffic. According to the data collected randomly from a store in A company for 1 month, the customer order cancellation rate is 17.20%, of which 45.23% are rejected or cancelled due to delivery overtime, and the customer order delivery overtime rate is 22.12%. The time for customers to place orders is mainly from 9:00 a.m. to 12:00 p.m. and from 13:00 p.m. to 16:00 p.m. During this time interval, the average number of orders placed by customers per hour is 200, and customers’ demands are random, but there are requirements for delivery time. In view of the uncertainty of customer demand and the limitation of service time window, each delivery vehicle can deliver packages from multiple customers, and the vehicles start from the store and finally return to the store to deliver the next batch of orders. Therefore, it is necessary to arrange the delivery schedule according to the customer’s location, order placing time, and delivery time. Assuming that customer demand obeys random distribution, according to these characteristics, it constitutes a logistics instant distribution routing problem with time windows under random demand.

According to the problem description, the following assumptions are made to facilitate the construction of distribution optimization model.

I. Chain supermarket stores have sufficient inventory, and there is no shortage, resulting in the loss of orders;
II. Each customer’s order product can be packaged into several packages according to the commodity category and standard packaging size;
III. Each delivery vehicle can deliver packages from multiple customers, but it cannot exceed the maximum loading capacity of the vehicle;
IV. Each car must start from the store and return to the store after delivery.

**Model Structure**

Developing an optimization model needs to define the objective functions and constraints (Xu et al. 2021; Zhu et al. 2021; Wang et al. 2021, 2022a, b; Zhang et al. 2022). Therefore, the objective function and constraints of the O2O store distribution optimization model are as follows:

**MinC = \sum_{m \in \Delta} \sum_{i \in I} \sum_{j \in \Gamma} GS_{ij} y_{ij}^m + \sum_{m \in \Delta} \sum_{i \in I} \sum_{j \in \Gamma, j \neq i} FX_{ij}^m y_{ij}^m + \sum_{m \in \Delta} \sum_{i \in I} \sum_{j \in \Gamma, j \neq i} \delta_{ij} x_{ij}^m**

(1)

s.t.

\[ \sum_{i \in I} \sum_{j \in \Gamma} P_{id} y_{id}^m \leq W_{id}, \forall m \in \Delta; \forall d \in D_i \]

(2)

\[ \delta_i = a, T_{ij}^m > T_i; \delta_j = 0, T_{ij}^m \leq T_j, \forall i \in I, \forall m \in \Delta, \forall k \in \Gamma_m \]

(3)

\[ \sum_{i \in I} \sum_{d \in D_i} P_{id} y_{id}^m \leq U, \forall m \in \Delta; \forall k \in \Gamma_m \]

(4)

\[ \sum_{m \in \Delta} \sum_{k \in \Gamma_m} x_{ik}^m = 1, \forall i \in I; \forall d \in D_i \]

(5)

\[ \sum_{m \in \Delta} \sum_{k \in \Gamma_m} D_{ik} y_{ik}^m \leq W_{id}, \forall i \in I, \forall d \in D_i \]

(6)

\[ \sum_{i \in I} \sum_{j \in \Gamma \setminus \{i\}} x_{ij} \leq K_{i}, \forall m \in \Delta; \forall k \in \Gamma_m \]

(7)

\[ \sum_{i \in I} \sum_{j \in \Gamma \setminus \{i\}} x_{ij} \geq 0, \forall m \in \Delta; \forall k \in \Gamma_m \]

(8)

\[ \sum_{j \in \Gamma \setminus \{i\}} x_{ij} \leq \sum_{j \in \Gamma \setminus \{i\}} x_{jm} \leq 1, \forall i \in I; \forall m \in \Delta; \forall k \in \Gamma_m \]

(9)

\[ \sum_{j \in \Gamma \setminus \{i\}} x_{ij} = 1, \forall i \in I; \forall m \in \Delta; \forall k \in \Gamma_m \]

(10)

\[ \sum_{i \in \Gamma \setminus \{j\}} T_{ij} + \frac{1}{T_{ij}} + S_{ij} / V \]

