Optimization of distribution path of urban terminal fresh food

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Abstract: The increasing demand for fresh food in the market promotes the rapid development of cold chain logistics. Based on the particularity of fresh food logistics distribution and the existing literature, a new cost function is established. In this paper, the distribution path of fresh food in distribution center is optimized by comprehensive saving method under the condition of considering road conditions. The results show that under the condition of considering the road condition, the path selection with the comprehensive cost saving maximization saves 1.07% of the total cost compared with the path selection with the mileage saving maximization.

Key words: fresh food, road conditions, comprehensive savings method, path optimization

I. INTRODUCTION

The development of e-commerce economy promotes the transfer of distribution center to customer-centered development mode. Compared with normal temperature logistics, fresh food distribution has perishability and time limitation of customer demand, which poses a challenge to the development of distribution center. Therefore, it is of great significance to study the optimization of the distribution path of urban terminal fresh food.

In the research field of urban terminal logistics distribution, domestic and foreign scholars have made a series of achievements. The optimization of urban end cold chain logistics is studied from different perspectives, such as distribution optimization problem [1,2], distribution mode [3], distribution cost composition [4,5], cargo loss [7], path optimization solution method [8,9]. However, the existing literature fails to fully consider the energy consumption cost at different stages and optimize the distribution cost by using comprehensive saving method. In terms of transportation cost, currently most literatures believe that transportation cost is proportional to transportation mileage. In fact, driving speed and vehicle load also have a great impact on vehicle fuel consumption [4,8]. The author also thinks that transportation cost should consider three factors. In terms of refrigeration cost and cargo damage cost, the in-transit stage and loading and unloading stage of vehicle distribution have been considered in some literatures [5,11], the research is not comprehensive enough. Here, the author considers the in-transit stage and loading and unloading stage of distribution.

Based on the general normal temperature distribution model and the particularity of fresh food distribution, this paper constructs the fresh food distribution model by considering the transportation cost, refrigeration cost, cargo damage cost and penalty cost, and then optimizes the target model according to the comprehensive saving method.

II. FRESH FOOD DISTRIBUTION MODEL

A. *Distribution center hypothesis*

(1) Suppose that the distribution center has N customers (i =1,2... , N), single type of fresh food delivered; (2) The location and demand of each customer are known, and the customer is constrained by a time window;(3)Vehicle distribution distance is limited and they are all cold chain vehicles with the same load; (4) All vehicles must start from the distribution center, complete the task, and finally return to the distribution center; (5) The demand per customer is greater than zero and less than the maximum load of the vehicle; (6) Each customer's needs must be met and delivered by only one vehicle; (7) The delivery process can be maintained at a fixed delivery temperature; (8) Regardless of the loading time and damage of the

goods in the distribution center; (9) Assume the delivery vehicle arrives at the customer's place, it can be carried out.

B. *Fresh food distribution cost composition*

(1) The cost of transportation The transportation cost of distribution vehicles includes fixed cost and variable cost. The fixed cost is a constant, which is not directly related to the transportation mileage and the number of customers [5]. Here, only the variable cost is considered, and the transportation mileage, driving speed and deadweight are taken into account [4 8]. If additional load W brings fuel consumption increase rate is p1 , Then, when the load of the vehicle from node I to node j is Hij, the actual fuel consumption FCij of this section is:

$$FC_{ij} = LPH_{ij} \bullet \frac{d_{ij}}{v_{ij}} \bullet \left(1 + p_1 \bullet \frac{H_{ij}}{W}\right) \qquad (1)$$

Where: fuel consumption per unit time $LPH_{ij}=v_{ij}/KPL_{ij}$, KPL_{ij} is the unit fuel mileage of an empty vehicle from node I to node j,v_{ij} represents the driving speed from node I to node j under the condition of considering road conditions. λ represents the unit fuel consumption price, R_r^u represents the u customer number on the path in article r . Therefore, transportation cost C_1 is:

$$C_1 = \sum_{r=1}^{N} \sum_{s=1}^{V_r - 1} \lambda \bullet FC_{\left(R_r^u\right)\left(R_r^{u+1}\right)} \qquad (2)$$

(2) Cooling costs In the distribution process,Vehicles in the distribution center can be divided into two parts: in-transit stage and loading and unloading stage (see FIG. 1). In this paper, two factors of literature [5] and literature [11] are combined to solve the refrigeration cost. Therefore, the author considers the in-transit stage and loading and unloading stage when calculating the refrigeration cost.

