Research on Green Vehicle Routing Based on Hybrid Genetic Algorithm

Liying Li, Jiaqi Shen*

Liaoning University of Engineering and Technology, School of Business Administration, Huludao, Liaoning, 125105, China

*Corresponding author: 473665702@qq.com

Abstract. In order to solve the green path planning problem in cold chain transportation, this paper uses the freshness decay model to accurately assess the loss of cold chain products in the distribution process and at the same time comprehensively analyzes the impact of multiple factors such as vehicle load and driving speed on fuel consumption and carbon emission efficiency, so as to establish an accurate calculation method for fuel consumption and carbon emission. In addition, the relationship between delivery time and customer satisfaction is discussed in detail, and a customer satisfaction evaluation function is established based on this. And a hybrid algorithm combining the advantages of forbidden search and genetic algorithm is developed to optimize the solution. The balance of dual objectives is brilliantly realized through the arithmetic simulation verification. The dual-objective model constructed in this paper refers to the equilibrium between the minimum cost and the maximum customer satisfaction in the distribution process.

Keywords: Cold Chain Logistics; Green Vehicle Routing; Genetic Algorithm; Taboo Search Algorithm

1 Introduction

With the rapid progress of society and the rapid development of e-commerce, the environmental consumption caused by carbon emissions and fuel consumption in traditional vehicle routing and distribution planning has become increasingly prominent. The development of green logistics conforms to the trend of the times for the sustainable development of the world's economic society, and it is an inevitable requirement for global economic integration and sustainable development. Therefore, green logistics has become an inevitable trend in the development of modern logistics. Moreover, the vehicle routing problem in cold chain logistics distribution has attracted extensive attention. References are derived from: Zhou Xiaoye and Dai Sicong[1] The vehicle path optimization problem of multi-energy hybrid fleet in fresh produce distribution is studied, and effective optimization strategies and methods are proposed. Shiyu Yang et al.[2] constructed a time-division dynamic traffic road network model based on intelligent transportation system, and established a two-stage mixed integer model for dynamic

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vehicle path problem considering urban road classification and dynamic traffic road network. Yong Wang,Huixing Li,Siyu Luo[3] Multi-center Co-distribution Electric Vehicle Path Optimization Problem involves the path planning of multiple distribution centers and electric vehicles, which is optimized by the algorithm so as to improve the distribution efficiency and reduce the operation cost. Zhishuo Liu[4] Aiming at the problem of high distribution cost, a linear programming model with the objective of minimizing the total distribution cost is constructed and a hybrid ant colony algorithm is designed to solve the problem, and experiments show that the algorithm can arrive at a feasible solution in a limited time. Guoqiang He[5] A two-population hybrid genetic algorithm is designed to solve the vehicle path problem with capacity constraints, which improves the global search and local optimization ability of the algorithm. Zhuo Li,Wenxia Li,Yuxiang Ju[6] In order to solve the vehicle path problem with soft time window, the proposed hybrid crow search algorithm HCSA achieves improved optimization quality through adaptive search strategy and multiple neighborhood search operators.

The core objective of this study is to construct a Green Vehicle Route Optimization Model for Cold Chain Logistics (GVRPCLD) and to develop efficient solution algorithms aiming at the dual optimization of transportation costs and environmental impacts in practical applications.

2 Problem Description and Modeling

2.1 Description of the Problem

Given the precise location of the distribution center and the many refrigerated vehicles of the same type that it owns, we will design a distribution plan based on the specific needs of the customer. We have obtained information about the number of customers, their locations, the amount of demand, the time intervals, and the length of service. Each vehicle has a limited maximum cargo capacity. In order to maintain the quality of the cold chain products, the refrigeration system must be relied upon to maintain a low temperature inside the vehicle throughout the distribution process.

The following assumptions will be made:

(1) The number of refrigerated trucks is sufficiently large and of the same model to ensure that the capacity of the trucks meets the maximum loading capacity;

(2) After completing the delivery task and departing from the distribution center, the vehicle will return to the original route, and its driving speed remains stable without worrying about traffic congestion.

