International Journal of Information Technology and Web Engineering
Volume 19 • Issue 1

Research on VRP Model Optimization of Cold Chain Logistics Under Low-Carbon Constraints

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ABSTRACT

The research in this article aims to consider low-carbon factors, through reasonable vehicle allocation and optimization of distribution routes, to achieve high satisfaction and low total cost, and to provide an optimized solution for fresh food distribution companies. In this article, cargo damage cost, energy cost, and carbon emission cost are added to the total cost, and customer satisfaction constraints based on time and quality are added, respectively, to construct a multi-vehicle cold chain VRP model under the low-carbon perspective. In order to obtain a good initial path method, a good chromosome is generated and added to the initial chromosome population according to the constraints of the vehicle type and time window, and the local elite retention strategy is combined to speed up the population convergence. Finally, taking the data of A Fresh Food Company as an example, the MATLAB software is used to realize the programming, which verifies the validity and superiority of the multi-vehicle cold chain VRP model under the low-carbon perspective.

KEYWORDS

Cold chain logistics, low-carbon environment, multi-vehicles, partheno genetic algorithm, VRP optimization

INTRODUCTION

In recent years, cold chain logistics has developed rapidly. As a representative industry for consumption upgrades in the logistics industry, it has received extensive attention (L. Zhang et al., 2019). China's aquatic product market, meat product market, agricultural product market, quick-frozen food market, and dairy product market all have broad development prospects. According to statistics, in 2017, the total demand for cold chain logistics in China reached 147.5 million tons, an increase of 22.5 million tons over the previous year. The total value of currency in circulation reached four trillion yuan, an increase of 18% year-on-year. The total revenue of the logistics industry was 255 billion yuan, a year-on-year increase of 13.3% (Y. Zhang et al., 2020).

DOI: 10.4018/IJITWE.335036
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The low-carbon concept advocated by the Chinese government continues to deepen, and cold-chain logistics distribution companies are gradually integrating low-carbon in the distribution process, comprehensively considering economic and environmental benefits (Chaudhuri et al., 2018). In the field of cold chain distribution, some experts and scholars have put forward corresponding suggestions for the low carbon emission of cold chain logistics (Rahmani et al., 2018). In order to enable cold chain distribution companies to achieve the goal of energy saving and emission reduction (Li et al., 2022), many scholars take carbon emission factors into consideration when studying the path optimization problem of a single distribution center and the path optimization problem of multiple distribution centers (Behzadi et al., 2013).

Taking into account the insufficient capacity of a single distribution center, scholars have gradually shifted from the study of single distribution center path optimization to multi-distribution center path optimization, taking carbon emission factors into consideration (Azad et al., 2022). However, this kind of research is relatively rare (Tan et al., 2006). Based on the concept of green logistics development (Kainuma & Tawara, 2006), some scholars have cost carbon emissions and proposed a cold chain distribution path optimization problem in which enterprises have multiple distribution centers (Gunasekaran & Ngai, 2012). Some scholars have proposed a multi-park green vehicle routing problem (Rabbani et al., 2018), constructed a multi-objective mathematical model that maximizes revenue (Lai et al., 2004), minimizes cost, minimizes time, and minimizes emissions and uses an improved ant colony optimization algorithm to effectively solve it (Jayaram & Tan, 2010). Some scholars have studied the multi-park vehicle routing problem with time windows (Chen, 2021). Under the constraints of time windows, vehicle capacity, fleet size, etc., they have constructed a multi-objective mathematical model with minimum total cost, fuel consumption, and carbon dioxide emissions as the optimization goals (W. Wang et al., 2021). A meta-heuristic algorithm based on ant colony algorithm is proposed to solve the problem (Ren et al., 2020).

In summary, domestic and foreign scholars have conducted certain research on the optimization of ordinary cold chain logistics (Obi et al., 2020), semi-open multi-distribution center cold chain logistics distribution path optimization, and cold chain distribution path optimization considering carbon emissions (Liu et al., 2021). However, in studying the optimization of the cold chain joint distribution route considering carbon emissions (Borumand & Beheshtinia, 2018), the related solving algorithms mainly focus on basic heuristic algorithms (Xiao & Konak, 2017), and there may be problems that consider the related costs in the distribution process (Bai et al., 2022). Cost benefit analysis is crucial in the optimization of cold chain joint distribution paths considering carbon emissions. The cost mainly includes direct costs, indirect costs, and carbon emission costs. The direct costs include direct expenses such as labor, vehicles, fuel, and maintenance. Indirect costs include such expenditures as management expenses, warehousing costs, etc. Carbon emission costs are typically used to measure environmental impacts. This may include government mandated carbon taxes or carbon trading costs. Optimizing distribution routes can reduce transportation mileage, fuel consumption, transportation costs, and reduce traffic congestion. Moreover, optimizing delivery routes can also reduce carbon emissions, improve air quality, and have a positive impact on the environment. In this paper, cargo damage cost, energy consumption cost, and carbon emission cost are added to the total cost (Wang & Wen, 2020), and customer satisfaction constraints based on time and quality are added to construct a multi-vehicle cold chain VRP Model under a low-carbon perspective (S. Zhang et al., 2019).

