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Cold Chain Distribution Route Optimization Considering Customer Satisfaction in the Context of Carbon Emission Reduction

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Abstract: *In view of the current situation of high energy consumption, high carbon emission, and increasingly demanding customer requirements for distribution services in cold chain logistics, this paper integrates carbon emission, time, and quality satisfaction factors to construct a path optimization model with the objectives of minimizing cold chain logistics costs and maximizing customer satisfaction, then converts the dual purpose into a single objective model through standardization and linear weighting method. In order to solve the model, it designs an improved genetic algorithm. The model and algorithm are tested using standard Solomon's algorithm, and the results are stable and accurate, which not only proves the effectiveness of the algorithm, but also shows that the model can reduce the cost of cold chain logistics to a low level while ensuring high customer satisfaction.*

Keywords: *cold chain logistics, carbon emissions, customer satisfaction, genetic algorithm*

1. Introduction

In the post-epidemic era, with the proliferation and advancement of Internet technology, food distribution has evolved into an essential aspect of community residents' daily lives. As cold chain logistics can significantly improve food safety and ensure the freshness of food, it is favored by many consumers. The concept of the cold chain was first proposed in 1894 by Albert Barrier and J.A. Ruddich successively. By analyzing the use of Internet of Things technology in cold chain logistics for fruits and vegetables, Ding Yang explains how non-contact identification technology, Savant network, and other crucial technologies can be used to obtain information on every segment of cold chain logistics[1]. Deng Yanwei constructs a performance evaluation system in his analysis of aquatic cold chain logistics to assist enterprises in realizing the monitoring of their operational conditions[2].

However, with the proliferation of distribution distances and demand, cold chain logistics has gradually become a high-energy and high-emissions industry. How to maintain distribution costs low while promoting the development of cold chain logistics in the direction of energy saving, emission reduction, and low-carbon environmental protection has become a significant problem to be solved in today's society[3]. In her analysis of the cold chain supply system, Liu Qianchen introduces the life cycle assessment method and establishes a fresh cold chain inventory model that includes carbon emission costs, which leads to an inventory solution with low carbon as the goal. And the study presents a low-carbon inventory solution as well[4]. Guo Hongxia and Shao Ming point out that integrating a low-carbon economy with agricultural cold chain logistics can improve the profitability and scale of the industry, lower the lag rate, and direct China's fresh cold chain logistics towards a low-carbon and environmentally friendly development path[5].

At the same time, as living standards continue to improve, customers' requirements for delivery services are becoming increasingly demanding, prompting companies to create and maintain reasonable customer satisfaction in order to build a loyal consumer base and boost their core competitiveness[6]. In building a model for cold chain fruit transportation, Ji Linlin et al. optimized the two goals of logistics cost and satisfaction. They also constructed customer satisfaction at various hierarchical levels using a grey-scale whitening power function and designed an optimized genetic algorithm to address the aforementioned issue[7]. Wu Yao et al. used minimizing cold chain logistics cost and maximizing freshness as the objectives of the path optimization model and applied a genetic algorithm with the elite strategy to solve the dual-objective model. They compared their findings to those of the simulated annealing algorithm, and discovered that the two objectives were mutually constrained and there was a benefit backlash[8].

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Based on the above background, this paper overcomes the limitations of the classic path optimization problem for distribution's vehicle dispatching costs alone, introduces green transportation costs such as carbon emission reduction based on the high cargo loss, high energy consumption, and high carbon emission characteristics of cold chain logistics, and establishes a time and quality satisfaction model based on a hybrid time window to guarantee customer satisfaction in urban distribution services, in order to promote the cold chain logistics industry in China High-speed development.