(3) A freezer is capable of transporting to a large number of customers, but for each consumer, only one transport is possible.

(4) The demand at each customer point must not exceed the capacity of the vehicle;

(5) Refrigerated trucks will generate fuel consumption and carbon emissions in the process of traveling, and their traveling fuel consumption and carbon emissions are affected by various factors such as real-time load, traveling speed and vehicle characteristic parameters;

(6) In order to maintain a low temperature environment in refrigerated compartments, vehicles need to be cooled during travel and service, and the amount of refrigeration fuel consumed in this process is directly proportional to the amount of carbon emissions and time spent.

(7) The freshness of the goods decreases as the delivery time increases, leading to a certain degree of loss of goods.

2.2 Description of Symbols

The symbol explanations of the article are shown in Table 1.

Table 1. The meaning of symbols

Number	notation	hidden meaning
1	S	Distribution network node set $S = \{0, 1, 2,..., N\}$, a total of $N + 1$ nodes, 0 represents the distribution center
2	S'	The set of customer points $S' = S\backslash\{0\}$, with a total of N customers
3	A	Distribution vehicle set $A=\{1,2,...,K\}$ with K refrigerated vehicles
4	d_{ij}	Distance from node i to node j for vehicles
5	D	Sum of all vehicle delivery distances
6	Q	Maximum vehicle weight
7	w_{ijk}	Load of vehicle k traveling on road (i,j)
8	q_i	Demand at customer point i
9	Z_1	Total cost of distribution
10	Z_2	Average customer satisfaction
11	M_i	Satisfaction of customer dot i
12	S_i	Service time for customer dot i
13	t_{ijk}	Travel time of vehicle k on road (i,j)
14	v	Travel speed of distribution vehicles
15	τ_0	The moment the vehicle departs from the distribution center
16	t_{ik}	The moment vehicle k reaches node i
17	$[e_0 ,l_0]$	Distribution Center Time Window
18	$[e_i ,li]$	Ideal service time window (hard time window) expected by customer i
19	$[E_i ,Li]$	Customer i's acceptable service time window (soft time window)
20	F_{ijk}	The amount of fuel consumption (in liters) generated by vehicle k traveling from node i to node j
21	F'_{ijk}	Fuel consumption of vehicle k from node i to node j due to refrigeration (in liters)
22	μ	Fuel Emission Parameters
23	E_{ijk}	Carbon emissions generated by vehicle k traveling from node i to node j (in kg)
24	E'_{ijk}	Carbon emissions from refrigeration of vehicle k from node i to node j (in kilograms)
25	φ	Fixed dispatch costs for distribution vehicles (in \$/vehicle)
26	gf	Unit time cost of vehicle use (in \$/hour)
27	cf	Price per unit weight of cold chain products (in yuan/kg)

28	θ	Decay factor for freshness of cargo while the vehicle is in motion
29	$\sigma 1$	Fuel consumption rate of the refrigeration system while the vehicle is in motion (in liters/hour)
30	$\sigma 2$	Fuel consumption rate for refrigeration systems of vehicles during distribution services (in liters/hour)
31	λ_f	Unit fuel consumption cost (unit: yuan/liter)
32	λe	Cost per unit of carbon emissions (in \$/kg)
33	ω_e	Time Window Violation Penalty Factor for Early Arrival at Customer Point of Service (in \$/hour)
34	ω_l	Time Window Violation Penalty Factor for Late Arrival at Customer Point of Service (in \$/hour)
35	x_{ijk}	A 0-1 variable that takes the value of 1 when vehicle k is traveling from node i to node j, and 0 otherwise.
36	y_{ik}	0-1 variable with value 1 when customer i is served by vehicle k and 0 otherwise

