Study on location and route of cold chain product logistics network considering customer value

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Abstract

To address the problem of lack of personalisation of Cold chain produce logistics services, a mathematical model of distribution centre location and refrigerated vehicle route planning for Cold chain produce logistics network considering customer value is established. The model is solved by a genetic algorithm, and differentiated logistics services are provided to different customers. Verified the validity of the model by comparing the solution of this paper with the traditional fresh produce logistics network solution without considering customer value.

Keywords

Customer value; Fresh produce; Site selection and route optimization; Genetic algorithms.

1. Introduction

As people's quality requirements for meat, eggs, vegetables and other cold chain products are getting higher and higher. Simultaneity, customs pay more attention to whether cold chain distribution enterprises can provide personalized distribution services. However, the logistics distribution service of the existing cold chain products is often aimed at the minimum transportation cost, without considering the customer value to develop the distribution service scheme. Peole value can refers to the company earnings realized by an enterprise from the purchase of customers. It is a measure of the relative importance of customers to an enterprise and an important standard for differentiation decision. Therefore, it is an important issue for distribution enterprises to design logistics network location and vehicle routing schemes according to different customer values, provide personalized cold chain product distribution services, and reduce the total logistics costs including customer loss costs.

Zhang Wenfeng [1] et al., aiming at the layout and transportation problems of cold chain logistics network, built a nonlinear integer programming model aiming at minimizing the construction cost and operating cost of logistics network, and used particle swarm optimization algorithm to solve the problem. Yao[2] et al. modeled the distribution Problem of cold chain seafood as a multi-warehouse Vehicle Routing problem, built a vehicle routing problem (VRP) model with the goal of minimizing the refrigeration cost and distribution cost of refrigeration equipment, and solved it through ant colony algorithm. In order to solve the problems of high distribution cost and long transit time of cold chain products, Yao Yuanguo etc. [3] is established based on real-time traffic products cold chain logistics distribution VRP mathematical model and used ant colony algorithm to solve the problem. In order to reduce the loss cost of perishable food in the distribution process, Ma Zujun [4] et al. established an optimization model by considering the time-varying characteristics of traffic distribution in road networks of production-distribution problem with minimum total system cost. Du Chen [5] et al. established a mathematical model of loss cost for the distribution problem of cold chain logistics enterprises, which also considered fuel consumption, refrigeration cost and freight damage cost, and solved it by simulated annealing algorithm. The above literature studies the distribution cost of cold chain products from various aspects, and the factors considered are more close to the practical problems, including refrigerated vehicle transportation cost, refrigeration cost, freight damage cost, and fixed departure cost.

Secondly, scholars have noted that improving the consumption experience of cold chain products is an important way for enterprises to improve their market competitiveness and market share. Therefore, scholars have studied how to improve customer consumption experience from the perspective of focusing on customers. For example, in terms of punctuality of customer delivery, Ren Teng[6] et al. improve customers' consumption experience by taking customers' time window as a constraint, built a VRP mathematical model of cold chain logistics network within the range of customer service time window, and solved it by improving ant colony algorithm. Liu Chunling [7] et al. Make full use of social idle logistics resources, establish a cold chain distribution model based on crowdsourcing mode, improve the timeliness of cold chain logistics terminal distribution, and enhance customer consumption experience. Timeout and others to establish the corresponding mathematical models to improve customer's consumption experience by comprehensively considering the time window and freshness of cold chain products. In addition, in terms of the quality of cold chain products, Song[8] et al. established a VRP mathematical model of multi-vehicle distribution by introducing vehicle driving time and the loss model of cold chain products, so as to improve customers' consumption experience by ensuring the freshness of cold chain products. Ma Yanfang [4] et al., considering the distribution loss and transportation cost of cold chain products, established a multi-agent model of location selection and route optimization for cold chain products to improve customer consumption experience. Ana Osvald[6] et al. regard the loss cost caused by the perishables of cold chain products as a part of the total cost, and reduce the decay rate of goods by 47% through optimization and solving, thus improving customers' consumption experience.