MATERIALS AND METHODS

VPR Basic Theory

VRP refers to formulating distribution rules for distribution vehicles, specifying optimization goals (such as minimum cost), and meeting corresponding constraints (such as not exceeding in terms of vehicle load and minimum delivery vehicles) (S. Wang et al., 2017). The delivery route and transportation vehicles are dispatched reasonably and effectively, so as to realize the most optimized dispatching plan (Tao et al., 2023). Effective vehicle routing scheduling can play a positive role in reducing distribution costs, increasing economic benefits, and saving time, and the transportation paths obtained with different objective functions are also different. Therefore, when optimizing the route plan, the preconditions for optimization must be determined. In the case that the distribution cost is only affected by the transportation distance, the minimum transportation distance should be used as the optimization purpose. In this case, the more difficult to calculate and less effective constraints can be ignored, so that the calculation speed can be increased, and time and effort can be saved. However, not all models have the least travel distance and the least cost, and the shortest distance is no longer suitable when the high-speed cost and the related cost under the rigid constraints are so large.

The precise algorithm is to obtain the optimal solution of the model by expressing the relationship between the quantity of the VRP model. The mathematical programming method is used to express it, specifically the cutting plane method, network flow algorithm, dynamic programming method, and other methods. The design of precise algorithms can only be applied to specific models, is not very adaptable, and does not have strong expansion capabilities. In the process of solving the VRP model problem, there are strict requirements on the mathematical programming method, which also shows that when the model scale is larger, the calculation amount of the algorithm will also increase several times, which is greatly restricted in more complex practical use.

The heuristic algorithm is researched on the basis of precise algorithm. The VRP problem is a Non-deterministic Polynomial (NP-hard problem. It is difficult to study accurate and efficient solving algorithms. In order to solve the drawbacks of too long calculation time and to quickly and accurately obtain the optimal solution or satisfactory solution of the model, academic experts have explored more heuristic algorithms:

(1) **Construction heuristic algorithm.** The algorithm is to add the points that meet the requirements into the route, in order and under certain criteria, until all the points are added to the end. This algorithm determines the maximum saving model according to certain rules or puts new requirements into the current model according to the principle of minimum cost and optimizes it by comparing the current path model at each step.
(2) **Improved heuristic algorithm.** The algorithm is based on the principle of the local search algorithm. It is divided into k-opt algorithm and λ interchange algorithm. The k-opt algorithm uses the method of transforming k edges or arcs to change the initial solution, and after calculating a relatively optimized solution, it continues to loop until it cannot be optimized and then stops. The lambda-interchange algorithm is improved by using repositioning, which specifically refers to the repositioning of multiple consecutive vertices (within the same path) in the other two vertices.
(3) **Sub-heuristic algorithm.** This algorithm is an algorithm with strong optimization capabilities among many VRP solving algorithms. Its principle is to use the initial solution as a starting point and then perform a local optimization on the current solution loop to find the optimal solution. At present, this algorithm is used most frequently, has a wider application range, is more practical, and can better simulate the actual state.

Multi-Model Cold Chain VRP Model Assumptions and Related Parameters

L {l|l=1, 2,..., L} ——the collection of delivery vehicles;

Kl- The number of l type vehicles; m-l type vehicles; Ql-type l vehicle maximum load (t); pfl -the fixed cost of a type l refrigerated vehicle (yuan/vehicle); pcl - the transportation cost per kilometer (yuan/km) of a type l refrigerated vehicle; fl-the fuel consumption per kilometer (L/km) of a type l vehicle; nml -l refers the number of customers delivered by the mth vehicle of l type vehicle; njlm -the jth customer delivered by the mth vehicle in the I type vehicle.

$$x_{ij}^{lm} = \begin{cases} 1 & \textit{the mth vehicle of I type vehicle from i to j} \\ 0 & \textit{other wise} \end{cases} \quad i \in N, m \in k_l, l \in L \tag{1}$$

$$y_{i}^{lm} = \begin{cases} 1 & \textit{ith customer delivered from mth vehicle of I type vehicle} \\ 0 & \textit{other wise} \end{cases} \quad i \in N, m \in k_l, l \in L \tag{2}$$

Equations 1 and 2 show the construction of a multi-vehicle cold chain VRP model under the low-carbon perspective.

