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PATH OPTIMIZATION OF FRESH PRODUCTS LOGISTICS DISTRIBUTION UNDER NEW RETAIL MODE

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Abstract. *Fresh products have high requirements for shelf life and preservation, and strict requirements for temperature and storage and transportation equipment, resulting in high cost of fresh cold chain logistics. To solve the distribution path optimization problem with fresh product characteristics and improve customer satisfaction while reducing costs, this work sets up a soft time window in the distribution process to reflect the customer satisfaction under the new retail. Then, a mathematical model for distribution path optimization integrating customer satisfaction loss cost and transportation cost is established under the new retail mode, which was solved by a genetic algorithm. Finally, a real example is given to verify the effectiveness of the distribution route model proposed in this paper.*

Keywords: Fresh products logistics, Customer satisfaction, Path optimization, New retail mode

1. **Introduction.** With the continuous improvement of people's living standards, the variety of fresh food is becoming more and more diversified, and the quality of fresh products is required to be higher, which forces the rapid development of fresh products logistics. Under the new retail mode, the deep integration of "online + offline + logistics" not only accelerates the growth of the online shopping business but also increases the total business volume of logistics, Internet platforms, manufacturers and other industries [1]. At present, there are many problems in the fresh products logistics network under the new retail, such as serious deterioration of fresh products, low circulation rate of fresh food, and high transportation cost.

Based on the above background, according to the characteristics of perishable fresh products and the operation characteristics of centralized distribution in fresh products base, as well as the analysis of the demand characteristics and damage cost of fresh products logistics under new retail, this paper aims at the optimization of fresh products logistics path under the new retail mode, and then constructs the distribution path optimization model which considers maximum customer satisfaction and optimal transportation cost.

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2. **Related Works.**

2.1. **Vehicle routing optimization.** Dantzig and Ramser proposed in 1959 that vehicle routing problem is the core of logistics management [2], which attracted many scholars to study. Among them, Liu et al. established a supplier-managed blood product inventory path optimization problem to optimize the blood product scheduling plan, and found that centralized scheduling is beneficial to the blood supply chain [3]. Yang and Guo discussed the fuzzy uncertainty of consumers' demand for fresh products and returned products under the new retail development mode, and established a fuzzy planning model of fresh products closed-loop logistics network under the new retail mode, aiming at the optimization problems of facility location and transportation path [1]. With the continuous development of e-commerce and the improvement of customer demand, enterprises need to complete the service within the prescribed time window when designing the logistics system, which can effectively improve the service level. To solve this problem, Solomon proposed a vehicle routing optimization problem with time window, and gave a classical example of this problem [4]. Zhang et al. considering the node and arc time window constraints imposed by the retailer and the government, respectively, formulated the vehicle routing plan of the distribution company [5]. Xiao et al. constructed a cold chain low-carbon logistics distribution route optimization model that minimizes the overall total cost by taking vehicle capacity and time window as constraints [6]. Ren et al. built a cold chain vehicle path optimization model with the goal of minimizing carbon emissions based on customer satisfaction [7]. Zhang and Li established a multi-distribution center route optimization model based on customer satisfaction based on time and quality factors [8].

2.2. **Fresh products logistics under new retail mode.** The essence of fresh product logistics under the new retail mode is the optimization and integration of online and offline, and the logistics are the fundamental guarantee to realize the concept of "customer-centered" [9,10]. The deep integration of "online + offline + logistics" has increased the logistics cost of services such as fragmentation, diversification, and fast delivery of logistics. However at the same time, through intelligent logistics, resource information sharing, and efficiency improvement, logistics management costs can be reduced [11]. Under the new retail mode, the logistics of fresh products should not only accelerate the speed, but also reduce inventory and cost, and finally speed up the circulation of goods, so as to achieve the purpose of reducing cost and increasing efficiency, and then improve the shopping experience of consumers.