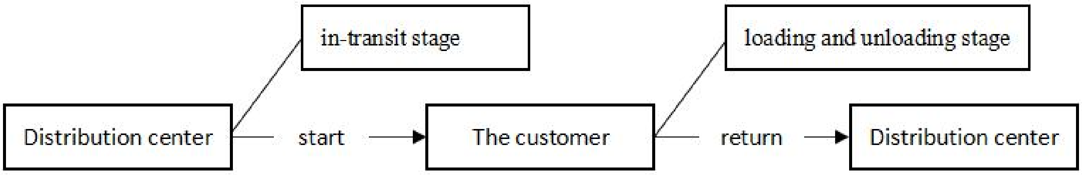

Figure 1. Vehicle distribution process

① In-transit refrigerant consumption is affected by factors such as heat transfer coefficient, surface area of the car body, and external temperature, etc. In-transit refrigerant consumption is also proportional to the remaining volume of goods in the car, and in-transit refrigerant consumption is

$$G = c_1 RS\Delta T \qquad (3)$$

$$C_{21} = \sum_{i=0}^{N} \sum_{j=0}^{N} p_2 \bullet G \bullet t_{ij} \bullet H_{ij} \bullet x_{ij} \qquad (4)$$

Where,p2 unit cooling cost, G is refrigerant consumption, c1 is constant, R is heat transfer coefficient, S is car body surface area, ΔT is the temperature difference between interior and exterior temperature; Hij is the load capacity of the vehicle from node I to node j, and xij is the decision variable,When the task is completed, there is no need to turn on refrigeration when returning to the distribution center.

②In the loading and unloading stage, the cooling cost caused by heat transfer exchange inside and outside the carriage when the door is opened is mainly considered, si is the residence time at node i, and yik is the cargo transported by vehicle k at node i. The cooling cost of this stage is

$$C_{22} = \sum_{i=1}^{n} \sum_{u=1}^{m} p_2 \bullet c_1 \bullet s \bullet \Delta T \bullet s_i \bullet y_{ik} \qquad (5)$$

Therefore, the total cooling cost is C2=C21+C22

(3) The cost of damage Fresh food is corrosive food. The damage cost of fresh food in the distribution process: first, the damage caused by fresh food during transportation due to the accumulation of transport time; Second, when serving customers, the opening of the carriage door of the vehicle causes convection of air [10], and the cargo damage caused is:

$$C_3 = p \sum_{i=0}^{N} \sum_{j=1}^{N} \sum_{k=1}^{M} x_{jk} \left(\alpha_1 d_{ij} H_{ij} z_{ij} + \alpha_2 A_j h\right) \qquad (6)$$

Where, the road conversion coefficient Z_{ij} is converted by the average speed v_{ij} of distribution vehicles running on the road,p is the price of fresh food per unit; α1 is the cargo loss ratio in the transit stage; α_2 is the cargo loss ratio in the loading and unloading stage; d_{ij} is the distance from node i to node j; x_{jk} is the decision variable; if the k vehicle service j is 1, otherwise it is 0,A_j represents the remaining load on the vehicle when going to node j,h is lay time.

(4) Punishment cost In the actual distribution, due to the existence of some uncertain factors (such as urban traffic congestion, distribution scheduling errors, etc.), it is often unable to meet the time requirements of customers. However, the customer can accept delivery within a certain time range beyond the specified time, resulting in time window penalty costs. The total penalty cost of soft time window in the distribution process is:

$$C_4 = \sum_{k=1}^{M}\sum_{i=0}^{N}\sum_{j=1}^{N} x_{jk}\varphi_{jk} \tag{7}$$

Suppose the time window of customer j is[m_j n_j], and the time window acceptable to customer j is[M_j N_j]. If the delivery time exceeds the time window acceptable to customer j, then the transaction may not be completed, and the penalty cost is extremely huge.We use B to represent it. If it is delivered early, that is, in time period [m_j n_j], the penalty cost is 0.Delayed arrival. In period [n_j N_j], penalty costs are related to the length of delay, the price of the goods, and the quantity of the goods.Therefore, the penalty cost of customer j is as follows:

$$\varphi_{jk} = \begin{cases} \mathrm{B} & t_i < M_j ,\ t_j > N_j \\ 0 & M_J \le t_j \le n_j \\ \beta p q_j (t_j - n_j) & n_j < t_j < N_j \end{cases} \tag{8}$$

Where: t_j is the time of node j; q_j is the demand of node j; β is the penalty coefficient.

C. Establishment of fresh food logistics distribution model

$$\min z = C_1 + C_2 + C_3 + C_4 = \sum_{r=1}^{N}\sum_{s=1}^{V_r - 1} \lambda \bullet FC_{\left(R_r^u\right)\left(R_r^{u+1}\right)}$$

$$+\sum_{i=0}^{N}\sum_{j=0}^{N} p_2 \bullet G \bullet t_{ij} \bullet H_{ij} \bullet x_{ij}$$

$$+\sum_{i=1}^{n}\sum_{u=1}^{m} p_2 \bullet c_1 \bullet s \bullet \Delta T \bullet s_i \bullet y_{ik}$$

$$+ p_2 \sum_{i=0}^{N}\sum_{j=1}^{N}\sum_{k=1}^{M} x_{jk}\left(\alpha_1 d_{ij} H_{ij} z_{ij} + \alpha_2 A_j h\right)$$

$$+\sum_{K=1}^{M}\sum_{i=0}^{N}\sum_{j=1}^{N} x_{jk}\varphi_{jk} \tag{9}$$

S.t.(1) $\sum_{i=0}^{N} x_{ij} = 1(0,1,\ldots,N)$, Each customer is only served once, there is no duplicate service;(2) $\sum_{i=0}^{N}\sum_{j=0}^{N} x_{ij} = N$, All customers are served, not missed;(3) $\sum_{k=1}^{M} x_{jk} = 1(j = 0,1,\ldots,N)$, Each customer is served by only one car;(4) $\sum_{k=1}^{M}\sum_{j=0}^{N} x_{jk} = M$, Every car is used, no car is left idle;(5) $\sum_{j=0}^{N} x_{jk} q_j \le g_{\max(k)}$, The load capacity of each vehicle shall not exceed its maximum load $d_{\max(k)}$;(6) $N_j \le t_j \le M_j$, Service hours shall be within the acceptable range of the customer.

III. MODEL DESIGN

A. Basic idea of algorithm design

The traditional mileage saving algorithm is mainly used to solve the shortest path VRP problem, but it has certain limitations in solving the optimization model of cold chain logistics distribution path with multi-objective cost minimization. In order to meet the needs of solving the model in this paper, the traditional mileage saving algorithm needs to be improved.The difference between the comprehensive saving algorithm and the original mileage saving method is that the distance is not simply used as the judgment basis for saving, but the time window of road condition and customer demand is comprehensively considered to convert the distance saving into comprehensive saving, including transportation cost, refrigeration cost, cargo damage cost and penalty cost.

The idea of comprehensive saving method is to start from the distribution center, looking for customers who join the principle of the lowest total cost of the line. That is, if the last customer currently joining the line is i, if j (i≠j) wants to be placed on the line. Then it must satisfy the following conditions :(1) It is not placed on any line; (2) Time window limit to meet customer needs; (3) After customer j joins, the total demand of customers on this line must be less than the maximum load of vehicles; (4) Meet the principle of minimum total cost added.

In order to minimize the transportation cost, mileage saving method can be adopted. The cost of refrigeration is determined by the type of cold chain truck, temperature difference between indoor and outdoor and time. Fresh food delivery is delivered under existing models and external environmental conditions. Only the delivery and transportation time from customer i to customer j is considered here. In a cold chain car traveling at a constant speed of v_{ij}, the time saved by transportation is related to the mileage saved by transportation. So when transportation costs are lowest, cooling costs are lowest.