To sum up, the current literature on cold chain product logistics network mainly studies how to reduce distribution costs from the perspective of enterprises, and also studies on factors such as delivery punctuality and cold chain product quality to improve customer consumption experience. The above literature provides ideas and basis for the research of this paper. However, there are few literatures to improve customer consumption experience from the perspective of customer value. In addition, most studies on reducing the cost of cold chain logistics network focus on the optimization of vehicle routing, but the location of distribution center is also an important link affecting the cost of cold chain logistics network. Therefore, considering customer value, this paper makes a comprehensive planning for the location of distribution centers for cold chain products and the selection of vehicle distribution routes, in order to provide customers with satisfactory consumption experience of cold chain products at the lowest cost.

2. Model building

2.1. Problem Description

The location and routing problems of cold chain product logistics network considering customer value studied in this paper are described as follows: In the two-level logistics network composed of several distribution centers and customer demand points, the value difference among customers is identified by analyzing the current value and potential value of customers at demand points. According to the difference in customer value, customers are divided into current and potential high value I customers, current or potential high value II customers, cLow current and potential customer value III. Based on customer value, the corresponding time-out penalty cost function is set up, and the location and route optimization model of cold chain product logistics network is built with the transport cost of refrigerated vehicle, the loss cost of cold chain products and the penalty cost of time-out customers as the minimum.

Based on the problems in this paper, the following conditional assumptions are made:

(1) The number, geographical location and storage capacity of candidate distribution centers are known, and each distribution center has a certain number of refrigerated vehicles, and each refrigerated vehicle belongs to only one distribution center.

(2) The number of customers, geographical location and demand for cold chain products are known, and the demand fluctuation of customers is predicted to be small in a period of time according to the current value and potential value.

(3) The traveling speed of refrigerated vehicles is known, and they return to the original distribution center after completing the distribution task from the distribution center, regardless of vehicle distribution.

(4) Each refrigerated vehicle can provide distribution service to multiple customers, and each customer can only be distributed by one refrigerated vehicle, and each refrigerated vehicle is of the same model.

2.2. Model parameter

Constant:

S :Represents the collection of distribution centers, $s=\{1,2,..,S\}$;

K: Represents the collection of customers $k=\{1,2,..,K\}$;

V :Represents the collection of transport vehicles $v=\{1,2,..,V\}$;

h_s :Represents the cost of building distribution centers s at alternative points;

w_s :Represents the unit operating cost of the distribution center s;

Q_s: represents the maximum capacity of the distribution center s;

f_s: indicates the actual storage capacity of the distribution center s;

d_{rk} :Represents the transportation distance from the node r to the customer k;

d_{ks}: represents the distance from the customer to the distribution center s;

c_0: Fixed delivery cost per unit of vehicle;

c_1: the driving cost per unit distance of the distribution vehicle;

U_k: represents the demand of customers k;

Q_v :Represents the maximum carrying capacity of the vehicle v;

Q_{rk} :Represents the quantity of products transported from node r to customer k, $r \in K$;

P :the price of cold chain products transported by the vehicle;

t_k^v :represents the time when the vehicle v arrives at the customer k;

T_k^v :represents the waiting time after the vehicle arrives at the customer in advance;

FT_k^v :represents the service time of the vehicle at the customer;

a_k :1 if the customer belongs to Level I, 0 if not;

b_k :1 if the customer belongs to Level II customer; 0 if not;

g_k :1 if the customer belongs to Level III; 0 if not;

Decision variable:

x_{rk}^v :if the vehicle drives to the customer after leaving from the customer, it is 1; otherwise, it is 0;

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x_{ks}^{v}: 1 if the vehicle drives from the customer to the distribution center; 0 if not;

y_s :1 when establishing distribution center at point, 0 otherwise;

y_k^v:When the demand of the customer point is met by the vehicle, it is 1, otherwise it is 0;

2.3. Customer classification and penalty function setting

Class I customers, which can bring considerable value to the enterprise, are the cornerstone of the current and future profits of the enterprise. Once the enterprise loses such customers, it will cause great losses. This kind of customer has a high requirement on the delivery arrival time of the enterprise. In order to avoid losing this kind of customer, it must be served within the specified time, so the penalty cost is a large number. The function expression is as follows:

$$G_1 = \begin{cases} m_1\left(ET_k - t_k^v\right), t_k^v < ET_k \\ 0, ET_k \le t_k^v \le FT_k \\ q, t_k^v > FT_k \end{cases} \tag{1}$$

Where: G_1 is the penalty function of level I customers; t_k^v is the actual time of vehicle v delivery to customers k; ET_k and FT_k is the delivery time window acceptable to customers k; m_1 is the penalty cost coefficient; q is the penalty cost over time.