Data from 2018 showed that the decay rate of China's cold-chain fresh products was about 10 percent [12]. In the context of the new retail, cold chain logistics pays more attention to the quality of easy-to-wear products, and fresh products can be delivered to customers in the shortest possible time to ensure the freshness of products to the greatest extent [13]. In the context of fresh e-commerce and based on the characteristics of fruits, Gao et al. studied the changes of fruit ripeness during transportation, which provided a research direction for the "first kilometer" problem of fresh agricultural products [14]. By using the method of demand segmentation, a mixed integer programming model for the multi-mode path problem of fresh fruit in online supermarket is established [15]. Based on the fragile characteristics of fresh products, improving customer satisfaction has become an urgent problem for enterprises to solve [8].

Under the background of new retail, enterprises pay more attention to the freshness of fresh products. At present, the research on the logistics and distribution of fresh goods is mainly focused on the distribution optimization of distribution cost and customer satisfaction, but there are few studies on the loss of customer satisfaction combined with the value of fresh products and the characteristics of time window. The value of fresh products will affect customer satisfaction to a great extent, so it is necessary to consider the value of fresh products when constructing the loss of customer satisfaction in the context of new retail.

In the logistics of the fresh product, the main research stream is aiming at the transportation between the distribution center and the store. The distribution center uniformly distributes products to multiple stores distributed in various areas of the city. Based on the historical sales of each store, it predicts the future store demand or summarizes the order volume within the next week and formulates a distribution plan within a limited period based on the store orders. To further reduce logistics costs, the distribution center adjusts the number of stores and product distribution within the distribution cycle and reorganizes the transportation path during the distribution period to ensure that the transportation cost and the customer's satisfactory loss reach a balance to minimize the total logistics cost.

On the basis of drawing lessons from the existing theories and combining with the fresh value, this paper constructs a mathematical model with the minimum loss of transportation cost and customer satisfaction, in order to reduce the transportation cost in the fresh food logistics network and improve the transportation efficiency. Itinerant distribution means that the vehicle uses the itinerary to transport it in various stores after departure, and finally returns to the distribution center. It maximizes the use of the vehicle load during transportation, reduces the loss of fresh products, and reduces the overall loss of the cold chain logistics network, and improved customer satisfaction.

3. **Fresh Products Logistics Distribution Path Optimization Model under New Retail Mode.**

3.1. **Problem description and assumptions.**

According to the characteristics of fresh products and the characteristics of the needs of the retail stores, this work proposes the jointly deliver mode for the needs of each store at night based on the single distribution center. Assuming that the refrigerated truck service starts from the distribution center and multiple stores, all the refrigerated trucks will be returned to the distribution center after the delivery is completed, regardless of the return load situation. The fresh products logistics distribution path optimization model takes the minimum total cost of transportation and customer satisfaction loss in the distribution center as the objective function. The route optimization model of transportation cost is to plan the route according to the demand of stores, and the loss of customer satisfaction is set according to the value of goods and delivery time of stores. Therefore, we make the following assumptions.

1) The inventory and distribution center has a definite ordering period, and the total demand of products within the period is known.

2) Suppose there is only one distribution center, n retail stores, the location and distance of the distribution center and stores are known.

3) The distribution center has sufficient products and refrigerated trucks of the same specifications and models. And each refrigerated truck can only be delivered once and one store can only be served by one refrigerated truck.

4) All stores must be served as long as there are orders.

5) All refrigerated trucks must return to the distribution center after delivery.

6) The number of stores distributed by each vehicle is not greater than the total number of stores.

7) Regardless of the store's ordering cost for the distribution center, the fixed cost of each order is certain.

8) Suppose that each store has the same price for the same product, but the actual demand of each store is different.

3.2. **Cost analysis for fresh products logistics distribution.** According to the attribute of fresh products logistics, its logistics distribution cost includes transportation cost, damage cost, refrigeration cost, and customer satisfaction loss cost.