2.3 Objective Function

The green vehicle routing optimization model of cold chain logistics constructed in this paper is a bi-objective model, with the total distribution cost Z_1 and the average customer satisfaction Z_2 respectively. The aim is to achieve a balance between the two objective functions during the vehicle distribution process. which includes the sum of the fixed usage cost C_1, cargo damage cost C_2, fuel consumption transportation cost C_3, carbon emission cost C_4 , and the penalty cost for violating the time window C_5 of the vehicle during the driving period, as shown in Equation (1); and the average satisfaction of all customers Z_2, as shown in Equation (2);

$$\min Z_1 = C_1 + C_2 + C_3 + C_4 + C_5 \tag{1}$$

$$Z_2 = \frac{\sum_{i \in A'} M_i}{N} \tag{2}$$

1) Cost Function Components.

a) Vehicle fixed cost of use C1 . Vehicles in the distribution process mainly include the time of the vehicle in the driving process, the vehicle suspension of the service period, as well as a fixed cost of sending a vehicle many costs C1, as shown in equation (3).

$$C_3 = \lambda_f \sum_{i \in S} \sum_{j \in S, i \neq j} \sum_{k \in A} F_{ijk} x_{ijk} + \lambda_f \sum_{i \in S} \sum_{j \in S, i \neq j} \sum_{k \in A} F'_{ijk} x_{ijk} \tag{3}$$

b) Cargo damage cost C2. Based on the freshness decay function proposed in reference [7] $\eta(t) = \eta_0 e^{-\theta t}$, as shown in equation (4).

$$C_2 = \sum_{i\in S'}\sum_{k\in A} cfq_i(1-e^{-\theta(t_{ik}-\tau_0)})y_{ik} \tag{4}$$

c) fuel consumption cost C3 and carbon emission cost C4 . Calculate the fuel consumption during vehicle driving based on the existing integrated modal emissions model. Where β_1 is the engine module coefficient, β_2 is the speed module coefficient, and β_3 is the load module coefficient. As shown in equation (6).

$$F_{ijk} = \beta_1 d_{ijk} / v + \beta_2 d_{ijk} v^2 + \beta_3 (w_0 + w_{ijk}) d_{ijk} \tag{5}$$

$$F'_{ijk} = \sigma_1 d_{ijk} / v + \sigma_2 t_{sj} \tag{6}$$

By reading the relevant references, the carbon emissions produced by the vehicle during driving are obtained by multiplying the fuel consumption by the fuel emission factor μ , which gives the carbon emissions (kg) , as shown in equation (7).

$$E_{ijk} = gf \times F_{ijk} \tag{7}$$

The total fuel consumption cost C_3 and the total carbon emission cost C_4 can be calculated according to Eq. (5) to Eq. (7) , as shown in Eq. (8) and Eq. (9), respectively.

$$C_3 = \lambda_f \sum_{i\in S,}\sum_{j\in S i\neq j}\sum_{k\in A,} F_{ijk}x_{ijk} + \lambda_f \sum_{i\in A}\sum_{j\in A, i\neq j}\sum_{k\in B} F'_{ijk}x_{ijk} \tag{8}$$

$$C_4 = \lambda_e \sum_{j\in S, i\neq j}\sum_{k\in A} \mu F_{ijk}x_{ijk} + \lambda_e \sum_{j\in S}\sum_{j\in S, i\neq j}\sum_{k\in A} \mu F'_{ijk}x_{ijk} \tag{9}$$

d) Penalty cost for violating the time window C5. to avoid slow freshness decay requires that the delivery be completed within the time window [ei, li] specified by the customer. The time window penalty cost C5 is calculated as shown in equation (10) and the total time window violation penalty cost C_5 is shown in equation (11).

$$C_5 = \begin{cases} \omega_e(e_i - t_{ik}), 0 < t_{ik} < e_i \\ 0, e_i < t_{ik} < l_i \\ \omega_l(t_{ik} - l_i), l_i < t_{ik} \end{cases} \tag{10}$$

$$C_5 = \omega_e \sum_{i\in S'} \max\{e_i - t_{ik}, 0\} + \omega_l \sum_{i\in A'} \max\{t_{ik} - l_i, 0\} \tag{11}$$

2) Customer Satisfaction.