Class II customers, this type of customer is the enterprise focus on exploring value and develop into the target of advanced customers. The penalty function of such customers is set as linear growth between the time of arriving at the customer's point in advance and the earliest time difference and penalty cost specified by the customer. When the delivery vehicle arrives at the customer's point in time, in order to avoid customer loss due to too long timeout, the penalty cost is set to increase exponentially. The function expression is as follows:

$$G_2 = \begin{cases} m_2\left(ET_k - t_k^v\right), t_k^v < ET_k \\ 0, ET_k \le t_k^v \le FT_k \\ m_2^{\left(t_k^v - FT_k\right)} + \left(t_k^v - FT_k\right) m_2, FT_k \le t_k^v \end{cases} \tag{2}$$

Where, G_2 is the penalty function for level II customers, and m_2 is the penalty cost coefficient.

The current value and potential value of level III customers are low, so the enterprise should not invest too much limited resources to maintain them. The penalty cost of early arrival and overtime arrival of such customers is set as fixed value. The function expression is as follows:

$$G_3 = \begin{cases} C_2, t_k^v < ET_k \\ 0, ET_k \le t_k^v \le FT_k \\ C_3, FT_k < t_k^v \le FT_k + l \end{cases} \tag{3}$$

Where, G_3 is the penalty function for level III customers, C_2 is the waiting cost of the vehicle arriving at the customer's point in advance, C_3 is the penalty cost of the vehicle delayed delivery over time, and l is the extended receiving time for level III customers.

2.4. Cost analysis of goods damage

The freshness attenuation function of cold chain products is introduced, and the formula is as follows:

$$q(t) = q_0 e^{-\xi t} \tag{4}$$

Formula (4) represents the corrosion loss ratio of products at a certain temperature [12]. Where $\theta(t)$ is the freshness degree of cold chain products at the moment t, θ_0 is the freshness degree of products from the production place, λ_1 is the freshness attenuation coefficient of cold chain products in the process of transportation, λ_2 is the freshness attenuation coefficient of products in the process of loading and unloading of vehicles. The freshness attenuation coefficient λ is usually related to the temperature and oxygen content around the goods. Because the carriage door is opened during loading and unloading, the temperature and oxygen content in the carriage change greatly, and the product freshness attenuation rate becomes faster, so there are $\lambda_1 < \lambda_2$,To sum up, the formula of freight damage cost of cold chain products in the process of transportation and loading and unloading is as follows

$$C_4^1 = \sum_{k \in K} \sum_{v \in V} y_k^v P U_k \left(1 - e^{-\lambda_1 \left(t_k^v - t_0^v\right)}\right) \tag{5}$$

$$C_4^2 = \sum_{k \in K} \sum_{v \in V} y_k^v P Q_k^v \left(1 - e^{-\lambda_2 F T_k}\right) \tag{6}$$

$$C_4 = C_4^1 + C_4^2 \tag{7}$$

Where, Formula (5) is the freight damage cost of cold chain products in the transport process of the distribution vehicle; formula (6) is the freight damage cost of the refrigerated vehicle in the loading and unloading process; t_0^v is the time when the refrigerated vehicle v leaves the distribution center; Q_k^v is the quantity of cold chain products remaining on the vehicle when the refrigerated vehicle leaves the customer point k.