(11)

where \( I = \{1, 2, \cdots, i\} \) set of customers; \( \Delta = \{0, 1, 2, \cdots, m\} \) collection of stores; \( \Gamma_m = \{1, 2, \cdots, k, \cdots, K_m\} \) the store \( m \) distributes a collection of vehicles, in which \( k \) represents the serial number of vehicles and \( K_m \) represents the total number of vehicles dispatched and distributed by store \( m \); \( N = \{1, 2, \cdots, n\} \) collection of distribution lines; \( U \) : maximum distance of vehicle; \( V \) : travel speed of vehicle; \( W_{id} \) : inventory in store \( m \) that meets the number of packages for all customers; \( F \) : fixed cost of one distribution vehicle; \( G \) : driving cost per unit distance of distribution vehicles; \( D_i \) : package number of goods by customer \( i \); \( D_i = \{1, 2, \cdots, d\} \); \( S_{im} \) : the \( m \)th distribution route is the distance from store \( m \) to customer \( i \) and then to store \( m, i \in I; S_{ij}^m \) : distance from store (or customer) \( i \) to store (or customer) \( j \), \( i \in I \cup m \), \( i \neq j \); \( \delta_i \) : customer \( i \)’s time deviation penalty; \( E_{im} \) : order placing time of customer \( i \); \( T_i^m \) : the latest delivery time of customer \( i \); \( T_{ij}^m \) : the residence time of the delivery vehicle \( k \) from the store \( m \) at the customer \( j \); \( x_{ij}^m \) = 0–1 variable, if the vehicle \( k \) departing from the store \( m \) is from customers \( i \) to \( j \), then \( x_{ij}^m \) takes 1, otherwise, it takes 0, \( i \neq j \), \( j \neq i \); \( y_{id}^m \) = 0–1 variable, if the vehicle \( k \) departing from the store \( m \) delivers the parcel \( d \) for the customer \( i \), then \( y_{id}^m \) takes 1, otherwise, it takes 0; \( T_{ij}^m \) : time when the vehicle \( k \) departs from the store \( m \) and arrives at the customer \( j \); \( P_{id}^m \) : The store \( m \) uses the vehicle \( k \) to deliver the package \( d \) to the customer \( i \); and \( C \) : total cost of distribution.

Equation (1) was the objective function which means that the total cost of logistics distribution is the smallest, and the first item is the total cost of distribution vehicles, which is proportional to the distribution distance; item 2 is the fixed total cost of delivery vehicles, which is directly proportional to the number of delivery vehicles, and item 3 is the time penalty cost, which is directly proportional to the number of overtime delivery customers (Yao 2014).

In the constraint equations, Eq. (2) indicates that the store inventory meets the demand of its distribution customers; Eq. (3) indicates that the customer delivery time deviates from the value of penalty fee; Eq. (4) indicates that the number of goods loaded and distributed by each vehicle when starting from the store cannot exceed its loading limit, and its empirical value of vehicle loading is 8 packages; Eq. (5) means that several packages for each customer can only be completed by one store and one delivery vehicle; Eq. (6) indicates that each customer’s order demand must be met; Eq. (7) indicates the restriction on the number of vehicles distributed in stores; Eq. (8) indicates that the vehicle starts from the store and returns to the store after distribution; Eq. (9) indicates that the delivery vehicle cannot go from one store to another; Eq. (10) means that each delivery vehicle departing from the store can deliver to customers at most once; and Eq. (11) represents the time when the delivery vehicle arrives at the customer.
Algorithm Design

The O2O store distribution optimization model based on customer order system allocation is essentially a new extension of the vehicle routing problem with time windows in a specific mode, and it is also a NP-hard problem. From the model (1), it can be made clear that the variables that affect the total cost of logistics distribution are the distribution distance, the number of distribution vehicles, and the delivery time. Firstly, according to the distance between customers and stores, the system distributes orders to corresponding stores according to the principle of proximity, and sets service time windows according to the speed of vehicles to ensure that customer orders can be delivered on time, and at the same time forms a directed graph from stores to customers in the service time windows, which is convenient for path calculation and planning; Then, combined with mileage saving method, the distribution route is optimized, so as to achieve the maximum distribution customers, the shortest distribution trip, and the maximum probability of on-time delivery, thus reducing the fixed cost, transportation cost, and time penalty cost of vehicles.

Design of Undirected Graph from Store to Customer

Customer demand and location are random. Any store has the goods required by a certain customer. After the system receives the order, it only needs to send the order to the corresponding store according to the principle of proximity, and at the same time forms a directed graph from stores to customers in the service time windows, which is convenient for path calculation and planning; Then, combined with mileage saving method, the distribution route is optimized, so as to achieve the maximum distribution customers, the shortest distribution trip, and the maximum probability of on-time delivery, thus reducing the fixed cost, transportation cost, and time penalty cost of vehicles.