The timeliness of distribution is crucial in cold chain logistics transportation, which is directly related to customer satisfaction. Specifically, once a customer exceeds the soft time window, the customer satisfaction is 0. The relationship between customer satisfaction and the arrival point of reefer trucks to the customer is shown in Figure 1, and the satisfaction of customer i, M_i, is as shown in Equation (12)

$$C_5 = \begin{cases} \omega_e(e_i - t_{ik}), 0 < t_{ik} < e_i \\ 0, e_i < t_{ik} < l_i \\ \omega_l(t_{ik} - l_i), l_i < t_{ik} \end{cases} \tag{12}$$

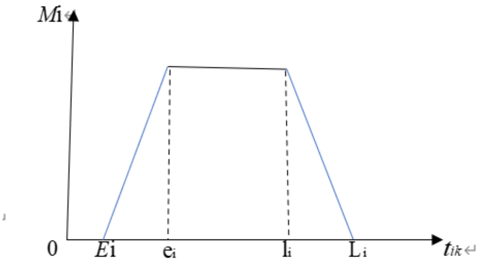

Fig. 1. The relationship between customer satisfaction and delivery time

2.4 Mathematical Models

Construct a two-target GVRPCLD model as shown in Eqs. (13)-(23).

$$\min Z_1 = C_1 + C_2 + C_3 + C_4 + C_5 \tag{13}$$

$$\max Z_2 = \frac{\sum_{i \in S'} M_i}{N} \tag{14}$$

$$\textbf{s.t.} \sum_{i \in S'} q_i y_{ik} \le Q, \forall k \in A \tag{15}$$

$$\sum_{k \in A} y_{ik} = 1, \forall i \in S' \tag{16}$$

$$\sum_{j \in S'} x_{0jk} = \sum_{i \in S'} x_{0k} \le 1, i \ne j, \forall k \in A \tag{17}$$

$$w_{rik} - w_{ijk} = q_i, \forall r \in S, \forall i, j \in S', r \ne i \ne j, \forall k \in A \tag{18}$$

$$\sum_{j \in S'} \sum_{k \in A} x_{0jk} = \sum_{i \in S'} \sum_{k \in A} x_{0k} \le K, i \ne j \tag{19}$$

$$\tau_0 = e_0 \tag{20}$$

$$t_{0k} \le l_0, \forall k \in A \tag{21}$$

$$t_{jk} = t_{ik} + t_{si} + t_{ijk}, \\ \forall i \in S', \forall j \in S, i \neq j, \forall k \in A \tag{22}$$

$$x_{ijk} \in \{0,1\}, y_{rk} \in \{0,1\}, \forall i, j \in S, i \neq j, \forall k \in A, \forall r \in S' \tag{23}$$

Equation (13) for the minimization of the total cost of distribution; Equation (14) for the maximization of average customer satisfaction Equation (15) for the capacity of each vehicle must not exceed its carrying capacity; Equation (16) for each customer only one vehicle to serve them once; Equation (17) for each vehicle has and only one service path, and after serving the customer to return to the distribution center; Equation (18) for the satisfaction of the customer's demand for point i ; Eq. (19) for the departure and departure of the vehicle to maintain the same; Eq. (20) for the vehicle departure time for the opening time of the distribution center; Eq. (21) for the return of the vehicle to arrive at the distribution center to be earlier than the closing time of the distribution center; Eq. (22) for the vehicle to reach the next node of the moment of arrival of the moment of arrival at the previous node; Eq. (23) for the decision-making variables to take the value of the constraints.

3 Hybrid Genetic Taboo Search Algorithm Design

3.1 Based on Traditional Algorithm Design

Genetic Algorithm (GA) is good at global search and suitable for complex optimization problems; Tabu Search Algorithm (TS) is based on local search and avoids local optimums by using taboo tables. Combining the two, the global search of GA and the local optimization ability of TS can be fully utilized to achieve efficient global optimization. The core principle is to use GA to generate new solutions, and then use TS for local optimization to improve the solution quality and accelerate the convergence. Based on this, this paper designs the hybrid genetic forbidden search algorithm with both excellent global search capability.

3.2 Genetic-Taboo Search Algorithm Flow

The flowchart of the hybrid genetic forbidden search algorithm designed in this paper is as follows:

Step 1. Initialize the population: a GA method is used to generate an initial population where each individual represents a possible solution to the problem.

