Optimization Study of Fresh Food Logistics Distribution Path in SY Company

Yuan Wang*

Shandong University of Technology
Zibo, China
* Corresponding Author

Abstract: With the continuous improvement of living standards, people's demand for fresh food logistics is increasing day by day, which greatly promotes the development of the cold chain logistics industry, but at the same time, it also brings many negative impacts on the ecological environment, which is contrary to the development of the low-carbon economy advocated by today. In order to actively respond to the national green low-carbon policy, this paper takes the fresh food logistics distribution as the entry point, incorporates the carbon emission cost generated in the process of fresh food distribution into the cost consideration, and integrates the carbon emission into the cost into the optimization of the distribution path of fresh agricultural products, and constructs a model that makes each part of the cost in the distribution link minimize the cost, fixed cost, transportation cost, refrigeration cost, penalty cost, and the cost of cargo damage, and constructs a model that makes each part of the cost in the distribution link minimize the cost. The model minimizes the sum of the costs of each part of the distribution chain. Through example analysis, the basic process and operation method of improved genetic algorithm are designed, and the model is coded with MATLAB R2016a, so that a reasonable distribution path can be planned in a scientific way to improve the overall logistics and distribution efficiency and reduce the distribution cost of the enterprise.

Keywords: Fresh produce logistics; Carbon emission cost; Path optimization; Genetic algorithm

1. Introduction

In recent years, society has been paying more and more attention to the issue of carbon emission reduction, and an overview of the global carbon emission data reveals that the amount of carbon emissions from the transportation industry has exceeded 10% of the global carbon emissions. Logistics industry as a pillar of the national economy, if the carbon emissions caused by the logistics and transportation process can be effectively controlled, it will be able to significantly reduce the proportion of overall carbon emissions, but also contribute to the improvement of global warming phenomenon.

The survey shows that the highest transportation efficiency of fresh agricultural products logistics in China is 69%, and the refrigeration equipment carried by our cold field vehicles consumes 2-4 liters of fuel for every one hundred kilometers of driving, and the vehicle exhaust emission is increased by 30% or even more at the same time, which creates great pressure on the environment, and the carbon emission of the cold chain logistics has already taken up a large proportion of the overall carbon emission, so we are in the Therefore, while we continue to promote the development of cold chain logistics industry, we should also regard green and low carbon as a prerequisite to achieve a win-win situation of economic development and environmental protection.

The Vehicle Routing Problem (VRP) was first proposed by Dantzig and Ramser, with the ultimate goal of enabling all customers' needs to be met with the objective of minimizing the total mileage traveled, the total cost of distribution, or the least amount of time spent, within a set of constraints [1]. Solomon & Desrosiers et al. first introduced the time window concept in VRP studies in 1987, and the time factor becomes more sensitive in the cold chain logistics and distribution of fresh produce [2,3]. Scholars at home and abroad have also carried out extensive research on path optimization considering carbon emissions. Xiao Y et al. In order to achieve the purpose of reducing carbon emissions drop in logistics system, they consider the impact of vehicle load and customer time window constraints on carbon emissions, and construct a new mixed-integer linear programming model to study the vehicle path optimization and scheduling problems [4]; Jabir E builds a vehicle path optimization model by combining vehicle transportation paths with green and incorporating carbon emission parameters in low-carbon logistics path optimization [5]; Wang Z models the low-carbon two-level heterogeneous fleet vehicle routing problem (LC-2EHVRP) for a cold chain third-party logistics service provider (3PL) with a hybrid time window and proposes an adaptive genetic algorithm (AGA) method for solving it [6].

From the current research status of scholars at home and abroad, the research on cold chain VRP problem has been very extensive, and scholars have improved the commonly used solution methods of VRP problem in many ways, and there are many similarities in the improvement of algorithms. Therefore, this paper takes the VRP problem of fresh food logistics with carbon emission constraints as the research direction, creates a VRP model that minimizes the total cost, and plans the most reasonable paths for enterprises in a scientific way, so as to lay the foundation for the construction of the overall cold chain logistics and distribution system.