2. Model description and notation

2.1 Model description

The model in this paper focuses on two objectives: maximizing customer satisfaction and minimizing cold chain logistics costs, where customer satisfaction includes time satisfaction and quality satisfaction, and cold chain logistics costs include fixed costs, transport costs, cargo damage costs, refrigeration costs, carbon emissions costs, waiting for costs and penalty costs. The optimization goal of the model is to identify a vehicle delivery path that results in relatively small delivery costs while ensuring a high degree of customer satisfaction. In comparison to previous research, this model can more effectively guarantee customer delivery time and quality while reducing CO2 emissions and accelerating China's "carbon peak" achievement. This model is based on the following scenario: a cold chain logistics company has only one distribution center with a known location and several trucks of the same type, which can provide delivery goods to n customer points simultaneously. Each customer point is served and only served once, and the location, demand, and service time of the customer point are known. Each van departs from the distribution center once and returns to the distribution center at the end of the distribution operation. The total demand for distribution cannot exceed its maximum load. The distribution company seeks a course that minimizes the weighted average of overall cost and client satisfaction.

2.2 Interpretation of symbols

Symbols and variables used in this paper are displayed in Table 1.

Table 1: Symbols and variables

Symbols	Description	Symbols	Description
V	Collection of customer points	p	Cost of loss per kg of goods lost
V_0	Supply points	c_e	Cost per hour of cooling
ET_i	Customer point i Earliest time expected	c_1	Cost of treating each unit of CO_2 emissions
LT_i	Customer point i Expected latest time	u	Emission factors for diesel CO_2
EET_i	Customer point i Earliest acceptable time	m_0	Vehicle deadweight
LLT_i	Customer point i Earliest acceptable time	a_{ij}	Road and model-related parameters
q_i	Customer point i demand	β	Road and model-related parameters
d_{ij}	Distance from node i to node j	c_2	Vehicle waiting cost per hour
v_k	Vehicle's k uniform speed of travel	c_3	Penalty cost per hour of vehicle
h	Unloading rate	g_k	Maximum load capacity of the vehicle k
$k_{\max}$	Temperature-independent reaction rate constants	t_i	Accumulated time of arrival at customer point i
E_a	Activation energy	Dt_i	Cumulative travel time to customer point i
R	Gas constants	Wt_i	Cumulative waiting time on arrival at customer point i
T_1	Temperature in the compartment when transporting refrigerated trucks	Ht_i	Cumulative unloading time on arrival at customer point i

T_2	Refrigerated vehicle compartment temperature after opening	$S(t_i)$	Customer point i Satisfaction with delivery times
β_1	Weighting of time satisfaction	r_{ij}	Fuel volume from node i to node j
β_2	Weighting of quality satisfaction	l_{ij}	Load of the vehicle when traveling from node i to node j
p_f	Fixed cost per vehicle	x_{ijk}	Whether the vehicle k accesses the node j after the node i ; yes = 1, otherwise = 0
p_c	Transport cost per kilometer of vehicle	y_{ik}	Vehicle k Serves customer point i ; yes = 1, otherwise = 0

3. Mathematical models

3.1 Objective function

Considering the costs and satisfaction of cold chain logistics distribution, i.e., fixed cost FC, transportation cost TC, damage cost DC, refrigeration cost EC, carbon emission cost CEC, waiting cost WC, penalty cost PC, time satisfaction CS_1, quality satisfaction CS_2, the objective function of this model is obtained as follows.