Step 2. Evaluate fitness:For each individual, evaluate the quality of its solution using the fitness function of the problem.

Step 3. Selection operation:Use the selection operation of GA to select a portion of individuals as parents based on the value of the fitness function.

Step 4. Crossover operation:Perform crossover operation on the selected parents to generate new individuals. You can use some common crossover methods in GA, such as single-point crossover, multi-point crossover and so on.

Step 5. Mutation operation:A mutation operation is performed on the generated individuals to introduce a certain degree of randomness. The mutation operation can be realized by changing some genes in the individual or introducing new genes.

Step 6. Taboo search operation:Taboo search operation is performed on the generated individuals.TS is a local search algorithm that avoids getting trapped in local solutions during the search based on a taboo table. Some heuristic rules can be used to guide the search direction.

Step 7. Update population:Add the generated individuals to the population.

Step 8. Repeat the above until the termination condition is met.

4 Simulation Example Analysis

4.1 Data Description

In this paper, Solomon's standard test library application type R1 and RC1 are selected as the research arithmetic cases, which have a distribution center with an opening time of 1000 and 960 minutes, respectively, and a customer service time of 10 minutes in both cases. The example RC206 is chosen for simulation experiments, with the distribution center coordinates of (25, 35) and an opening time of 840 minutes; the number of demand points is 50, and the total demand is 862 weight units. Assuming that one weight unit is 6 kg, the total demand is 862 weight units.

The demand of the vehicle is 5172 kg. The vehicle travels at a fixed speed during the distribution process, and the model parameters take the values shown in Table 2.

Table 2. Model parameter values

number	model parameter	take a value
1	φ	\$180/vehicle
2	P	8 yuan/kg
3	v	60 km/h
4	ω_e	\$7/hour
5	ω_l	\$10/hour
6	θ	0.003
7	σ_1	4 liters/hour
8	σ_2	8 liters/hour
9	μ	50 RMB/hour
10	β_1	1.007×10^{-3}
11	β_2	1.153×10^{-2}
12	β_3	4.012×10^{-4}
13	w_0	1870 kg
14	Q	2800 kg
15	ψ	2.21 kg/l
16	λ_f	\$6.35/liter
17	λ_e	0.08 yuan/kg

The algorithm parameters are set as shown in Table 3, Matlab programming is used and the program running software is Matlab R2021a.

Table 3. Algorithm parameter settings

algorithmic parameter	retrieve a value
Pm (crossover probability)	1
Pc (probability of variation)	0.7
ξ1 (population size of the algorithm)	60
ξ2 (optimized chromosome extraction ratio)	30%
Genmax (maximum number of iterations of the algorithm)	700 Generation
TSGenmax (TS maximum number of iterations)	20th generation
K (number of neighborhood operations)	8 times

4.2 Analysis of Operational Results

After the program has been run 25 times, analysis of the results in Table 4 leads to the following conclusions: (1) The algorithm is optimized to obtain 16 distribution schemes to choose from, all of which use 6 vehicles. (2) The relationship between the two is inversely proportional. (3) Node 1 distribution cost is the lowest, the satisfaction is also the lowest, and node point 16 comparison, its cost is 6.87% lower, satisfaction is 3.7% lower; fully expressed if you want to improve customer satisfaction needs to pay with the cost of large, if the appropriate reduction in customer satisfaction, the distribution cost can be greatly reduced. The total cost fitness curve is shown in Figure 2.