2.5. Mathematical Model

According to the above description, the location and route optimization model of logistics network based on customer classification is constructed. The objective function expression is as follows:

$$\begin{aligned}(1)\min TC = &\sum_{s \in S} (h_s y_s + w_s f_s y_s) + \sum_{k \in K} \sum_{s \in S} \sum_{v \in V} (c_1 d_{ks} x_{ks}^v + c_0 x_{sk}^v) + \\ &\sum_{k \in K} \left(\alpha_k G_1 + \beta_k G_2 + \gamma_k G_3\right) + C_4^1 + C_4^2\end{aligned} \tag{8}$$

$s.t.$

$$\sum_{s=1}^{S} y_s \geq 1 \tag{9}$$

$$\sum_{k=1}^{K} U_k \leq \sum_{s=1}^{S} f_s y_s \leq \sum_{s=1}^{S} Q_s y_s \tag{10}$$

$$\sum_{k=1}^{K} U_k \leq \sum_{v=1}^{V} q_v \leq \sum_{s=1}^{S} f_s y_s \tag{11}$$

$$\sum_{v=1}^{V} y_k^v = 1, \forall k \in K \tag{12}$$

$$\sum_{k \in K} U_k y_k^v \leq Q_v, \forall v \in V \tag{13}$$

$$\sum_{s=1}^{S}\sum_{k=1}^{K} x_{sk}^{v} = \sum_{s=1}^{S}\sum_{k=1}^{K} x_{ks}^{v}, \forall v \in V \tag{14}$$

$$\sum_{v=1}^{V} x_{sz}^{v} = 0, \forall s \in S, z \in S \tag{15}$$

$$\sum_{r=1}^{K}\sum_{k=1}^{K} x_{rk}^{v} \le 1, \forall v \in V \tag{16}$$

$$\alpha_k + \beta_k + \gamma_k = 1, \forall k \in K \tag{17}$$

$$t_k = t_r + FT_r + t_{rk}, \forall k \in K, r \in K, r \ne k \tag{18}$$

$$y_s = \{0,1\}, \forall s \in S \tag{19}$$

$$x_{sk}^{v} = \{0,1\}, \forall k \in K, s \in S, v \in V \tag{20}$$

$$\alpha_k = \{0,1\}, \beta_k = \{0,1\}, \gamma_k = \{0,1\}, \forall k \in K \tag{21}$$

The objective function (8) for distribution center construction costs, operating costs, fixed vehicle distribution costs, transportation cost from distribution center to each customer point, penalty cost of overtime service and cargo damage cost of cold chain products. Constraint formula (9) is the quantity limit of distribution center; Constraint formula (10) is that the actual storage of cold chain products in the distribution center meets the total demand of customers and does not exceed the total maximum capacity of the distribution center; Constraint formula (11) indicates that the actual load capacity of refrigerated vehicle meets the total demand of customers and does not exceed the actual storage capacity of distribution center; Constraint (12) means that each customer can only have one refrigerated truck to serve them; Constraint (13) is that the deadweight of the refrigerated truck cannot exceed its maximum deadweight; Restriction (14) The refrigerated vehicle starts from the distribution center and returns to the original distribution center after completing the distribution; Constraint formula (15) indicates that vehicles cannot travel between the two distribution centers; Constraint formula (16) indicates that each distribution vehicle can only belong to one distribution center; Constraint formula (17) indicates that customers k can only belong to one level of customers; Constraint formula (18) represents the relationship between the arrival time t_k^v of the vehicle v to the next customer k and the arrival time t_s^v of the previous customer s; Constraints (19), (20) and (21) are 0-1 variables. :

3. Analysis of solution methods and examples

3.1. Solution method

Location and path problems are NP-hard problems, and the solving time will increase exponentially with the number of nodes in the distribution network. For complex LRP problems, it is difficult to solve them with accurate algorithms, which will lead to the occurrence of no solution. Due to the relatively large number of factors and nodes in the distribution network considered by the model in this paper, in order to obtain a satisfactory solution quickly, the genetic algorithm will be adopted to solve the problem.

Genetic algorithm was proposed by Professor Joho holland in the United States in 1975 . It simulates the natural selection principle of Darwin's biological evolution. Through mathematical means, it uses computer simulation operation to convert the solving process of problems into the process of chromosome crossing and variation in biological evolution.