2. Problem Description and Modeling

2.1. Problem Description and Assumptions

It is known that SY Logistics mainly provides storage and distribution services for low-temperature frozen and chilled food products from large supermarkets, and fresh food is one of its main businesses, the location information and demand for each supermarket point has been determined, and the distribution center has a large number of refrigerated vehicles, and the number of these used vehicles is sufficient, however, when using these vehicles for operations, certain carbon emission costs are incurred during the distribution process. In addition, the distribution center incurs fixed and transportation costs for running the vehicles on a daily basis, refrigeration costs for ensuring the quality of the fresh product, penalty costs for failing to meet the customer's time window requirements, and cargo damage costs due to the nature of fresh products increasing over time. To ensure that the constructed model is feasible, we assume the following conditions:

(1) The location of the distribution center is known and has a sufficient number of logistics vehicles and goods;

(2) The customer's location, unloading volume, and time window have been determined;

(3) Each customer can receive unloading service from only one reefer truck and can only be serviced once;

(4) The maximum load capacity of each refrigerated truck is known;

(5) The temperature requirements for cold chain goods at the distribution center are consistent;

(6) The vehicles are traveling at the same speed;

(7) There is a penalty cost associated with a vehicle not being serviced within the time specified by the customer.

2.2 Parameter Descriptions and Decision Variables

A description of the parameters covered in this paper is given as in Table 1:

Table 1. Parameter symbols and their definitions

Parameter symbol	Definition
C	Number of customer points served by logistics and distribution centers
O	The set of distribution centers and customer points, i.e., $O=\{0\}\cup C$
K	Refrigerated truck pools at distribution centers, $K=1,2,...,k$
d_{ij}	Distance traveled by refrigerated truck K from node i to node j
t_i	Moment when refrigerated truck K reaches node i
tt_i	Moment when refrigerated truck K leaves node i
t_{ij}	Travel time of refrigerated truck K between node i and node j
Q^*	Rated capacity of refrigerated trucks
Q_0	Reefer truck deadweight
Q	Load capacity of refrigerated trucks when traveling
q_i	Demand for goods at customer point i
Q_{ik}	Weight of cargo remaining at the time the refrigerated truck leaves the customer's point i
E_t	Earliest delivery time
L_t	latest time for delivery
EE_t	Earliest delivery time specified by the customer
LL_t	The latest delivery time specified by the customer
λ_1	Penalty cost per unit of time incurred by the vehicle to reach the customer's point within $[E_t, EE_t]$
λ_2	Penalty cost per unit of time incurred by the vehicle to reach the customer's point within $[L_t, LL_t]$

The model is constructed with two decision variables: (1) x_{ij}^k denotes when the reefer truck delivers from customer point i to customer point j, $x_{ij}^k=1$, and 0 otherwise; (2) y_i^k denotes when the reefer truck provides service to customer point i, $y_i^k=1$, and 0 otherwise.

2.3 Cost Analysis

In order to be closer to the actual distribution process, the total distribution cost includes fixed cost, transportation cost, refrigeration cost, penalty cost, cargo damage cost and carbon emission cost. p_1, p_2, p_3, p_4, p_5, p_6 are the fixed cost per unit vehicle of reefer trucks, transportation cost per unit distance traveled by reefer trucks, refrigeration cost per unit driving time in the driving process, refrigeration cost per unit unloading time in the unloading process, unit price of cold chain goods, and unit carbon emission price. The calculation method of each cost is as follows:

(1) Fixed costs

The fixed costs of vehicles are mainly vehicle repair costs, maintenance costs and driver's wages. This part of the cost is not related to the vehicle traveling time and vehicle traveling distance, generally a constant, with the increase in the number of distribution vehicles and increase the fixed cost of vehicles C_1 for:

$$C_1 = p_1\Sigma_{k\in K}\Sigma_{i\in C}x_{0i}^k \tag{1}$$

(2) Transportation cost

Assuming that the transportation cost of refrigerated trucks is positively related to the distance traveled by the vehicle, its unit distance transportation cost is, so the transportation cost C_2 can be expressed as:

$$C_2 = p_2 \Sigma_{k \in K} \Sigma_{i \in O} \Sigma_{j \in O} d_{ij} x_{ij}^k \quad (2)$$