Path Optimization Using Mileage Saving Method

Combined with directed graph, the optimal distribution route is found by mileage saving method. The core idea of mileage saving method is to optimize and merge two loops in transportation problem into one loop in turn according to the mileage saving size. After each route optimization and merger, the total transportation distance decreases to the maximum extent, until the loading limit of one vehicle is reached, the next vehicle is optimized, and the best distribution route is gradually found to realize efficient distribution, so as to minimize the distribution time, the shortest distance, and the lowest cost. The specific steps are as follows:

Step 1: Expression of distribution route optimization solution. For node numbers such as stores and customers, P0 represents stores and P1 represents customers, then the distribution route for customers is P0-P1-P0, and the distribution route forms a loop from stores to customers and then back to stores;
Step 2: According to the directed graph from the store to the customer, taking the store as a fixed node, two customer nodes are selected in turn to form a triangular distribution route. According to the principle that the sum of the two sides is greater than the third side, the distribution mileage saved by the two nodes is calculated to form a mileage saving table;
Step 3: Sort according to the saved mileage to form a sorted list of saved mileage;
Step 4: Select two customers with large mileage savings, connect with the store to form a primary distribution line, and then add customers with large mileage savings according to the maximum vehicle load. Until the vehicle load on the distribution line is less than or equal to the maximum vehicle load, but it cannot be overloaded, the first distribution line is solved, and the solution is expressed as P0-P1-P2-P3-0;
Step 5: Solve the 2nd, 3rd, ..., and n distribution routes according to step 4, until all customers are on the distribution routes within the service time window, and then the optimization of the distribution routes is finished, that is, the distribution routes are solved into n distribution routes.

Example Analysis

In view of the model problem studied, the time range of placing orders is set from 10:00 to 10:30, and 150 customer orders are randomly selected from the back-office system of company A for distribution and mileage saving calculation, so that the total cost of logistics distribution can be minimized on the basis of meeting customers’ time demands. According to the statistical analysis of the company’s operation data, the fixed cost of distribution vehicles is 3 CNY/train number, the variable cost is 1.4 CNY/km, the maximum load of vehicles is 8 parcels, the average driving speed is 40 km/h, and the penalty for late arrival is 3.5 CNY per order.
Analysis of Undirected Graph from Store to Customer

According to the principle of proximity, among the 150 customer orders extracted by the system, 12 customer orders are assigned to a certain store, with store coordinates of 120.72123, 28.004919 and user-defined store serial number of P0, i.e., \( m = 0 \). After the order is processed by the information system, the package number, location (latitude and longitude), order placing time, and the set latest delivery time corresponding to each customer’s order number are shown in Table 1. Combined with the data analysis of GPS software, the system forms a directed graph covering 12 customers including P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, and P12 from store P0 (He 2021) as shown in Fig. 1.

At the same time, calculate the shortest travel path distance between nodes, as shown in Table 1.

Calculation Results and Analysis

Calculated by the Method in This Paper

Based on the directed graph analysis from store to customer, the route is optimized by mileage saving method (Fig. 2). The distribution from store P0 to 12 customers, such as P1, P2, P4..., P12, can complete the distribution task within the time window, and can be completed through three distribution routes, that is, the first optimal distribution route is P0-P3-P4-P8-P1-P0. The second optimal distribution route is P0-P12-P6-P11-P7-P0. The optimal distribution

| Customer node | Business order number | Package number | Longitude | Latitude | When the customer placed the order | Latest delivery time of order |
|---------------|-----------------------|----------------|-----------|----------|----------------------------------|-------------------------------|
| P1            | 6,000,207,333,778,580,969 | 1              | 120.694314 | 28.001572 | 10:06:24                        | 11:30:00                      |
| P2            | 6,000,208,585,408,960,969 | 2              | 120.72425  | 28.001054 | 10:06:27                        | 11:30:00                      |
| P3            | 6,000,207,951,816,650,969 | 2              | 120.698593 | 28.005429 | 10:09:29                        | 11:30:00                      |
| P4            | 6,000,207,952,084,330,969 | 2              | 120.702874 | 28.014095 | 10:09:29                        | 11:30:00                      |
| P5            | 6,000,208,406,320,910,969 | 3              | 120.711418 | 28.002773 | 10:17:23                        | 11:30:00                      |
| P6            | 6,000,208,408,640,930,969 | 1              | 120.717967 | 27.986901 | 10:10:28                        | 11:30:00                      |
| P7            | 6,000,208,410,131,000,969 | 2              | 120.725948 | 27.998592 | 10:06:27                        | 11:30:00                      |
| P8            | 6,000,208,406,964,410,969 | 2              | 120.694548 | 28.005544 | 10:06:27                        | 11:30:00                      |
| P9            | 6,000,208,407,048,880,969 | 1              | 120.715534 | 28.004111 | 10:16:31                        | 11:30:00                      |
| P10           | 6,000,208,411,228,880,969 | 3              | 120.719552 | 28.00485  | 10:29:21                        | 11:30:00                      |
| P11           | 6,000,208,414,860,360,969 | 2              | 120.725653 | 27.995724 | 10:29:21                        | 11:30:00                      |
| P12           | 6,000,208,413,018,490,969 | 3              | 120.717154 | 27.996256 | 10:29:21                        | 11:30:00                      |