Table 4. nalysis of program operation results

nodal	Z1	Z2	C1	C2	C3	C4	C5	D	K
1	6681.01	0.92	2919.41	1226.07	2053.33	55.72	640.52	834.84	6
2	6692.44	0.921	2921.96	1226.15	2054.54	55.75	648.07	836.97	6
3	6737.05	0.924	2938.14	1225.98	2073.16	56.28	657.54	850.45	6
4	6739.05	0.927	2948.17	1197.8	2087.95	56.7	662.47	858.81	6
5	6753.42	0.929	2958.55	1207.41	2101.71	57.09	642.7	867.46	6
6	6770.98	0.93	2965.78	1237.43	2114.28	57.44	510.1	873.48	6
7	6781.2	0.932	2955	1205.19	2120.49	57.62	638.95	879.5	6
8	6805.26	0.934	2974.74	1212.7	2123.5	57.7	650.96	880.95	6
9	6822.9	0.935	2977.86	1217.62	2128.24	57.83	655.39	883.55	6
10	6855.63	0.936	2992.57	1243.63	2144.86	58.3	630.3	895.81	6
11	6907.05	0.939	3033.77	1227.07	2201.59	59.9	598.75	930.15	6
12	6964.85	0.94	3039.87	1267.72	2215.21	60.29	595.8	935.23	6
13	6979.97	0.941	3041.24	1269.91	2216.99	60.34	605.54	936.37	6
14	7131.49	0.942	3066.46	1252.17	2247.38	61.2	618.31	957.39	6
15	7136.47	0.942	3077.24	1274.34	2239.67	60.98	598.28	966.36	6
16	7159.99	0.946	3114.84	1238.6	2311.85	63.02	545.72	997.7	6

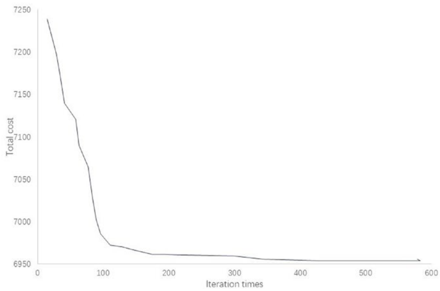

Fig. 2. Total cost fitness curve

4.3 Comparative Analysis with Single-Target GVRPCLDs

In order to ensure the effectiveness of the model, we set up three single-objective optimization problems based on the structure of the model: minimizing the total cost of distribution, minimizing cargo loss, and minimizing carbon emission, which together constitute the green vehicle path problem model for cold chain logistics distribution. In the solution process, we adopt the algorithm design concept proposed in this paper, and form a hybrid algorithm by combining TS-GA to solve the problem. The parameters of the model are shown in Graph-1 and the parameters of the algorithm are shown in Graph-2.The optimization results of the three single objective GVRPCLD models are shown in Table 5, which all have a vehicle usage of 6 vehicles. Comparison of the three single-objective GVRPCLD models shows that the average customer satisfaction of the three single-objective GVRPCLD models is low; the optimization results of the dual-objective GVRPCLD model constructed in this paper can take into account the total cost and customer satisfaction, and the increase of the total cost by a small percentage can obtain a large increase in customer satisfaction, which indicates that the model constructed and the proposed algorithm can achieve a reasonable balance between the total cost of distribution and customer satisfaction. This indicates that the model and the proposed algorithm can strike a reasonable balance between total distribution cost and customer satisfaction.

Table 5. ptimization results of three single-objective GVRPCLD models

Optimization goals	Z1	Z2	C1	C2	C3	C4	C5	D	K
Minimal total cost	7037.2	0.86	3.019.8	1224.2	2089.1	56.33	627.84	841.52	6
Minimal cargo damage	7162.6	0.90	3076.9	1237.8	2261.3	58.56	612.16	905.72	6
Minimal carbon emissions	7068.5	0.89	2937.2	1224.7	2143.6	61.73	637.40	805.31	6

5 Conclusion

In the complex process of cold chain logistics and distribution, enterprises need to weigh the distribution cost, commodity loss, fuel consumption and carbon emission, and customer satisfaction and other dimensions, and to achieve the harmonious coexistence between these optimization goals is an urgent challenge for enterprises. This paper employs a dual-objective function model for research, achieving a greater degree of balance between total distribution cost and customer satisfaction. However, when faced with large-scale, multi-node distribution networks, the computational efficiency and solution speed of the model may pose challenges. Although certain research achievements have been made in the field of green route planning for cold chain transportation, there are still some limitations. Future research can delve into and innovate upon these limitations to promote the sustainable development of the cold chain logistics industry.

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