3.2.1. *Transportation cost.* The transportation cost of fresh products logistics mainly includes fixed cost and transportation cost [16], in which the fixed cost does not include the cost changed by the transportation of vehicles. Transportation cost will vary with the increase of vehicle transportation distance and time.

Firstly, the fixed cost of fresh products logistics transportation refers to the cost that does not change with time and distance in the process of transportation [17]. Its fixed cost mainly includes the driver's salary and the depreciation cost of the vehicle, which is only related to the number of refrigerated vehicles $\text{sign}(d_k)$. The fixed cost is the average cost of the driver's salary and the depreciation cost of the vehicle g.

$$C_{gd} = g * \sum_{k=1}^{k} \text{sign}(d_k) \tag{1}$$

$$\text{sign}(d_k) = \begin{cases} 1 & d_k \neq 0 \\ 0 & d_k = 0 \end{cases} \tag{2}$$

$$d_k = \sum_{i=0}^{n} \sum_{j=1}^{n} x_{ij}^{k} * d_{ij} \tag{3}$$

where d_k indicates the transportation distance, d_{ij} represents the distance between two nodes, x_{ij}^k indicates that the refrigerated car k is designated to complete the transportation from node i to j (0-1 variable), and g represents a fixed cost.

Secondly, the transportation costs are mainly divided into two categories: fuel consumption costs and maintenance costs. Because the fuel consumption costs of no-load and full-load are different, this paper will calculate respectively. The maintenance cost includes the cleaning and repair costs of the vehicle.

Fuel consumption cost of goods:

$$C_{ys1} = \sum_{k=1}^{k} \sum_{i=0}^{n} \sum_{j=1}^{n} \frac{d_{ij}}{v_y} * x_{ij}^{k} * b * (c_{mz} + c_{kz}) \tag{4}$$

No-load fuel consumption cost:

$$C_{ys2} = \sum_{k=1}^{k} \sum_{i=1}^{n} \frac{d_{i0}}{v_y} * x_{i0}^{k} * c_{kz} \tag{5}$$

Maintenance cost:

$$C_{ys3} = \sum_{k=1}^{k} \sum_{i=0}^{n} \sum_{j=1}^{n} d_{ij} * x_{ij}^{k} * c_{by} \tag{6}$$

The total transportation cost is

$$C_{ys} = C_{ys1} + C_{ys2} + C_{ys3} \tag{7}$$

where c_{mz} indicates the unit fuel consumption cost at full load, c_{kz} indicates the unit fuel consumption cost when there is no load, c_{by} indicates unit maintenance cost, b indicates the parameter to adjust the loading rate, and v_y represents the transport rate.

3.2.2. *Damage cost.* Damage cost is mainly divided into two parts of transportation and unloading. The transportation damage and the waiting time for unloading will bring damage cost caused by the corruption of fresh products over time. The damage cost of unloading is caused by the bumping of fresh products caused by the transfer of goods and accelerated decay.

Damage of transportation:

$$C_{yd} = \sum_{k=1}^{k} \sum_{i=0}^{n} \sum_{j=1}^{n} x_{ij}^{k} * \lambda * z_j * \left(\frac{d_{ij}}{v_y} + t_j^d \right) \tag{8}$$

Damage cost of unloading:

$$C_{xh} = \sum_{k=1}^{k} \sum_{j=1}^{n} x_j^k * z_j * \left(1 - e^{-\lambda * G_j \div v_x}\right) \tag{9}$$

where λ indicates the average rate of corruption, z_j represents the value of the goods at point j, G_j represents the demand for point j, v_x indicates the unloading rate of the store, x_j^k indicates that the k car is designated to complete the transportation of node j, and t_j^d represents the unloading waiting time of the j node.