(3) Refrigeration Costs

Refrigeration costs need to be considered in the cold chain logistics and distribution process. The refrigeration costs in this study include the costs incurred for vehicle refrigeration equipment and unloading. The refrigeration cost C_3 can be expressed as:

$$C_3 = p_3 \Sigma_{k \in K} \Sigma_{i \in O} \Sigma_{j \in C} t_{ij} x_{ij}^k + p_4 \Sigma_{k \in K} \Sigma_{i \in O} \Sigma_{j \in C} (tt_i - t_i) x_{ij}^k \quad (3)$$

(4) Penalty cost

In the actual distribution process, reefer trucks are not distributed according to the customer's agreed time, it will produce the corresponding penalty cost, this paper studies the penalty cost under the soft time window, which is formulated as a segmented function as shown in Equation (4):

$$f(t_i) = \begin{cases} \lambda_1 (E_t - t_i) & EE_t \le t_i < E_t \\ 0 & E_t \le t_i \le L_t \\ \lambda_2 (t_i - L_t) & L_t < t_i \le LL_t \\ M & t_i < EE_t,\ t_i > LL_t \end{cases} \quad (4)$$

Where time window $[E_t,\ L_t]$ is the time window of customer satisfaction, the reefer truck will not generate penalty cost if it is delivered within the time window; time window $[EE_t,\ E_t] \cup [L_t,\ LL_t]$ is the time window of service acceptable to the customer, but waiting penalty cost will be generated within the time window $[EE_t,\ E_t]$, and overtime penalty cost will be generated within the time window $[L_t,\ LL_t]$; if it arrives before EE_t or arrives after LL_t, the customer refuses to the reefer truck to carry out the corresponding service at the customer's point, and then the penalty cost will be the maximum value. λ_1, λ_2 are the penalty coefficients of waiting for early arrival and the penalty coefficients of overtime tardiness respectively, and $\lambda_1 < \lambda_2$, so the total penalty cost C_4 can be expressed as:

$$C_4 = \Sigma_{k \in K} \Sigma_{i \in O} \Sigma_{j \in C} f(t_i) x_{ij}^k \quad (5)$$

(5) Cargo damage cost

θ_0 is the freshness of fresh products when they depart from the distribution center, which is generally set to 1; ∂ is the freshness decay coefficient of fresh products; ∂_1, ∂_2 are the freshness decay coefficients of fresh products in the process of transportation and unloading; η is the carbon emission coefficient, i.e., the carbon dioxide emissions generated by the vehicle consuming the unit of fuel. In this paper, it is assumed that only the initial freshness of the cold chain product itself and the impact of distribution time on the cost of cargo damage are considered, in which the distribution time is divided into the transportation time when the door is closed and the environment of the compartment is stable, and the unloading time when the door is opened and the environment of the compartment is affected by the outside world, and the freshness attenuation coefficient of the fresh products is introduced into the function $\theta(t)$ [7]:

$$\theta(t) = \theta_0 e^{-\partial t}$$

Where ∂ by the influence of ambient temperature and oxygen content, in the unloading process, the compartment door is in the open state, at this time the temperature and oxygen content of the compartment received the impact of the external environment, exacerbating the rate of decline in freshness of the product, therefore, $\partial_1 < \partial_2$. So the cost of cargo damage C_5 can be expressed as:

$$C_5 = p_5 (\Sigma_{k \in K} \Sigma_{i \in O} \Sigma_{j \in C} q_i \left(1 - e^{-\partial_1 t_{ij}}\right) x_{ij}^k + \Sigma_{k \in K} \Sigma_{i \in C} Q_{ik} \left(1 - e^{-\partial_2 (tt_i - t_i)}\right) y_i^k) \quad (6)$$

(6) Carbon emission cost

Cold chain distribution as an important part of the logistics field, its main carbon emission cost is generated through the fuel consumption, invoking the load estimation method [8] to calculate the fuel consumption, the fuel consumption per unit mileage as a function of the load capacity as shown in Equation (7):

$$P(Q) = P_0 + \frac{Q(P^* - P_0)}{Q^*} \quad (7)$$

There is a certain linear relationship between carbon emissions and fuel consumption [9], so the carbon emissions G of the whole distribution process is:

$$G = \Sigma_{k \in K} \Sigma_{i \in O} \Sigma_{j \in O} \eta P(Q) d_{ij} x_{ij}^k \quad (8)$$