Compared with some conventional optimization algorithms, genetic algorithm can usually obtain satisfactory solutions faster when solving some complex combinatorial optimization problems.

3.2. Example analysis

Think about the customer value, a increase number example of cold chain product logistics network location and routing problem is analyzed based on reference , and appropriate modifications are made. The number of candidate distribution centers S is 5, the maximum capacity of distribution centers Q_s is 18t, the construction cost h_s is 350000 yuan, the unit operation cost w_s is 0.5 yuan/kg, the fixed delivery cost of refrigerated vehicles c_0 is 400 yuan/vehicle, the unit transportation cost c_1 is 15 yuan/km, and the unit driving cost of no-load is 0.3 yuan/km. The maximum load Q_v is 8t, the price of cold chain products P is 200 yuan/kg, the penalty cost of timeout q for class I customers is 1500 yuan, the extended receiving time l is 0.5 hour, the penalty cost factor m_1 is 400 yuan/hour, m_2 is 200 yuan/hour, the waiting cost C_2 is 30 yuan, the timeout cost C_3 is 50 yuan, The coefficient of corruption rate of cold chain products in the process of refrigerated vehicle transportation ℓ_1 is 0.03, and that of cold chain products ℓ_2 is 0.06 when the door is opened during unloading. The refrigerated vehicle starts from the distribution center at 4:00 AM and runs at a constant speed of z is 50km/h for distribution to various customers. After completing the distribution task, the refrigerated vehicle returns to the original distribution center.

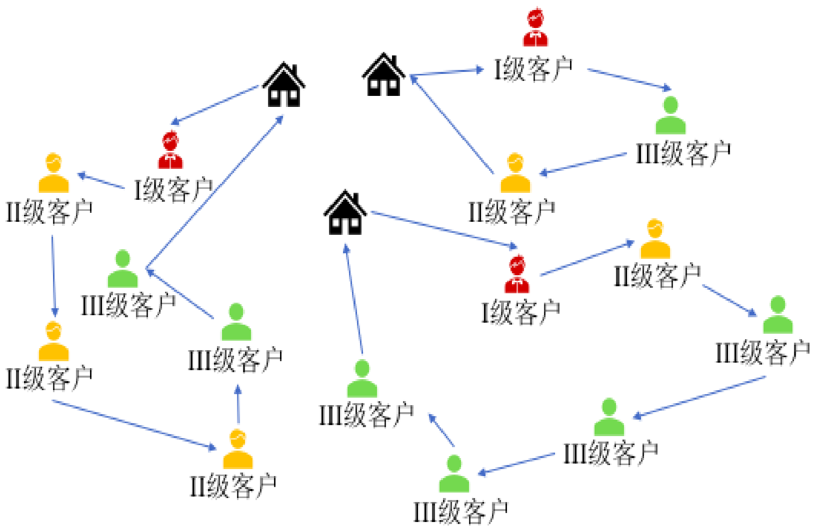

Figure 1 Distribution network diagram of cold chain products by customer classification

(1) Candidate distribution center node information

Node information of candidate distribution centers mainly includes: number of candidate distribution centers, longitude and latitude location coordinates, maximum capacity limit of distribution centers, construction cost and unit operating cost, etc., as shown in Table 1.

Table 1 Parameters related to candidate distribution centers

Distribution center	Longitude coordinates	Latitude coordinates	capacity (t)	Construction cost (yuan)	Unit operating cost (yuan/kg)
1	117.4405	41.05568	18	350000	0.5
2	117.4396	41.04953	18	350000	0.5
3	117.4503	41.06534	18	350000	0.5

4	117.4588	41.05759	18	350000	0.5
5	117.4632	41.05421	18	350000	0.5

(2) Terminal customer point information

Terminal customer point information mainly includes: the number of customer points, the longitude and latitude position coordinates of each customer point, the demand of cold chain products, the time window and service time required by the customer point and the category of the customer, as shown in Table 2.