Under the premise of considering multiple models, it includes factors such as fixed costs, transportation costs, vehicle maximum load limits, customer satisfaction, penalizes costs for cargo damage costs, energy costs, carbon emissions costs, and time windows for early and late arrivals of transport vehicles, and the time and quality satisfaction constraints based on MTW are added to the model.

Multi-Model Cold Chain VRP Objective Function

Regarding the objective function and the calculation method of customer satisfaction based on time and quality, the Arrhenius formula and the total deterioration rate equation of the goods are used to calculate the amount of cargo damage and the cost of cargo. The energy cost is calculated based on the operation steps of the refrigerated truck and the operation mechanism of the refrigeration unit. For the operation of refrigerated vehicles, it is necessary to consider the energy consumption of the refrigeration unit. Collect energy consumption data of refrigerated vehicles, including the power and working hours of the refrigeration unit. We calculate CO2 emission cost based on the input-output method with fuel consumption as input data and calculate overall customer satisfaction based on MTW and deterioration rate. For the cost of carbon emissions, we first collect specific information about refrigerated vehicles, including model, fuel type, transportation distance, etc. According to the input-output method, calculate carbon dioxide emissions using fuel consumption data. This can be calculated by converting fuel consumption into carbon emissions using standard carbon emission coefficients. Then, calculate the cost of carbon emissions based on the price of carbon dioxide emissions or external costs. Taking into account factors such as carbon emission costs, energy costs, and customer satisfaction, a comprehensive cold chain logistics optimization model can be established to minimize costs while maximizing the quality of goods and customer satisfaction. Such a model can provide important decision-making support for the sustainable development of the cold chain logistics industry.

The objective function of the multi-vehicle cold chain VRP problem under the low-carbon perspective is:

$$\text{Min}z = p_f^l \sum_{j=1}^{N}\sum_{l=1}^{L}\sum_{m=1}^{k_l} x_{0j}^{lm} + p_c^l \sum_{i=0}^{N}\sum_{j=0}^{N}\sum_{l=1}^{L}\sum_{m=1}^{k_l} x_{ij}^{lm} d_{ij} + p\sum_{i=1}^{N}\left(1 - e^{-\text{Æ}_2 \times Ht_i - \text{Æ}_1 \times \left(t_i - Ht_i\right)}\right) q_i + c_e \sum_{i=1}^{N}\sum_{l=1}^{L}\sum_{m=1}^{k_l} x_{0j}^{lm}\left(Dt_i + Wt_i\right) + Cu\sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{l=1}^{L}\sum_{m=1}^{k_l} x_{ij}^{lm} d_{ij} f_l + c_1 \sum_{i=1}^{N}\max\left(EET_i - t_i, 0\right) + c_2 \sum_{i=1}^{N}\max\left(t_i - ELT_i, 0\right) \tag{3}$$

Equation 3 means that the total delivery cost is minimized, including the fixed cost, transportation cost, cargo damage cost, energy cost, carbon emission cost, transportation vehicle waiting cost, and transportation vehicle late arrival penalty cost.

Multi-Model Cold Chain VRP Constraints

The constraints that the objective function of the multi-vehicle cold chain VRP model must meet under the low-carbon perspective are:

$$\sum_{i=1}^{N}\sum_{l=1}^{L}\sum_{m=1}^{k_l} q_i y_i^{lm} \le Q_l, \ \forall l \in L, \forall m \in k_l \tag{4}$$

$$\sum_{j=1}^{N}\sum_{l=1}^{L}\sum_{m=1}^{k_l}x_{ij}^{lm}=\sum_{j=1}^{N}\sum_{l=1}^{L}\sum_{m=1}^{k_l}x_{ji}^{lm}\leq 1,\ i=0 \tag{5}$$

$$\sum_{i=1}^{N}\sum_{l=1}^{L}\sum_{m=1}^{k_l}x_{ij}^{lm}=1,\ \forall j\in N,\forall j\in N` \tag{6}$$

$$\sum_{i=0}^{N}\sum_{j=0}^{N}\sum_{l=1}^{L}\sum_{m=1}^{k_l}x_{ij}^{lm}-\sum_{j=0}^{N}\sum_{i=0}^{N}\sum_{l=1}^{L}\sum_{m=1}^{k_l}x_{ij}^{lm}=0,\ \forall l\in L,\forall m\in k_l \tag{7}$$

$$EET_i\leq t_i\leq ELT_i \tag{8}$$

$$t_i=Dt_i+Wt_{i.}+Ht_i \tag{9}$$

$$s\geq ë \tag{10}$$

Formula 4 is that the total demand on the route of the distribution refrigerated truck cannot exceed the maximum load of the refrigerated truck. Formula 5 ensures that the vehicle is sent from the distribution point and returns. Formula 6 ensures each customer is served by a vehicle of a certain model. Formula 7 is the conservation formula for traffic flow, which means that for each incoming customer, the vehicle must leave. Formula 8 is that the delivery vehicle can only arrive within the maximum service time period. Formula 9 is the time to arrive at customer i. Formula 10 indicates that the customer's overall satisfaction with time and quality is not less than λ.