So the total carbon emission cost C_6 can be expressed as:

$$C_6 = P_6 \Sigma_{k \in K} \Sigma_{i \in O} \Sigma_{j \in O} \eta P(Q) d_{ij} x_{ij}^k \quad (9)$$

2.4 Modeling

In summary, the total distribution cost includes: fixed cost of vehicles, transportation cost generated in the distribution process, refrigeration cost generated to ensure the low temperature environment, penalty cost generated by the vehicle failing to arrive at the customer's point within the specified time window, the loss of cold chain products generated in the distribution process, and the cost of carbon emission generated by the vehicle's fuel consumption [10], therefore, the optimization model of the distribution path for the cold chain logistics with the consideration of carbon emission is:

$$\min Z = C_1 + C_2 + C_3 + C_4 + C_5 + C_6 \quad (10)$$

The constraints are:

$$\Sigma_{k\in K}\Sigma_{i\in O}x_{ij}^{k}=1,\quad \forall j\in C \quad (11)$$

$$\Sigma_{j\in C}\Sigma_{i\in O}q_{j}x_{ij}^{k}\le Q^{*},\quad \forall k\in K \quad (12)$$

$$\Sigma_{j\in C}x_{0j}^{k}=\Sigma_{i\in C}x_{i0}^{k},\quad \forall k\in K \quad (13)$$

$$\Sigma_{j\in C}x_{ij}^{k}=\Sigma_{i\in C}x_{ji}^{k},\quad i\neq j;\forall i\in C;\forall k\in K \quad (14)$$

$$t_{i}^{s}=tt_{i}-t_{i},\ \forall i\in C \quad (15)$$

$$t_{j}=t_{i}+(tt_{i}-t_{i})+t_{ij},\ \forall i,j\in C \quad (16)$$

$$x_{ij}^{k}(x_{ij}^{k}-1)=0,\ \forall i,j\in O;\forall k\in K \quad (17)$$

$$y_{i}^{k}(y_{i}^{k}-1)=0,\ \forall i\in O;\forall k\in K \quad (18)$$

Where Equation (11) indicates that each customer point can only be served by one vehicle and can only be served once; Equation (12) indicates that the sum of the weights to be delivered by each reefer vehicle is less than the rated load of the vehicle; Equation (13) indicates that the reefer vehicles all start from the distribution center when they perform their distribution tasks and return to the distribution center after completing the specified distribution tasks; Equation (14) indicates that the vehicles visit the node and then leave, i.e. the the number of visits is the same as the number of departures; Equation (15) represents the unloading time of the refrigerated truck at the customer point; Equation (16) represents the relationship between the moment when the refrigerated truck arrives at the next node j and the moment when it arrives at the previous node i, i.e., the continuity of time; and Equations (17) and (18) represent the constraints on the decision-making variables and the variables that are 0-1.

3. Improved Genetic Algorithm Design

Genetic algorithm refers to an initialized population, in each iterative operation, the fitness function is used as a criterion for evaluating the individuals, the individuals with low fitness are eliminated, and the individuals with high fitness are retained, and then the genetic operation is carried out, successively through the selection, crossover, and mutation of three such processes, to produce a new population, and to realize the iteration of the population. After many iterations, the adaptive ability of the new population will be continuously improved until the optimal solution appears. This algorithmic process includes: chromosome encoding, population initialization, evaluation of individual fitness, genetic operations (selection, crossover, mutation), and algorithm termination.

The genetic algorithm resides in the characteristics of robustness and simple operation, which can effectively solve the vehicle path problem, but there is also the possibility of local optimization. Therefore, this paper carries out certain improvements to its design, and the designed process is shown below:

3.1 Coding and Generating Initial Populations

Since each node in the distribution network is numbered with natural numbers, the coding method of natural number coding is chosen, and the resulting coded number column is "082301405690", which means that 3 refrigerated trucks are involved in the distribution, and a total of 3 paths are formed for distribution. Route 1: 0-8-2-3-0, Route 2: 0-1-4-0, Route 3: 0-5-6-9-0; the size of the population is one of the key factors in the performance of the genetic algorithm, so the initial population size is set to 150 in this paper.