Table 2 Customer point parameters

Customer point	Longitude coordinates	Latitude coordinates	demand	Time window	Service time	Customer category
Customer 1	117.4402	41.06758	2.5	5:30-7:30	25	I
Customer 2	117.4496	41.06788	0.4	5:00-7:00	10	III
Customer 3	117.4793	41.06586	1.2	6:30-8:00	15	III
Customer4	117.4362	41.06269	1.1	7:00-9:00	15	III
Customer5	117.4556	41.06355	2.6	5:30-7:30	20	I
Customer6	117.4800	41.06123	2.2	6:00-7:00	20	I
Customer7	117.4293	41.06169	1.9	5:00-8:00	20	II
Customer8	117.4468	41.05563	1	6:30-7:30	10	III
Customer9	117.4683	41.06030	1.8	7:30-9:00	15	II
Customer10	117.4566	41.05789	0.3	6:30-9:00	10	III
Customer11	117.4599	41.05422	2.9	4:50-6:30	15	I
Customer12	117.4736	41.00578	1.6	6:30-7:30	15	III
Customer13	117.4538	41.05003	1.8	8:00-9:00	15	II
Customer14	117.4755	41.06986	1.2	7:00-8:00	25	III
Customer15	117.4366	41.05963	0.5	7:30-9:00	10	III
Customer16	117.4468	41.05963	2	6:00-9:00	20	II
Customer17	117.4801	41.04866	0.8	8:00-10:00	15	III
Customer18	117.4678	41.04936	1.8	7:00-9:00	15	II
Customer19	117.4736	41.04469	1.5	5:30-8:30	20	II
Customer20	117.4694	41.04693	2	7:30-9:00	25	II

3.2.1. Consider customer value

According to the above data information, the parameters were substituted into the corresponding expressions and calculated by Matlab2017b programming. The relatively optimal results were obtained, as shown in Table 3.

Table 3 Scheme of this paper

Site selection	Distribution scheme	Not delivered to customers on time	transport Cost (yuan)	Cargo damage Cost (yuan)	punishment Cost (yuan)	Total cost (yuan)
S2	S2-7-3-S2 S3-11-15-S2 S2-14-16-S2 S2-5-17-S2	- - -	4441	180.7	100	704721.7

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	S3-12-1-20-S3	
	S4-18-2-S4	2
S4	S4-9-6-13-8-10-S4	8
	S5-4-19-S4	-

The number of candidate distribution centers is 2, namely, distribution center 2 and distribution center 4. A total of 8 refrigerated vehicles are needed for distribution. The first refrigerated truck starts from distribution center 2 to deliver customers 7 and 3 in turn; The second refrigerated truck delivered to customers 11 and 15 in turn; The third refrigerated truck delivered to customers 14 and 16 in turn; The fourth refrigerated truck is delivered to customers in turn 5 and 17; The fifth refrigerated truck will deliver customer 12, customer 1 and customer 20 successively; The sixth refrigerated truck starts from distribution Center 4 to deliver customers 18 and 2 in turn; The 7th refrigerated truck successively distributes customer 9, customer 6, customer 13, customer 8, customer 10; The eighth refrigerated truck is delivered to customers in turn. 4. The number of customers who did not arrive on time is 2, and the total transportation cost is 4,441 yuan. The damage of cold chain products in the whole logistics network is 180 yuan, and the total cost is 704,440 yuan. The transportation path of refrigerated vehicles is shown in Figure 2.