The cost of cargo damage is determined by three factors, namely, transportation mileage, road condition and cargo weight. Distribution optimization does not change the weight of goods, and the road condition coefficient is converted by the average speed v_{ij} of distribution vehicles running on the road. Therefore, the cost of cargo damage is directly related to the transportation mileage. When transportation costs are lowest, so are cargo damage costs.

The penalty cost is related to the delivery time of fresh food to customers, which can be directly calculated by the penalty cost formula.

According to the above algorithm principle, we can see that: in order to achieve the lowest total cost, it can also be converted into the largest comprehensive cost saving. Therefore, the objective function can be translated into:

$$\max\sum_{i=1}^{N}\sum_{j=1}^{N} l_{ij} = \max\sum_{i=1}^{N}\sum_{j=1}^{N}\left(p_k H_{ij} S_{ij} + p_2 G S_{ij} / v_{ij} + \alpha_1 p H_{ij} S_{ij} z_{ij}\right) - \sum_{j=1}^{N}\varphi_{jk} \qquad （10）$$

Where: l_{ij} refers to the cost saving in the process from customer I to customer j; P_k is unit transportation cost; q_j is the demand of fresh food from the JTH customer; S_{ij} is the transportation mileage saved from customer I to customer j; Z_{ij} is the road conversion coefficient; G is refrigerant consumption per unit time; p_2 is the unit refrigerant price; p unit fresh food price; ψ_{jk} is the penalty cost of customer j for serving k car.

According to the above formula, the order of searching for new customers is as follows:

(1) Sequence of time Windows. Because of the high penalty cost of exceeding the acceptable time window range for customers, it is necessary to ensure that all customers are served within the acceptable time range, and the time window sequence is one by one.

(2) Order of transportation mileage. Transportation mileage directly affects the transportation cost, cargo damage cost and refrigeration cost of distribution, and has a greater impact on the total distribution cost. Therefore, as the second order.

B. Model solving steps

According to the above sequential principle of finding new customers, the specific steps are as follows:

(1) First, sort the time window of customers;

(2) Secondly, calculate the mileage saved for each two customers S_{ij};

(3) According to the sequence of step (1), start from the distribution center to find the customer who meets the principle of "lowest comprehensive cost" and join the first customer to be served in the line;

(4) Repeat step (3) to add suitable customers to the line in turn. So far, all customers who are not discharged to the line are unable to meet the limit of time window or the cold chain cars of the line have reached the limit of vehicle capacity;

(5) Re-establish a new line and repeat steps (3) and (4) until all customers are served.

IV. CONCRETE EXAMPLE

A. The basic data

Through field visits and investigations, a distribution center in wuhan sold products to 10 customers (j=1,2... ,10) single delivery of fresh food. The demand q_j (unit: ton) and time window of each customer are given in table 1 below. Distance (unit: km) between distribution center 0 and each customer and road condition are given in table 2. The maximum load of the cold chain truck in the distribution center is 3t. Other parameters are given in table 3.Table 4 shows the driving speed of vehicles and the driving distance per unit of fuel in each road condition.

Table 1 customer demand and time window

The customer	1	2	3	4	5	6	7	8	9	10
Demand for	0.7	1.5	0.8	0.4	1.4	1.5	0.6	0.7	2.5	0.6
Customer demand time window	20:30	21:30	20:50	21:50	21:00	22:10	21:20	22:40	23:10	20:00
	21:00	22:00	21:20	22:20	21:30	22:40	21:40	23:10	23:40	20:30
Customer acceptable time window	20:00	20:00	20:20	21:20	20:30	21:40	20:40	22:10	22:40	19:30
	21:30	22:30	21:50	22:50	22:00	23:10	22:20	23:40	00:20	21:00