3.2.3. *Refrigeration cost.* To prolong the shelf life of fresh products after picking, they will be refrigerated in the distribution center. In order to defer the decay of fresh products due to temperature differences, refrigerated vehicles are needed for transportation.

$$C_{zl} = \sum_{k=1}^{k} \sum_{i=0}^{n} \sum_{j=1}^{n} \Delta T * Z_{zl} * s * \theta * (1 + u) * \frac{d_{ij}}{v_y} * \frac{x_{ij}^k}{E} \tag{10}$$

where u represents the depreciation rate of vehicles, s indicates the surface area of the carriage, θ indicates the thermal conductivity of the car, E indicates the thickness of the carriage, ΔT indicates the temperature difference between inside and outside the car, and Z_{zl} indicates the unit price of the refrigerant.

3.2.4. *Customer satisfaction loss cost.* For the transportation of the fresh product, retail stores have high requirements for delivery time. In the distribution path optimization, the lowest total cost should be considered, and the time satisfaction of the store should also be considered. The general relationship between customer satisfaction and delivery time is: in a certain time range, customer satisfaction is 100%, with the increase of time, customer satisfaction decreases [18].

$$M(t_{nk}) = \begin{cases} \alpha * (ET_i - t_{nk}) & t_{nk} < ET_i \\ 0 & ET_i \le t_{nk} \le LT_i \\ \beta * (t_{nk} - LT_i) & t_{nk} > LT_i \end{cases} \tag{11}$$

where ET_i and LT_i denote the upper time limit and lower time limit respectively, α indicates early arrival penalty parameter, β indicates the late penalty parameter, and t_{nk} indicates the time of arrival of the vehicle.

$$S = \sum_{j=1}^{n} \emptyset M(t_{nk}) * Z_j \tag{12}$$

The loss of customer satisfaction is usually related to delivery time, goods value, goods vulnerability and so on. In order to simplify the model, only the influence of the value of goods and arrival time on the loss of customer satisfaction is considered. Here Z_j denotes fresh product value.

3.3. **Optimization model.** To sum up, the fresh products logistics distribution path optimization model under new retail mode is designed as follows:

Objective:

$$Q = C_{gd} + C_{ys} + C_{yd} + C_{xh} + C_{zl} + S \tag{13}$$

Constraints:

$$\sum_{k=1}^{k} \sum_{i=0}^{n} x_{ij}^{k} = 1 \quad j = 1, 2, \ldots, n \tag{14}$$

$$\sum_{j=0}^{n} x_{0j}^{k} = \sum_{i=0}^{n} x_{i0}^{k} \quad j = 1, 2 \ldots, n \quad i = 1, 2, \ldots, n \tag{15}$$

$$\sum_{j=1}^{n} \sum_{i=0}^{n} x_{ij}^{k} \leq n \quad k \in K \tag{16}$$

$$\sum_{k=1}^{k} G_j * x_j^k \leq W \tag{17}$$

In the above constraints, Formula (14) indicates that a store can only be delivered once; Formula (15) indicates that the vehicle must return to the distribution center after the delivery is completed; Formula (16) indicates that the number of customers served by a car cannot exceed the number of all stores; Formula (17) indicates that the actual load of the vehicle cannot exceed its maximum load, where W indicates the maximum load of the vehicle.

4. **Case Study.** The cost caused by customer satisfaction loss is usually related to delivery time, value, vulnerability, weight, etc. This paper selects the value of goods Z_j as a reference.

4.1. **Background.** This paper takes the secondary network composed of 9 stores and 1 distribution center in Chongqing, China, as an example to optimize inventory and distribution. The location of the store and distribution center is marked by Baidu Maps, where the star mark is the distribution center and the flag is marked as the store, as shown in Figure 1.

Distance between each node (Unit: km) is shown in Table 1.

Distribution centers are responsible for the storage and distribution of all store products, and retail stores will send orders to distribution centers in time to optimize the analysis of the two commodities. The demand for fresh products of each store within a certain planning period is shown in Table 2.

The unit purchase price and unit fresh-keeping cost of various products are shown in Table 3.

The various parameters in transportation are shown in Table 4, and the parameters of the data are cited in [19].

In the design process of the genetic algorithm, the relevant parameters of the algorithm are set as shown in Table 5.