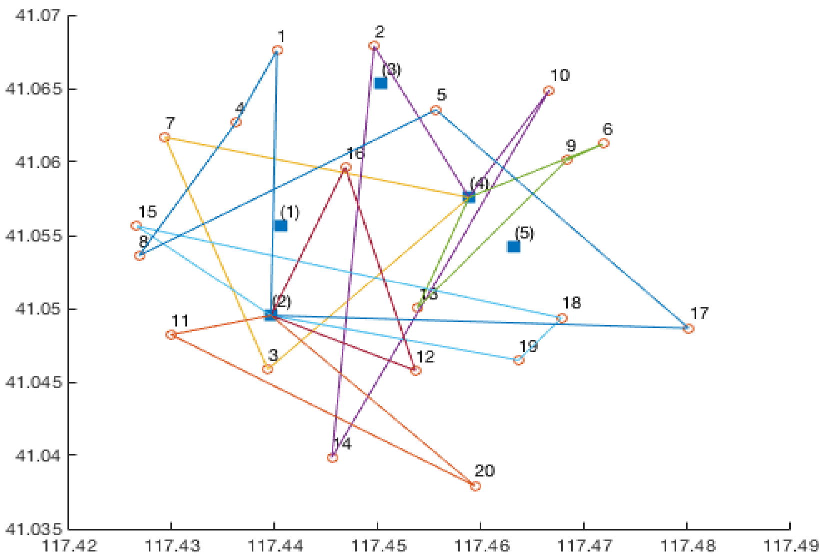

Figure 2 Cold chain product logistics network considering customer value

3.2.2. Customer value is not considered

By calculating the mathematical model of cold chain product logistics network location and route planning without considering customer value, this paper obtains the location of distribution center and the distribution route scheme of refrigerated vehicles (traditional scheme). The penalty cost generated by the failure to deliver to the customer on time is calculated by the penalty cost function, as shown in Table 4.

Table 4 Traditional scheme

Site selection	Distribution scheme	Not delivered to customers on time	transport Cost (yuan)	Cargo damage Cost (yuan)	punishment Cost (yuan)	Total cost (yuan)

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S2	S2-19-18-15-S2	18	4163.3	294.7	874.455	705332.5
	S2-12-16-S2	-				
	S2-1-4-8-5-17-S2	4、17				
	S2-11-20-S2	20				
S4	S4-3-7-S4	-				
	S4-2-14-10-S4	14				
	S4-6-9-13-S4	9、13				

It can be concluded from the above table that the candidate distribution centers 1 and 3 are selected without considering customer value, and a total of 6 refrigerated trucks are dispatched for distribution. The total transportation cost is 4163.3 yuan, the cost of goods damage is 294.7 yuan, and the penalty cost for non-punctual delivery is 874.455 yuan.

3.3. Comparative analysis

Compared with traditional products cold chain logistics network planning scheme, the scheme in this paper sends 8 refrigerated trucks for distribution, so the transport cost is higher than that of the traditional scheme, but the freight damage cost and penalty cost of the scheme are lower than that of the traditional scheme. At the same time, in terms of the number of customers not delivered on time, the scheme in this paper has 2 customers not delivered on time, and they are all level-III customers, while the traditional scheme has 8 customers not delivered on time, including Level-II customers and level-III customers. It can be seen from the cost of goods damage, penalty cost and the number of customers not delivered on time that the scheme in this paper is superior to the traditional scheme in improving customer consumption experience, as shown in Table 5.

Table 5 Comparative analysis

	Scheme of this paper	Traditional scheme	gap
Transportation cost	4441	4163	278
Damage cost	180.7	294.7	-114
Penalty cost	100	874.455	-774.455
Number of customers not delivered on time	2	8	-6

4. Conclusion

Based on the location and route problems of cold chain products, this paper considers the factor of customer value, classiifies customers according to their current value and potential value, and describes the punctuality of refrigerated vehicle distribution by using different timeout penalty functions. A comparative analysis between the cold chain product logistics network considering customer value and the traditional cold chain product logistics network shows that, when considering customer value, the transportation cost of cold chain product logistics network is slightly higher than the traditional scheme, but it is better than the traditional scheme in terms of goods damage cost, penalty cost and the number of customers not delivered on time. Thus, the feasibility and effectiveness of the personalized logistics network for cold chain products provided by this model are verified. The innovation point of this paper lies in the overall planning of the location and route of cold chain logistics network from the perspective of customer value, so as to provide strong support for the location decision and route selection of cold chain logistics enterprises and guarantee the overall operation effect. On the basis of the research in this paper, there are many aspects to be expanded, such as considering the real-time road conditions of refrigerated vehicles in the driving process and the uncertainty of customers' demand for goods, and the diversification of the types of refrigerated vehicles available in distribution centers, so as to make the problem more suitable for the actual life.

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