Multi-Vehicle Cold Chain VRP Partheno Genetic Algorithm Design Under Low-Carbon Vision

By studying the literature review related to multi-vehicle VRP, it is found that most scholars use the traditional genetic algorithm based on parental breeding. Single parent genetic algorithm is a common optimization technique. The single parent genetic algorithm has efficient computational performance because it does not require complex crossover and mutation operations, but adopts simple parent selection and new individual generation strategies. This makes the calculation time of the algorithm shorter than other genetic algorithms. Single parent genetic algorithm can be applied in various problem fields because its operation does not depend on specific problem structures. In addition, single parent genetic algorithms can flexibly adjust parameters to adapt to various problems. Single parent genetic algorithm has good robustness in selecting initial solutions and adjusting parameters, so it is not easy to fall into local optimal solutions when dealing with practical problems. In the literature that uses partheno genetic algorithm to solve the multi-vehicle VRP model, there is no single parent based on the local elite retention strategy. Genetic algorithm is used to solve the problem in this study. The specific flow of the algorithm is as follows.

Step 1 **Chromosome coding**. We use the principle of "path first, customer second," and add the constraints of the vehicle model and the maximum time window for customers to receive service.

Step 2 **Initialize the population**. We add the constraint factors of the vehicle model and the maximum time window for customers to accept the service to order the visits.

Step 3 **Chromosome fitness calculation.** We calculate the fitness of all sub-paths after decoding.

Step 4 **Partial elite retention.** We randomly group the chromosomes in the population, each group gets a total of eight chromosomes, and the best chromosomes in the region are directly saved to the offspring.

Step 5 **Single parent genetic manipulation.** We perform seven different single parent genetic operations on the preserved local best chromosomes, and the seven chromosomes generated from each chromosome are together with the previous generation form offspring.

Step 6 **We determine whether the termination conditions are met.** If satisfied, we terminate and output the result, otherwise go back to Step 3.

RESULTS AND ANALYSIS

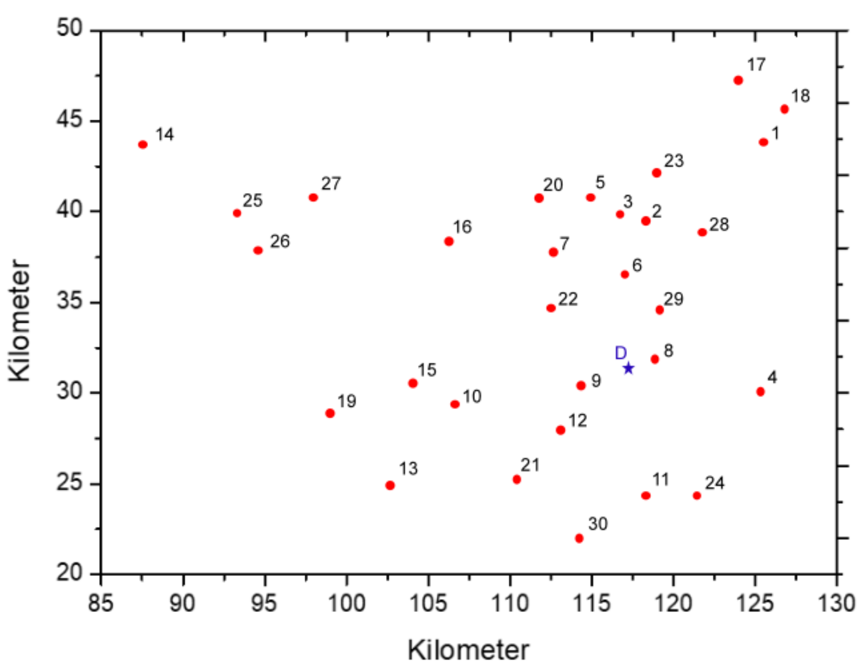
Empirical Result Analysis

A Fresh Food Company is a large-scale food company mainly dealing in fresh products such as vegetables, fruits, meat and poultry, and aquatic products. A Fresh Food Company adopts high-tech cold storage facilities and implements full cold chain control to provide distribution to major shopping malls across the country. Most of its distribution branches are located in first-tier cities and have a variety of types of refrigerated vehicles. This paper studies the cold chain logistics VRP distribution problem of A Fresh Food Company, collects relevant data of A Fresh Food Company based on online information collection and actual investigation, and conducts an empirical analysis. This article only selects the distribution data of a certain regional branch of A Fresh Food Company as the research object. In the distribution task of a certain day, there are 30 customers who need to distribute, and the distribution center is denoted by D (Figure 1).