4.2. **Result analysis.** The optimal cost considering the loss of customer satisfaction is 5060.003, and the optimal distribution path is $0 \to 4 \to 7 \to 0 \to 3 \to 9 \to 0 \to 5 \to 1 \to 0 \to 6 \to 8 \to 2 \to 0$ (starting at 3 o'clock). The cost of each distribution vehicle is shown in Table 6. The distribution road map is shown in Figure 2 (where VRPTW represents the distribution road map with time window).

The optimal cost without considering the loss of customer satisfaction is 3862.735, and the optimal distribution path is $0 \to 9 \to 8 \to 0 \to 2 \to 0 \to 5 \to 1 \to 0 \to 7 \to 4 \to$

$0 \to 6 \to 3 \to 0$ as shown in Table 7. The distribution road map is shown in Figure 3 (where VRP represents the distribution road map without time window).

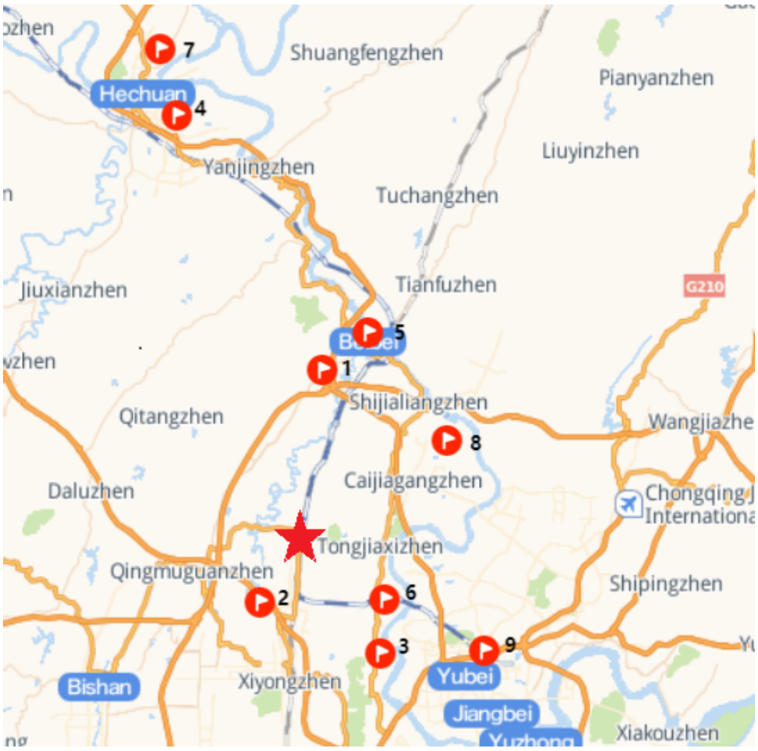

FIGURE 1. Geographical location of stores and distribution centers

TABLE 1. The straight-line distance between each node

	Delivery center	Store 1	Store 2	Store 3	Store 4	Store 5	Store 6	Store 7	Store 8	Store 9
Delivery center	0	14.9	4.2	9.4	34.9	18.6	6.6	39.2	13.7	15.6
Store 1	14.9	0	18.5	22.4	21.3	5	18.4	25.8	11.6	25.2
Store 2	4.2	18.5	0	9.4	37.1	22.5	8.6	41.8	17.8	17.1
Store 3	9.4	22.4	9.4	0	43.1	24.9	4.1	47.8	16.1	8.1
Store 4	34.9	21.3	37.1	43.1	0	21.4	39.3	4.7	32.3	46.6
Store 5	18.6	5	22.5	24.9	21.4	0	20.8	25.4	11.2	26.3
Store 6	6.6	18.4	8.6	4.1	39.3	20.8	0	44	12.2	9
Store 7	39.2	25.8	41.8	47.8	4.7	25.4	44	0	36.5	51
Store 8	13.7	11.6	17.8	16.1	32.3	11.2	12.2	36.5	0	15.5
Store 9	15.6	25.2	17.1	8.1	46.6	26.3	9	51	15.5	0