$$\begin{cases} \min\ Z_1 = FC + TC + DC + EC + CEC + WC + PC \\ \quad = p_f \sum_{j=1}^{n}\sum_{k=1}^{m} x_{0jk} + p_c \sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{k=1}^{m} x_{ijk} d_{ij} + p \sum_{i=1}^{n}\left(1 - e^{-\psi_2 \times Ht_i - \psi_1 \times (Dt_i + Wt_i)}\right) q_i \\ \quad + c_e \sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{k=1}^{m} x_{ijk}\left(\frac{d_{ij}}{v} + \max\{EET_i - t_i, 0\}\right) \\ \quad + c_1 \cdot u \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{m} x_{ijk}\left[\alpha_{ij}(m_0 + l_{ij}) + \beta v^2\right] d_{ij} \\ \quad + c_2 \sum_{i=1}^{n} \max\{EET_i - t_i, 0\} + c_3 \sum_{i=1}^{n} \max\{t_i - LLT_i, 0\} \\ \max\ Z_2 = \beta_1 \cdot CS_1 + \beta_2 \cdot CS_2 \\ \quad = \beta_1 \cdot \sum_{i=1}^{n} S(t_i) + \beta_2 \cdot \sum_{i=1}^{n} e^{-\psi_2 \times Ht_i - \psi_1 \times (Dt_i + Wt_i)} \end{cases}$$

To simplify the calculation, the two objective functions are unified as a minimization problem.

$$\begin{cases} \min\ Z_1 = FC + TC + DC + EC + CEC + WC + PC \\ \min - Z_2 = -\beta_1 \cdot CS_1 - \beta_2 \cdot CS_2 \end{cases}$$

Since the two objective functions have different magnitudes, we first normalize them by dividing Z_1 by the constants B_1 and Z_2 by the constants B_2, after which we use weighting coefficients to sum them and assign a weight of 0.5 to cold chain logistics cost and customer satisfaction respectively, transforming the dual objective problem into a single objective problem: The following is a summary of the problem.

$$\min Z = 0.5\frac{Z_1}{B_1} - 0.5\frac{Z_2}{B_2}$$

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3.2 Constraints

$$\sum_{i=1}^{n} x_{ijk} = y_{jk} \quad j = 1, 2, \cdots, n, \forall k \tag{1}$$

$$\sum_{j=1}^{n} x_{ijk} = y_{ik} \quad i = 1, 2, \cdots, n, \forall k \tag{2}$$

$$\sum_{i=1}^{n} q_i y_{ik} \leqslant g_k \quad , \forall k \tag{3}$$

$$\sum_{k=1}^{m} y_{ik} = 1 \quad , i = 1, 2, \cdots, n \tag{4}$$

$$\sum_{k=1}^{m} \sum_{j=1}^{n} x_{ijk} \leqslant m \quad , i = 0 \tag{5}$$

$$\sum_{j=1}^{n} x_{ijk} = \sum_{j=1}^{n} x_{jik} = 1 \quad , i = 0, k = 1, 2, \cdots, m \tag{6}$$

$$\sum_{i=1}^{n} \sum_{k=1}^{m} y_{ik} = n \tag{7}$$

$$t_i + \frac{d_{ij}}{v} + \max\{EET_i - t_i, 0\} + \frac{q_i}{h} \leqslant t_j \tag{8}$$

$$t_i \leqslant LLT_i \tag{9}$$

$$t_i = Dt_i + Wt_i + Ht_i \tag{10}$$

$$S(t_i) = \begin{cases} 0 & , \ t_i < EET_i \\ \dfrac{t_i - EET_i}{ET_i - EET_i} & , \ EET_i \leqslant t_i < ET_i \\ 1 & , \ ET_i \leqslant t_i < LT_i \\ \dfrac{LLT_i - t_i}{LLT_i - LT_i} & , \ LT_i \leqslant t_i < LLT_i \\ 0 & , \ t_i \geqslant LLT_i \end{cases} \tag{11}$$

$$\psi_1 = k_{\max} \exp\left(- \frac{E_a}{RT_1}\right) \tag{12}$$

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$$\psi_2 = k_{\max}\exp\left(-\frac{E_a}{RT_2}\right) \tag{13}$$