The data corresponding to the model-related parameters in the actual operation of A Fresh Food Company are:

(1) **Vehicle related parameters.** The average speed of the three types of refrigerated trucks is 60km/h, and the diesel price is RMB 6.59 per liter.
(2) **Carbon emission cost parameters.** The CO2 coefficient of diesel is 2.72, and the environmental cost per unit of CO2 emissions consumed is 0.28 yuan.
(3) **Energy and cargo damage cost parameters.** The cost of energy is the cost of refrigeration, which is 60 yuan/h; the penalty cost for deterioration of fresh products is 2,100 yuan/t.
(4) **Arrhenius formula parameters.** The temperature in the compartment of the vehicle is -15°C while the vehicle is running, and the temperature rises by 5°C after the compartment door is opened, which is converted into thermodynamic temperature by T(K)=273.15+t(°C). The values

Figure 1. Scatter diagram of distribution centers and customers



of other parameters of Arrhenius formula are as follows, namely Kmax=5×1014/s, Ea=100 kJ/mol, R=8.314 J/mol·K.

(5) **Satisfaction parameters.** It is stipulated that λ=0.6, ω1=0.5, and ω2=0.5.

(6) **Time penalty parameters.** The early waiting cost of the delivery refrigerated truck is 100 yuan/h, and the late penalty cost is 400 yuan/h. Because under MTW, it is stipulated that the delivery time of the delivery vehicle cannot exceed the maximum value of the customer's maximum service time range ELTi.

Table 1 shows the distribution center coordinates and delivery times of the Fresh Food Company. The three types of refrigerated vehicles are represented by A, B, and C, respectively. The number of the three types of vehicles in the distribution center is shown in Table 1.

Based on the distribution business information data of A Fresh Food Company, three models are used to complete the distribution service for 30 customers at the same time, and the low-carbon multi-vehicle VRP model and algorithm empirical analysis constructed are used to solve the company's multi-model cold chain logistics VRP optimization model. The first partheno genetic algorithm is used to solve the three types of refrigerated trucks A, B, and C and 30 customers, and the calculation is performed according to the method of population initialization and parameter setting above.

As the number of vehicle types increases from a single vehicle to three vehicle types, the population size will also increase accordingly. Through multiple runs, the population size pop_size=500, the maximum number of iterations num_iter=500, and the fusion probability merging_prob=0.45. After multiple runs of Matlab, the optimal path for cold chain logistics has been found. The fresh multi-vehicle cold chain logistics is shown in Figure 2. The solution time of the multi-vehicle cold chain VRP algorithm under the low-carbon vision threshold is 304.63s. As shown in Figure 3, the number of iterations for the first appearance of the optimal path is 198 generations. The overall satisfaction curve of 30 customers is shown in Figure 4, and the overall customer satisfaction is 0.73. The optimal delivery route obtained is that route 1, route 2, route 3, and route 5 all use type B refrigerated trucks, and route 4 uses type A refrigerated trucks. The total delivery mileage is 233.45 kilometers, and the total cost is 6,648 yuan.

By solving the multi-vehicle cold chain VRP model under the low-carbon perspective, it can be seen from the path result Figure 2 that the partheno genetic algorithm designed for the multi-vehicle VRP model in this paper has achieved relatively satisfactory results in solving such problems. According to the population iteration process, Figure 3 shows that the convergence of this genetic algorithm is relatively good. According to Figure 4 of the overall customer satisfaction curve, the change of the satisfaction curve is consistent with the iterative process of algorithm evolution, and the optimal solution with higher satisfaction is produced. The final satisfaction value obtained by the multi-vehicle cold chain VRP model tends to be a better level rather than the optimal value. Because the objective function of the VRP model established in this article is to minimize the total cost, and it is required that the overall customer satisfaction s should not be lower than the minimum value λ. Therefore, in the entire logistics and distribution process, in order to improve customer satisfaction, some cost concessions can be made. The overall trend

Table 1. Three types of refrigerated truck parameters

Type	Number	Loading capacity/t	Fixed fee/yuan	Shipping cost/yuan	Fuel consumption per kilometer/L
A	5	8	450	7	0.22
B	12	6	320	4.5	0.19
C	6	4	270	3.5	0.17