TABLE 2. Demand parameters of fresh products

Store number	Product 1	Product 1's value	Product 2	Product 2's value	Total store demand	Value of products	Waiting time for unloading	The upper limit of time window	The lower limit of time window
1	9	27000	10	50000	19	77000	0.13	0	1
2	4	12000	9	45000	13	57000	0.07	0	1
3	11	33000	10	50000	21	83000	0.12	0	1
4	17	51000	5	25000	22	76000	0.21	0	1.5
5	12	36000	8	40000	20	76000	0.19	0	1.5
6	8	24000	5	25000	13	49000	0.16	0	2
7	5	15000	8	40000	13	55000	0.23	0	2
8	4	12000	8	40000	12	52000	0.25	0	1.5
9	6	18000	9	45000	15	63000	0.11	0	2
Total demand	76		72		148				

TABLE 3. Costs of fresh products

Types of goods	Symbol	Product 1	Product 2
Unit purchase price	p	3000	5000
Unit inventory cost	h_p	5000	3000
Unit fresh-keeping cost	b_p	600	400

TABLE 4. Related parameter settings

Parameter	Symbol	Number
Refrigerated vehicle	k	10
Number of stores	n	9
Fixed cost per distribution	g	260
Maximum load weight	W	40
Unit fuel consumption cost at full load	c_{mz}	53
Unit fuel consumption cost at no load	c_{kz}	39
Unloading rate	v_x	3000
Unit maintenance cost	c_{by}	0.1
Carriage heat conductivity	θ	35
Carriage thickness	E	0.08
Depreciation rate of carriages	u	0.1
Parameters	b	0.55
Early arrival penalty parameter	α	40
Late arrival penalty parameter	β	80
Transportation rate	v_y	90
The rate of corruption of goods	λ	0.002
Temperature difference inside and outside the car	ΔT	7
Unit price of refrigerant	Z_{zl}	0.0008
The surface area of the carriage	s	32

TABLE 5. Parameter setting of genetic algorithm

Parameter name	Population size	Crossover probability	Mutation probability	The maximum number of iterations
Parameter value	50	0.98	0.2	400

TABLE 6. Cost per route in time window conditions

Vehicle	1	2	3	4
Total distance	78.8	33.1	38.500	40.800
Driving path	$0 \to 4 \to 7 \to 0$	$0 \to 3 \to 9 \to 0$	$0 \to 5 \to 1 \to 0$	$0 \to 6 \to 8 \to 2 \to 0$
Load weight	35	36	39	38
Cargo damage cost in transit	656.800	529.280	592.107	584.693
Cost of unloading damage	1.696	3.428	5.406	6.670
Time of arrival	3:00 → 3:23 → 4:50 → 6:09	3:00 → 3:06 → 5:53 → 6:59	3:00 → 3:13 → 5:34 → 6:58	3:00 → 3:04 → 5:40 → 7:29 → 9:32
Penalty cost	230.8	360.578	369.311	431.331
Total cost	1251.466	1196.202	1276.742	1335.593