Eq. (1) and Eq. (2) indicate that each demand point can only be visited once, once in and once out; Eq. (3) indicates that the total amount of distribution per vehicle does not exceed the maximum capacity of this vehicle; Eq. (4) indicates that each demand point is served by only one vehicle; Eq. (5) indicates that the number of vehicles dispatched does not exceed the total number of vehicles owned by the supply point; Eq. (6) indicates that all vehicles depart from the supply point and return to the supply point after service is completed; Eq. (6) indicates that all vehicles depart from the supply point and return to the supply point; equation (7)(8) indicates the time window constraint for each customer point; equation (9) indicates that the delivery vehicle can only arrive before the latest service time accepted by the customer; equation (10) indicates that the time for the vehicle to arrive at the demand point from the distribution centre is the sum of the cumulative travel time, cumulative waiting time and cumulative unloading time on arrival; equation (11) indicates the calculation of time satisfaction; equation (12)(13) represents the calculation related to quality satisfaction.

4. Genetic algorithm design

4.1 Coding design

In this paper, natural number coding is used. The length of the chromosome is n, where n indicates the number of customer points. The distribution center is coded as 1, and the individual customer points are coded as 2,3,4,...,n +1. The coded chromosomes are obtained by randomizing the codes of the customer points.

4.2 Stock initialisation

The population consists of coded chromosomes, and the initial population size is set as pn .

4.3 Decoding design

Taking a chromosome as an example, q_j represents the demand of the j client point in the chromosome, if $\sum_{j=1}^{a} q_j \leqslant g_k$ and $\sum_{j=1}^{a+1} > g_k$, then insert 1 after the a position of the chromosome until it traverses to the last client point and insert 1 after this client point to get the decoded chromosome.

4.4 Adaptation function

The objective function is $\min Z = 0.5\frac{Z_1}{B_1} - 0.5\frac{Z_2}{B_2}$, and a larger fitness function means that the chromosome is more suitable for survival, so the inverse of the objective function is used as the fitness function, i.e., $f_i = \frac{1}{Z}$.

4.5 Genetic manipulation

4.5.1 Selection

$Step\,1$: Two chromosomes were randomly selected from the population.

$Step\,2$: The fitness function values of these two chromosomes are compared, and the one with the more excellent fitness value is selected as the optimal chromosome and saved directly for the next generation.

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$Step\,3$: Repeat this process over and over again.

4.5.2 Crossing

$Step\,1$: Two chromosomes were randomly selected from the population.

$Step\,2$: A randomly selected segment of sub-paths from chromosome 1.

$Step\,3$: A new chromosome is obtained by placing this sub-path in front of chromosome 2 and removing the client points in the original chromosome 2 that duplicate the sub-path.

4.5.3 Variation

A new chromosome is obtained by picking two client sites at random on a chromosome and swapping the positions of the two client sites.

4.6 Termination conditions

The program is terminated when the maximum number of iterations is reached, and this termination condition allows the algorithm to control the solution accuracy and running time.

5. Example tests and analysis of results

5.1 Calculation example design

The CPU of this experimental platform is Intel(R) Core(TM) i5-1035G1 1.19 GHz with 8 GB of RAM and a Windows 10 64 operating system. All code was implemented on Matlab (version R2017a).

The primary test data in this paper are the speed of the reefer truck is 60km/h , the capacity is 150 kg , the unloading rate is 1400 kg/h . The temperature of the car during the journey is $-15°C$, the door is opened $-10°C$, the reaction rate is $5\times10^{-14}s^{-1}$, the activation energy is 100kJ/mol , the gas constant is 8.314$J/mol\cdot K$, the percentage of damage during transportation is 0.0008/h , the unloading process is 0.0012/h [9]. Time and quality satisfaction are both weighted at 0.5. The fixed cost of the vehicle is 500 yuan/vehicle and the cost of transporting the vehicle is 1.60 yuan/km . The CO_2 emission factor is 2.6kg/L and the cost of treating each kg of CO_2 emissions is 0.25 yuan, the dead weight of the truck is 3200kg , α_{ij} is taken as 0.15, and β is taken as 3.4[10].The cost of cargo damage is 2 yuan/kg [3] . Refrigeration cost is 50 yuan/h [3] . The waiting cost is 100 yuan/h and the penalty cost is 100,000 yuan/h [3].