Figure 2. Multi-Model cold chain VRP result graph

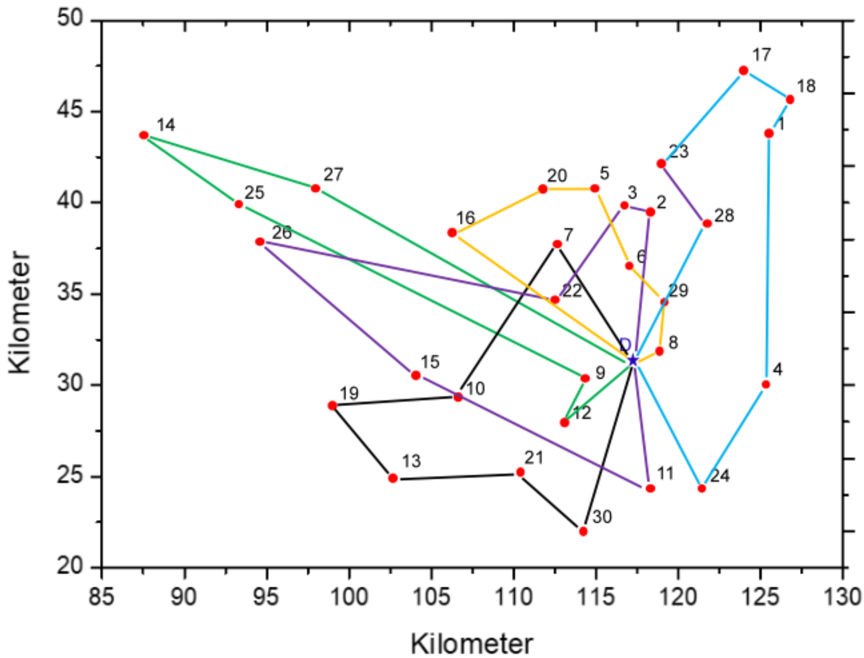
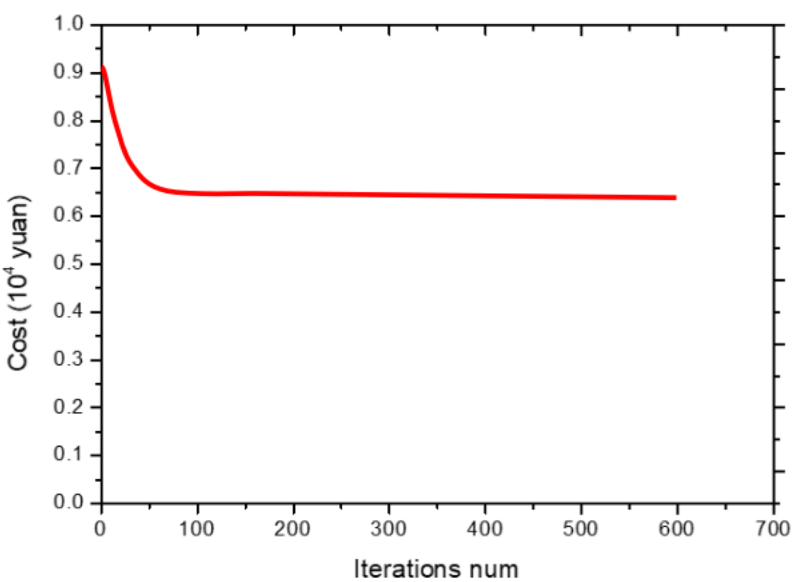
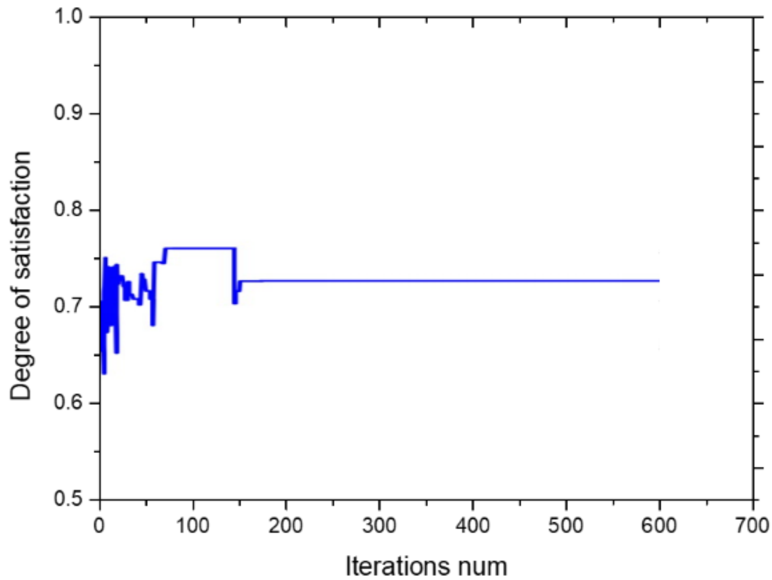