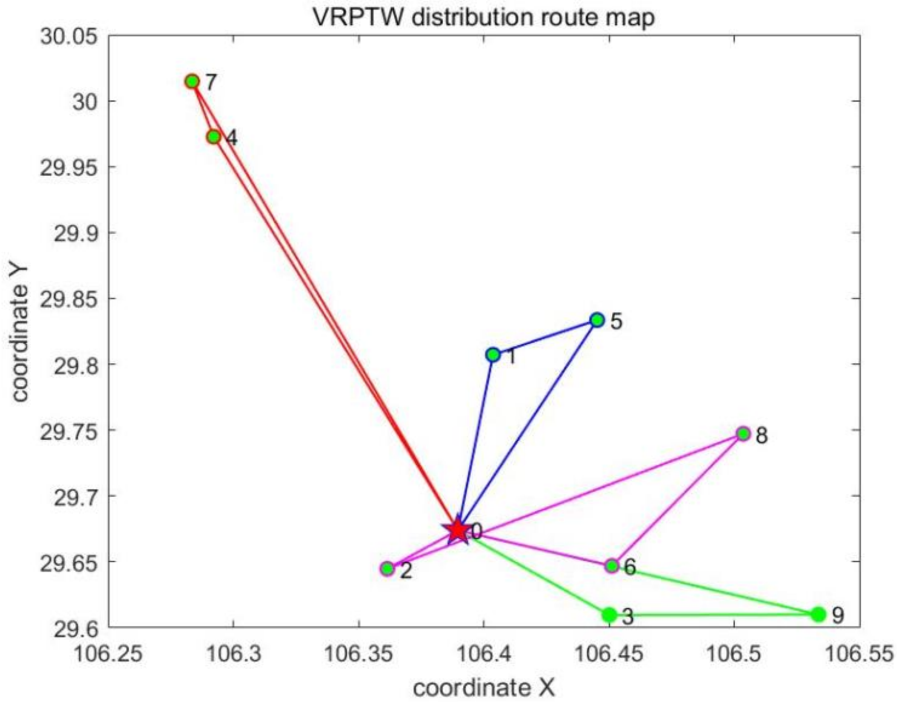

FIGURE 2. Distribution route map with time windows

TABLE 7. Cost of each route

Vehicle	1	2	3	4	5
Total distance	44.8	8.4	38.500	78.800	20.100
Driving path	$0 \to 9 \to 8 \to 0$	$0 \to 2 \to 0$	$0 \to 5 \to 1 \to 0$	$0 \to 7 \to 4 \to 0$	$0 \to 6 \to 3 \to 0$
Load weight	27	13	39	35	34
Cargo damage cost in transit	425.040	162.587	592.107	655.756	460.587
Cost of unloading damage	0.966	1.409	5.406	5.083	6.670
Time of arrival	$3{:}00 \to 3{:}10 \to 4{:}17 \to 6{:}04$	$3{:}00 \to 3{:}03 \to 5{:}05$	$3{:}00 \to 3{:}13 \to 5{:}34 \to 6{:}58$	$3{:}00 \to 3{:}26 \to 4{:}22 \to 6{:}09$	$3{:}00 \to 3{:}04 \to 5{:}34 \to 8{:}21$
Total cost	744.091	434.887	907.431	1023.008	753.318

Through the analysis of the above results, it can be concluded that the optimization model of the transportation cost and customer satisfaction loss cost of the fresh retail logistics network established in this paper is feasible, and the simulation calculation of this model can achieve the optimization purpose.

The comparative analysis of costs in the two cases is shown in Table 8. As can be seen from Table 8, when the distribution center transports fresh products to stores, the total transportation distance is the same regardless of whether or not the loss of customer satisfaction is taken into account. In the case of considering the loss of customer satisfaction, in the process of vehicle transportation, in order to make fresh products delivered within a specified time, priority will be given to the distribution of fresh products with high value, thus increasing the cost of goods loss on the way. However, due to the reduction of distribution vehicles, the fixed cost and the cost of unloading damage are reduced. Without considering the loss cost of customer satisfaction, due to the restrictions of vehicle load and other conditions, one of the nodes is transported by one vehicle, resulting in a waste of resources. Although the total cost of logistics is high under the limitation of the loss cost of customer satisfaction, the number of vehicles used is reduced and customer