5.2 Analysis of results

5.2.1 Determination of the objective function

Using Solomon arithmetic example c102, 2000 iterations, 30 customer points, and 4 vehicles. The optimal values of the two single objective functions are first found separately, and the results are shown in Figure 1 and Figure 2.

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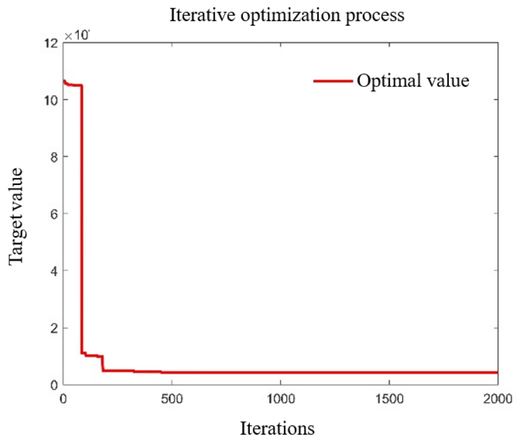

Figure 1: Iterative process for cost

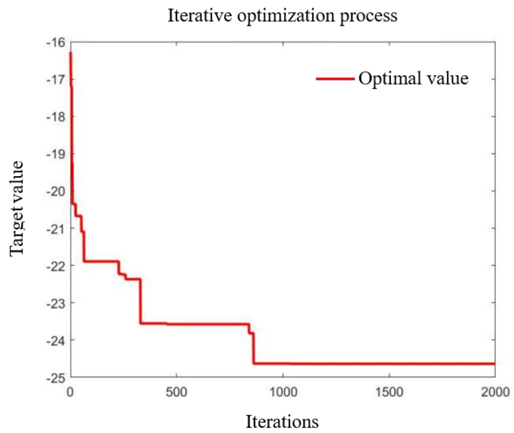

Figure 2: Iterative process for satisfaction

Because the minimum cost is 4163.84 yuan and the maximum satisfaction is 24.64, so let $B_1 =$ 4251.07 and $B_2 =$ 25.78. Then the objective function is:

$$\min Z = 0.5\frac{Z_1}{4163.84} - 0.5\frac{Z_2}{24.64}$$

5.2.2 Algorithm test results

Table 2: Algorithm test results

Example of an algorithm	Number of vehicles	Optimal value of the objective function
c104-30	4	0.12
c109-30	4	0.10
c205-30	4	0.06
r107-30	3	-0.03
r112-30	3	-0.05
r204-30	3	-0.09
r210-30	5	-0.06
rc104-30	5	0.22
rc201-30	5	0.14
rc206-30	5	0.18

The algorithm was tested using Solomon arithmetic cases c104, c109, c205, r107, r112, r204, r210, rc104, rc201, and rc206, with a client point count of 30 and a maximum iteration count of 2000. The demand was highest for arithmetic cases beginning with rc, second highest for cases beginning with c, and lowest for cases beginning with r. The test results are displayed in Table 2.

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As can be observed from the above table, the results of solving the 10 sets of Solomon cases with the genetic algorithm all revolve around 0. The solution quality is high, indicating that the algorithm has good stability. By analyzing the solution results, it can be seen that the lower the customer demand, the lower the number of vehicles used, and the smaller the corresponding optimal value of the objective function will be.

5.2.3 Path optimization results

The optimal value of the objective function is 0.07 using Solomon's algorithm c107 with 10,000 iterations and 4 vehicles. Path optimization results are shown in Figure 3 and Figure 4.