Figure 3. Multi-Model cold chain VRP chromosome evolution diagram



of satisfaction curve s is to increase first and then decrease after the value reaches to a certain extent. This means that in the optimization process, the reduction of the total cost in the early stage will increase customer satisfaction. In the later stage, the continued reduction of the total cost will lead to a decrease in customer satisfaction, which reveals the actual coldness of fresh

Figure 4. Multi-Model cold chain VRP customer satisfaction curve



food enterprises. In the chain distribution process, customer satisfaction should be emphasized while seeking low cost. Therefore, it is recommended that fresh food enterprises, in the actual cold chain distribution service process, pay attention to customer satisfaction while seeking low-cost, so that the total cost is the lowest under the premise of maintaining a certain level of customer satisfaction, thereby improving customer satisfaction and enhancing corporate image. It is recommended that all fresh food enterprises adopt a multi-model distribution model, which will help them achieve the optimal level of the lowest overall cost, small carbon emissions, and high satisfaction during the distribution process, thereby increasing the effective utilization of cold chain logistics and distribution equipment.

The multi vehicle cold chain VRP model in this article is not the only example. For example, in the actual cold chain logistics scenario of a fresh food company, they also adopted a multi vehicle cold chain VRP model and achieved significant success. Through this model, the company has successfully reduced logistics costs, improved economic efficiency, and achieved a development model of energy conservation, emission reduction, and low-carbon environmental protection. Firstly, the company has chosen a multimodal distribution model during the transportation process, which comprehensively utilizes various transportation methods such as road transportation, railway transportation, and waterway transportation. This multimodal distribution model has significant advantages in reducing energy costs and carbon emissions. By effectively planning and organizing the coordinated operation of different transportation methods, the company has reduced transportation costs, energy consumption, and carbon emissions. Secondly, the company optimized the distribution route and goods allocation plan based on the model results and mixed time window constraints. This makes the driving distance of the vehicle more compact, reducing empty driving and unnecessary dwell time, thereby reducing the cost of transportation time and time. At the same time, in terms of cargo allocation, they arrange the loading sequence of goods and vehicle load rate reasonably, minimizing the cost of cargo damage to the greatest extent possible. By implementing the multi vehicle cold chain VRP model, the company has achieved significant results in instance data. The total cost has significantly decreased, with significant reductions in cargo damage costs and energy costs, as well as effective control of carbon emission costs. This reflects the practicality and feasibility of the model in optimizing cold chain logistics systems from a low-carbon perspective. Therefore, we suggest that similar cold chain logistics companies consider adopting a multi vehicle cold chain VRP model combined with a multimodal distribution model. This will help reduce logistics costs, improve economic efficiency, and achieve the development goals of energy conservation, emission reduction, and low-carbon environmental protection.

Analysis of Challenges in Cold Chain Transportation

With the development of the global economy and the progress of the logistics industry, cold chain logistics has become an indispensable part of many industries. In recent years, the multi vehicle cold chain VRP model has received widespread attention. By optimizing distribution routes and cargo allocation plans through intelligent algorithms and real-time data analysis, transportation costs and energy consumption can be reduced. In addition, there are a series of potentially useful strategies, such as optimizing preservation technology, optimizing vehicle load rate, optimizing route planning, strengthening management, which can further improve the economic benefits and environmental performance of cold chain logistics. However, when implementing these strategies, enterprises may face a series of potential challenges and constraints, including issues such as technology investment, industry standards, data integration, partner collaboration, employee training, and market recognition. Therefore, enterprises need to fully consider these factors and develop corresponding solutions and response strategies.