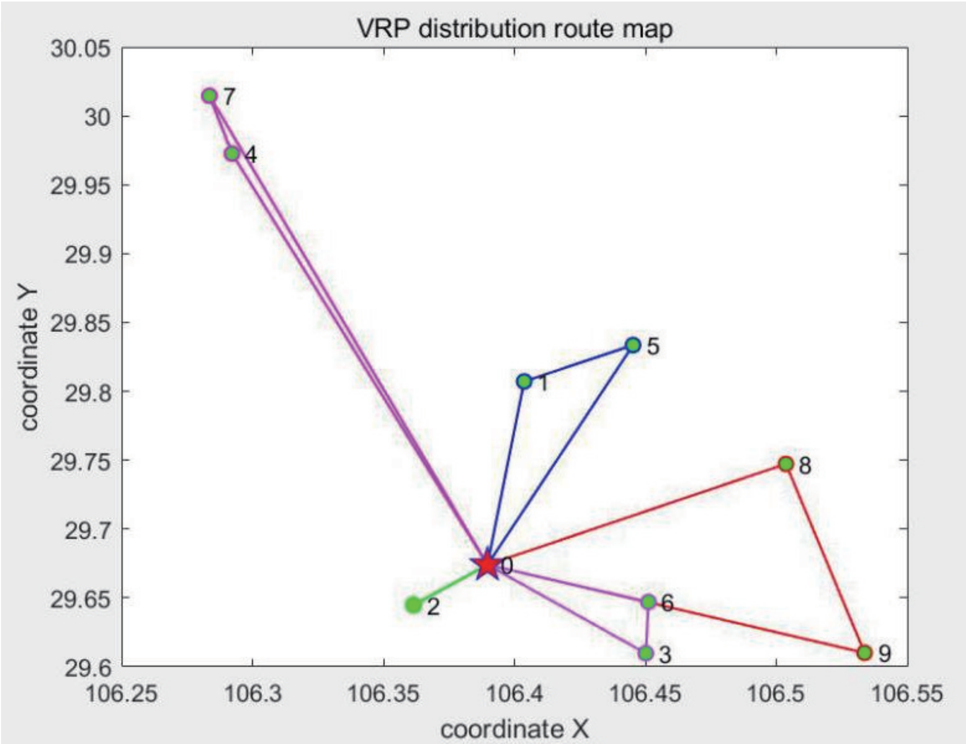

FIGURE 3. Distribution route map

TABLE 8. Comparison of results

	Number of vehicles	Penalty cost	Cargo damage cost in transit	Cost of unloading damage
There is a loss of customer satisfaction.	4	1392.02	2362.88	17.2
No loss of customer satisfaction.	5	–	2296.077	19.534

satisfaction is high. When the distribution center carries on the route optimization, the loss of customer satisfaction is considered, which reduces the transportation cost, ensures the customer satisfaction, increases the economic benefit of the distribution center, and is more beneficial to the long-term development of the distribution center.

5. **Conclusion.** For the current logistics system, in order to pursue the minimum cost, the service quality of the store is largely ignored, which will further affect customer satisfaction with the purchase. Combined with the particularity of fresh products, this paper constructs a model integrating transportation cost and customer satisfaction loss cost to minimize the total cost of fresh products logistics distribution. In this model, by using the soft time window and calculating the unique fresh-keeping cost of fresh products, the cost control and service satisfaction are combined to make the research more in line with reality. The results of the study provide an important implication for logistic firms and transportation businesses in understanding customer satisfaction as the logistics service quality is found to have a significant impact on customer loyalty [20].

In this paper, the transportation cost and the loss cost of customer satisfaction are considered at the same time, in order to balance the relationship between them, which not only reduces the transportation cost of the distribution center but also improves the customer satisfaction, which is more conducive to the long-term development of fresh products logistics. However, there are still shortcomings, such as the current environmental pollution caused by the cold chain distribution process, and the model assumes that the model of the delivery vehicle is the same, which is not suitable for the actual delivery vehicle situation. In view of the above shortcomings, future research will be divided into two parts: research on how green and low-carbon logistics is reflected in the fresh cold chain; due to the different losses of different types of refrigerated trucks in actual transportation, the randomness of road conditions, unloading time and product damage, etc. It is necessary to enhance the dynamic adjustment ability of the algorithm to solve the optimization of the distribution route.

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