3.2 Adaptation Function and Selection Strategy Determination

Select the appropriate fitness function to ensure that the genetic algorithm's optimization speed, and find the optimal solution. The optimization goal of this paper is to reduce the total distribution cost, so the inverse of the objective function as the fitness function, that is, $fit(m)=1/c(m)$, where $fit(m)$ represents the fitness function, $c(m)$ is the total cost function value of chromosome m. The smaller the objective function is, the higher the fitness is; through the selection of the operation of the excellent individuals screened out, at this time, it is not suitable to complicate the operation, so the roulette wheel method is chosen to get the best fitness value of the individual.

3.3 Crossing Operations

Fixed crossover may happen that the retained individuals are inferior to the eliminated ones and negatively affects the parallelization of the algorithm, considering that the encoding of the nodes in the distribution network does not occur repeatedly, the adaptive crossover probabilistic crossover operator is chosen to ensure that the fitness value of the new chromosome is better than that of the original individual.

3.4 Variational Operations

The crossover operator only interchanges individual alleles or segments in the process of free association and does not create new gene species, i.e., it lacks the phenomenon of genetic mutation in nature. Therefore, in order to prevent the computation from entering a local optimum, adaptive mutation probabilities are used to complete the mutation operation of the operator.

3.5 Optimization Operator and Termination Conditions

The genetic algorithm seeks the optimal solution by iterating continuously, takes out the optimal solution in this iteration, exchanges each gene point in the chromosome genes of the optimal solution with all other gene points, generates a new chromosome and calculates the fitness value of the chromosome after the exchange, compares the fitness value of the chromosome before and after each exchange, selects the result with a high fitness value and carries out the next iteration; sets up a termination condition to end the algorithm, the maximum number of iterations is 200, the algorithm terminates. In this paper, we set the maximum number of iterations 200 to terminate the algorithm and produce the optimal solution.

4. Arithmetic Verification and Analysis

4.1 Algorithm Design

The simulation experimental data in this study come from a fresh food logistics distribution center, which provides distribution services to 20 customer points within 10 km of the distribution center, with the customer points numbered 2-21 and numbered 1 as the distribution center. Assuming that there are enough refrigerated trucks available in the cold chain distribution center, the maximum mass of the distribution vehicles is 10 t. p_1, p_2, p_3, p_4, p_5, p_6 are \$200, \$3 /km, \$2 /h, \$3 /h, \$5 /kg, \$1 /km; λ_1, λ_2 are \$20 /h, \$40 /h; ∂_1, ∂_2 are 0.001, 0.002. Specific locations of the customer points and the demand and service time are shown in Table 2.and service time are shown in Table 2.

Table 2. Customer point information

Serial number	x-coordinate	y-coordinate	Demand/t	Service time/min
1	60	60	0	0
2	10	15	2	15
3	50	0	3	15
4	0	54	2	15
5	32	58	4	15
6	35	50	5	15
7	98	45	1	15
8	102	42	2	15
9	92	90	4	15
10	110	88	4	15
11	112	91	3	15
12	115	98	3	15
13	131	82	3	15
14	122	78	4	15
15	126	72	5	15
16	118	123	2	15
17	92	120	3	15
18	98	112	5	15
19	110	108	4	15
20	75	131	4	15
21	82	135	5	15

4.2 Calculation Example Solving

Programmed according to the steps of the improved genetic algorithm described in the previous section, the known customer point information is substituted into the program to solve the distribution path problem considering carbon emissions, and the optimal vehicle distribution path is obtained as shown in Figure 1 and Table 3.