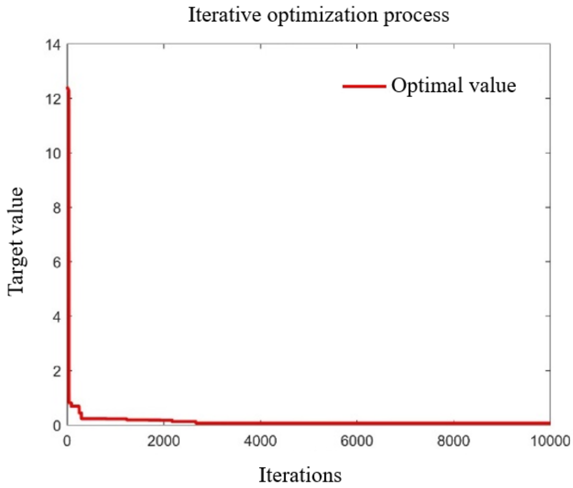

Figure 3: Iterative process

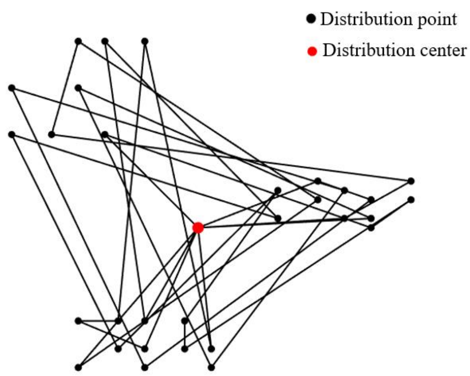

Figure 4: Optimal path

6. Research conclusions and future prospects

This paper constructs a cold chain logistics path optimization model based on low carbon and customer satisfaction. The model first introduces time and quality satisfaction, followed by cargo damage cost, refrigeration cost, and carbon emission cost according to the characteristics of cold chain logistics. Finally, this paper uses the genetic algorithm to solve the model. Through several tests of Solomon's algorithm, the results are found to be around 0, demonstrating the excellent stability and accuracy of this algorithm and its capacity to more effectively balance the two goals of customer satisfaction and cold chain logistics cost.

Although this paper takes into account factors such as low carbon and customer satisfaction, there are still significant limitations. For example, all vehicles travel at the same and constant speed because the effect of road conditions on vehicle speed is not considered, which could be further improved.

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References

[1] Ding Yang. Research on the application of Internet of things technology in cold chain logistics of fruits and vegetables [J]. Logistics Engineering and Management, 2017,39(09):61-63.
[2] Deng Yanwei, Wu Wenbing, Xu Jinli, Zhang Yihua. Research on the performance evaluation index system of aquatic product cold chain logistics [J]. Management Modernization, 2013(05):85-87.
[3] Li Yanming. Research on the optimization of cold chain logistics VRP under the threshold of low carbon vision [D]. Yanshan University, 2017.
[4] Liu Qianchen. Research on Cold Chain Logistics Considering Carbon Emissions [D]. Tsinghua University, 2010.
[5] Guo Hongxia, Shao Ming. Research on the reengineering of agricultural cold chain logistics process based on the low-carbon economy[J]. Anhui Agricultural Science,2012.
[6] Wang X, Cao W. Research on optimization of distribution route for cold chain logistics cooperative distribution of fresh e-commerce based on price discount[J]. Journal of Physics Conference Series, 2021, 1732:012041.
[7] Ji Linlin, Wang Qingwei, Zhou Hao, Zheng Mei-Mei. Cold chain fruit path optimization considering customer satisfaction[J]. Journal of Zhejiang University (Engineering Edition),2021,55(02):307-317.
[8] Wu Yao, Ma Zujun, Zheng Bin. Collaborative production-distribution scheduling of perishable goods with freshness constraints[J]. Computer Applications,2018,38(04):1181-1188.
[9] Wang Min. Genetic algorithm-based cold chain logistics network node location research [D]. Hunan University, 2010.
[10] Li J, Zhang JH. Research on the influence of carbon trading mechanism on logistics distribution path decision[J]. Systems Engineering Theory and Practice,2014,34(07):1779-1787