Fig. 1 Location distribution map of stores and customers
route is P0-P10-P2-P5-P9-P0, then $\delta_i = 0$, there are 3 distribution lines $N$ and 3 vehicles $K$, and the total distribution distance is $S = \sum_{n \in N} S_n = 23.9$ (km) (Table 2). According to the O2O store distribution optimization model, the fixed total cost of distribution is 9 CNY, the distribution cost is 25.30 CNY, and the penalty cost for late arrival is 0, so $\text{MinC} = 34.30 \text{CNY}$.

**Table 2** The shortest driving distance between the store and the customer and the customer

|        | P0  | P1  | P2  | P3  | P4  | P5  | P6  | P7  | P8  | P9  | P10 | P11 | P12 |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| P1     | 3.2 |     |     |     |     |     |     |     |     |     |     |     |     |
| P2     | 0.83| 3.6 |     |     |     |     |     |     |     |     |     |     |     |
| P3     | 2.7 | 0.82| 3.1 |     |     |     |     |     |     |     |     |     |     |
| P4     | 3.9 | 1.5 | 4.1 | 1.3 |     |     |     |     |     |     |     |     |     |
| P5     | 1.4 | 2.2 | 1.5 | 1.7 | 2.7 |     |     |     |     |     |     |     |     |
| P6     | 3.4 | 3.7 | 2.6 | 3.8 | 4.8 | 2.5 |     |     |     |     |     |     |     |
| P7     | 1.4 | 4   | 0.62| 3.5 | 4.6 | 1.9 | 2.2 |     |     |     |     |     |     |
| P8     | 3.5 | 0.97| 3.9 | 1.1 | 1.3 | 2.5 | 4.6 | 4.3 |     |     |     |     |     |
| P9     | 0.97| 2.5 | 1.3 | 2   | 2.9 | 0.72| 2.5 | 1.5 | 2.8 | P9  |     |     |     |
| P10    | 0.39| 3.1 | 0.82| 2.6 | 3.6 | 1.1 | 2.7 | 1.4 | 3.4 | 0.89|     | P10 |     |
| P11    | 2.1 | 3.6 | 1.4 | 3.5 | 4.5 | 1.7 | 1.7 | 0.85| 4.3 | 1.7 | 1.7 |     | P11 |
| P12    | 1.4 | 3.1 | 1.2 | 3.1 | 4.1 | 1.3 | 1.8 | 1.8 | 3.8 | 1.2 | 1.5 | 0.78| P12 |

**Conclusion**

In this paper, we have discussed the joint optimization of order allocation and distribution path of large supermarket chains in online to offline, and built a model around three variables that affects distribution cost: distribution distance, number of distribution vehicles, and delivery time. Sample orders are randomly selected through time window constraints, and the orders are allocated according to the principle of proximity and the set delivery time range. Taking
the order delivery of a certain store as the path optimization object, the route optimization is carried out by using the mileage saving method, saving the delivery mileage by 26.5 km, and the mileage saving rate is 52.58%; According to the constructed O2O store distribution optimization model, the total cost of logistics distribution has decreased by about 67.80% compared with Xin et al. (2020), which shows that the model is feasible and suitable for large supermarket chains or single-store retail enterprises with low probability of order split distribution due to the shortage of certain products. In the algorithm design, the empirical value is adopted to set the delivery service time window. On the one hand, the rationality of setting the time window is not analyzed, and on the other hand, the difference between soft and hard time windows is ignored. In the future, in-depth research will be carried out in these two aspects to improve the applicable scope of the model.

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**Data availability** All data are available from the corresponding author.

**Declarations**

**Conflict of Interest** The author declares no competing interests.

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