(1) **Technology and equipment investment.** Introducing new preservation technologies and intelligent monitoring systems requires a significant amount of technology and equipment investment, including purchasing and installing new equipment, training employees to use new technologies, etc. This may cause some pressure on the company’s funds and resources. Enterprises can establish partnerships with technology suppliers, share technology and equipment resources, or seek subsidies and funding projects to reduce investment burdens.
(2) **Industry standards and regulatory requirements.** There may be complex industry standards and regulatory requirements in the field of cold chain logistics, involving food safety, temperature monitoring, environmental standards, and other aspects. Enterprises need to make extra effort and cost to meet these requirements. Therefore, enterprises need to maintain close contact with regulatory agencies, understand the latest requirements, and establish standardized operational processes and management systems.
(3) **Integration of data and information systems**. Implementing intelligent algorithms and real-time data analysis requires the establishment of a sound information system and data platform. However, in reality, there are problems with different data sources and formats, so data integration and processing are necessary, which may be a challenging task. Therefore, it is possible to consider establishing a unified data platform to share data with supply chain partners, or to use intelligent algorithms and data analysis tools to process and analyze data.
(4) **Cooperation with supply chain partners.** In cold chain logistics, it often involves multiple links and partners, including suppliers, transportation companies, warehousing service providers, etc. Enterprises should ensure cooperation among all parties as much as possible, in order to jointly promote the implementation of the multi vehicle cold chain VRP model from a low-carbon perspective.
(5) **Employee training and awareness enhancement.** The introduction of new technologies and processes requires employees to possess corresponding skills and knowledge, as well as to enhance their awareness of low-carbon concepts and environmental awareness. This requires training and education.
(6) **Market recognition and balance of interests.** When implementing new models and strategies, enterprises need to consider the degree of market recognition for low-carbon logistics, actively promote and promote the advantages of low-carbon logistics, communicate

effectively with consumers and stakeholders, and form consensus and support. At the same time, enterprises need to balance environmental and economic benefits to ensure that the implementation of new models and strategies is in line with the long-term development interests of the enterprise.

In addition, when implementing a multi vehicle cold chain VRP model, some social issues need to be considered. For example, the cold chain logistics process involves energy consumption and emissions, which have a negative impact on the environment. To reduce environmental impact, enterprises should take measures to reduce carbon emissions, optimize energy use, and seek more environmentally friendly transportation methods, such as choosing clean energy vehicles or promoting renewable energy. Moreover, cold chain logistics requires a large amount of resources including energy, water resources, and materials. Enterprises should make reasonable use of resources, carry out effective management and conservation, and avoid waste. Enterprises should bear social responsibility, care about employee welfare and safety, and ensure that employees' rights and benefits are protected in their work. In addition, it is necessary to comply with labor laws and regulations to ensure reasonable compensation and working conditions.

Cold chain logistics involves the transportation of perishable items such as food and drugs with high requirements for product quality and safety. Enterprises should strictly comply with relevant food safety standards and regulations to ensure the safety and quality of products during transportation.

In the process of cold chain logistics, a large amount of data collection and processing is involved. Enterprises should ensure the security and privacy of data, strengthen information security management, comply with relevant laws and regulations, and protect the privacy rights of customers and partners.

CONCLUSION

We constructed a cold chain logistics multi-vehicle VRP model suitable for considering low-carbon factors and customer satisfaction constraints. In the multi-vehicle cold chain VRP model constructed under the low-carbon perspective, the cold chain logistics has the characteristics of high cargo damage, high energy consumption, and high carbon emissions, and the cost of cargo damage, energy cost, and carbon emissions are added to the model objective function. We also establish time and quality satisfaction constraints based on a mixed time window to obtain the lowest total cost including fixed costs, transportation costs, cargo damage costs, energy costs, carbon emissions, and time costs. The research results show that the multi-vehicle cold chain VRP model constructed in this paper has strong practical applicability under the low-carbon perspective. By using the multi-vehicle cold chain VRP model under the low-carbon perspective to solve and compare the example data of A Fresh Food Company, it is verified that the multi-vehicle cold chain VRP model under the low-carbon perspective is closer to the actual situation. The total cost of the multi-vehicle cold chain VRP model is low. Among them, cargo damage costs and energy costs, which account for the largest proportion, have a large reduction in carbon emission costs. Therefore, it is recommended that companies use a multi-model distribution model in actual distribution tasks, which will help companies reduce logistics costs, improve economic benefits, and enable cold chain logistics to achieve a development model of energy saving, emission reduction, low-carbon, and environmental protection. In addition, more effective preservation techniques such as vacuum packaging, freezing, or low-temperature storage can be used to reduce the rate of damage to goods and the rate of energy consumption during transportation. The use of protective measures during cargo loading and unloading can also reduce the likelihood of cargo damage. Additionally, it is also possible to maximize the load rate of vehicles through reasonable cargo allocation and loading sequence in order to reduce empty driving and unnecessary dwell time, thereby reducing energy costs. The company can also consider using more energy-efficient vehicle models and conducting regular maintenance and upkeep to ensure their optimal operation and minimize energy consumption.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

FUNDING STATEMENT

This work was not supported by any funds.

ACKNOWLEDGEMENTS

The authors would like to show sincere thanks to those techniques who have contributed to this research.

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