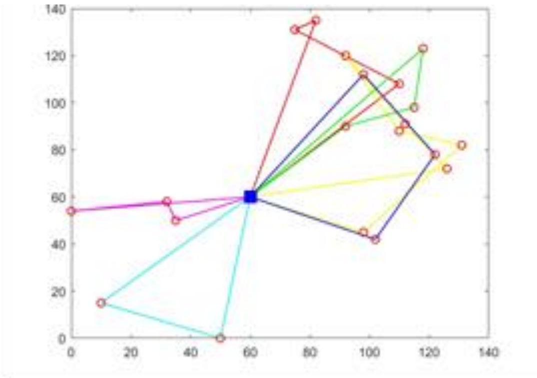

Figure 1. Vehicle optimal path diagram

Table 3. Table of optimal vehicle paths

Vehicles	Optimal path
1	0->20->19->18->0
2	0->6->12->9->16->10->14->0
3	0->15->11->8->0
4	0->1->2->0
5	0->7->13->17->0
6	0->3->4->5->0

This section calls MATLAB R2016a software to run the improved genetic algorithm to solve the model, in order to prevent the algorithm from falling into the local optimum, set the maximum number of iterations for 200 times, and at the same time set the algorithm related parameters: the population size of 200, the maximum value of adaptive population crossover probability of 0.4, the minimum value of 0.2, the maximum value of the probability of the adaptive population variance of 0.3, the minimum value of 0.1. The result shows that the distribution center sends 6 refrigerated trucks for distribution, and the total distribution cost is \$2236.6034, of which the fixed cost is \$1200, the transportation cost is \$259.5932, the refrigeration cost is \$152.1281, the penalty cost is \$93.9595, the cargo damage cost is \$369.4642, and the carbon emission cost is \$161.4584. Therefore, the total cost of cold chain logistics and distribution considering carbon emission will be one more cost directly than that of cold chain logistics and distribution without considering carbon emission, and the carbon emission cost will be borne by the enterprise itself with the implementation of the national low-carbon emission reduction policy, so the enterprise should further consider the carbon emission cost generated by the vehicle distribution in the path optimization.

5. Conclusion

Based on the concept of green logistics development, this paper constructs a distribution path optimization model for fresh agricultural products with the minimization of distribution cost considering carbon emission with the constraint of carbon emission cost, optimizes the individual selection strategy, crossover operation and mutation operation of the traditional genetic algorithm, and solves the design model of the improved genetic algorithm, and simulates the algorithm by using arithmetic examples. The results show that the new improved algorithm has better arithmetic efficiency and optimization effect. Meanwhile, the distribution path scheme considering carbon emission can achieve the effect of cost reduction and carbon emission reduction, which provides a realistic basis for logistics enterprises to reduce costs and increase efficiency.

References

[1] Dantzig, B. G.; Ramser, H. J. The Truck Dispatching Problem. Management Science, 1959, 6(1).

[2] Solomon, M. M.; Desrosiers, J. Time Window constraint routing and scheduling problems. Transportation Science, 1988, 22(1): 1-13.

[3] Cao, Q.; Shao, J. P.; Sun, Y. A. Multi-objective delivery path optimization for fresh produce based on improved genetic algorithm. Industrial Engineering, 2015, 18(1): 71-76.

[4] Xiao, Y.; Konak, A. The heterogeneous green vehicle outing and scheduling problem with time-varying traffic congestion. Transportation Research Part E Logistics & Transportation Review, 2016, 88: 146-166.

[5] Jabir, E.; Panicker, V.; Sridharan, R. Design and development of a hybrid ant colony-variable neighbourhood search algorithm for a multi-depot green vehicle routing problem. Transportation Research Part D: Transport and Environment, 2017, 57: 422-457.

[6] Wang, Z.; Wen, P. Optimization of a Low-Carbon Two-Echelon Heterogeneous-Fleet Vehicle Routing for Cold Chain Logistics under Mixed Time Window. Sustainability, 2020, 12(5).

[7] Li, L.; Fan, T. J. A comparative study of pricing strategies in retailer-led fresh produce supply chains. China Management Science, 2015, 23(12): 113-123.

[8] Xiao, Y. Y.; Zhao, Q. H.; Ikou, K. K.; Xu, Y. C. Development of a fuel consumption optimization model for the capacitated vehicle routing problem. Computers and Operations Research, 2012, 39(7).

[9] Roger, D.; Ottmar. Wildland fire emissions, carbon, and climate: Modeling fuel consumption. Forest Ecology and Management, 2014, 317.

[10] Shen, L.; Li, C. Y.; Gan, Y. et al. Distribution Route Optimization of Fresh Products Considering Cargo Damage and Carbon Emission. Journal of Shanghai Maritime University, 2021, 42(1): 44-49, 70.