Table 2 Distance between nodes and road condition

	0	1	2	3	4	5	6	7	8	9	10
0	0	15	12	13	11	10	15	19	13	9	14
1	M	0	14	7	14	18	18	13	14	11	15
2	G	M	0	13	8	14	15	9	11	12	10
3	M	G	P	0	9	13	12	10	15	11	14
4	M	M	M	G	0	18	12	15	11	19	10
5	M	M	G	G	M	0	7	14	13	10	8
6	P	G	P	M	G	M	0	8	11	9	19
7	M	G	P	G	G	M	G	0	15	13	8
8	M	P	G	G	G	P	M	G	0	9	12
9	M	G	G	G	P	P	G	G	M	0	18
10	M	P	P	G	P	M	G	G	P	P	0

The bottom left corner of table 3 shows the road condition coefficient, G- good, M- middle and P- poo

Table 3 other parameter value table

parameter	value	parameter	value
λ	5.8yuan/L	P	4000yuan/t
P_1	45	W	50t
C_1	0.05	p_k	0.8yuan/tkm
P_1	0.02	h	10min
α_1	0.002	α_2	0.002
R	0.2	S	10m^2
ΔT	10K		

Table 4 unit fuel driving distance of each road condition

Road conditions	speed（km/h）	KPL（km）
good	35	5.56
middle	30	8.33
poor	25	6.25

B. Model solving

According to the time window after sorting the time requirements of each customer, customer 10 requires the earliest time. Therefore, customer 10 is the first customer, and the departure time of the delivery vehicle is 20:00. According to formula (10), the comprehensive cost saved by reaching the next customer can be calculated. The mileage saved by its customers and related costs are shown in table 5 customer selection table.

Table 5 customer selection table

The customer	Transportation mileage savings	Transportation cost savings	Savings in cooling costs	Cost savings in cargo damage	Punishment cost	Total cost savings	Whether you choose
1	14	7.84	16.8	3.14	0	27.78	no
2	16	19.2	19.2	7.68	∞	－∞	no
3	13	8.32	11.14	2.38	0	21.84	no
4	15	4.8	18	1.92	∞	－∞	no
5	16	17.92	16	5.97	0	39.89	yes
6	10	12	8.57	3.43	∞	－∞	no
7	25	12	21.43	3.42	0	36.85	no
8	15	8.4	18	3.36	∞	－∞	no
9	5	10	6	4	∞	－∞	no

Select the next route according to the principle of minimum comprehensive cost, add customer 5 to the distribution route and continue to calculate, and obtain the first distribution route: 0 — 10 — 5 — 7 — 0. The remaining distribution routes can be obtained by using the same method.

C. Results analysis

Through calculation, the optimal distribution scheme is to arrange 4 vehicles for distribution, respectively：0—10—5—7—0；0—1—2—4—0；0—3—6—8—0；0—9—0。The optimized distribution plan is to choose the route with the maximum mileage cost saved under the premise of meeting customer demand and vehicle load limitation. The distribution path plan is as follows:0—10—7—6—0 ； 0—1—3—4—8—0 ； 0—5—2—0；0—9—0。And the cost of refrigeration is not fully considered, resulting in the total cost estimate is far from the reality. By comparing the distribution path schemes before and after optimization, it is found that when selecting the route with the maximum comprehensive cost saving, the total cost is 1.07% lower than that before optimization. The comparison and analysis of the distribution path schemes before and after optimization is shown in table 6.

Table 6 comparison of distribution path schemes before and after optimization

Indicators	The optimized	Before optimization
Number of vehicles required	4	4
Gross mileage	170	162
The cost of transportation	118.32	134.68
Cooling costs	409.14	405.24
The cost of damage	70.45	64.39
Punishment cost	0	0
The total cost	597.91	604.31

V. CONCLUSION

According to the particularity of goods distributed in cold chain logistics, this paper describes the cost consumption of each aspect in detail from the aspects of transportation cost, refrigeration cost, cargo damage cost and penalty cost, and establishes the cost model of cold chain logistics aiming at the minimum sum of the four costs, and designs the comprehensive saving method to solve the problem. The feasibility of the algorithm is verified by a concrete example, and the results are compared with previous literatures, and it is found that the actual distribution cost is reduced.

At the same time, the follow-up research will focus on the development of pick-up, return and replacement services in the terminal fresh food distribution service. The use of multiple models in the distribution service is worthy of our in-depth study.

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