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Research on Green Transformation of Logistics Distribution Path Planning

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Abstract: In response to the call of national low-carbon emission reduction, green transformation has become the key to the development of logistics enterprises. In order to reasonably plan the logistics distribution path and realize the coordinated progress of economic benefits and environmental protection goals, this paper monetizes the carbon emissions in the logistics distribution process and converts them into green costs into the accounting of the total distribution costs. The vehicle path model is constructed with the goal of minimizing the total cost. The actual operation data of the logistics enterprise is input into the ant colony algorithm designed by MATLAB software, and the optimal path arrangement and cost of logistics distribution are obtained by solving the model. The research of this paper provides reference for the green transformation of logistics enterprise distribution path, and hopes to provide enlightenment for the sustainable development of logistics enterprises.

1. Introduction

The current increase in carbon emissions has been identified by the World Climate Conference as a key culprit leading to global warming. Countries have proposed corresponding emission reduction policies to control the increase in carbon emissions and improve climate change. In 2021, a unified national carbon emission trading market will be opened, and more than 2,000 units will be absorbed to carry out key emission reduction work, which will provide an early warning for the future development direction of enterprises, and the future development goals of enterprises will move closer to green transformation. As a logistics enterprise in CH city, FX company aims to improve economic efficiency in daily operation, and lacks consideration of carbon emissions in logistics distribution process. This paper mainly focuses on the planning of its logistics distribution path. In the case of meeting customer needs, the carbon emission cost is included in the accounting of the total distribution cost, and the distribution path is planned with the minimum total cost as the goal, taking into account economic benefits and environmental protection requirements. The green transformation of the distribution path provides a theoretical basis.

Logistics distribution path planning is actually a vehicle routing problem (VRP). Zhang Qin et al[1] first introduced the concept of the earliest and latest start service time and the earliest and latest service time acceptable to customers when studying the vehicle routing problem to construct the time penalty function, and solved the operation results under the time window constraint by improving the genetic algorithm. Li Jin et al[2] studied the impact of changes in carbon quotas and carbon prices under the carbon trading mechanism on the carbon emission cost and economic cost of enterprise logistics distribution, and then helped enterprises choose the optimal distribution path. Sun et al[3] applied the vehicle routing problem to the study of the same city running errand business, established a vehicle routing model considering the order pickup time, and optimized the number of vehicles and the load capacity during pickup and delivery. Demir E et al[4] took reducing carbon emissions and shortening delivery time as optimization objectives, and constructed a vehicle pollution path optimization model under dual objectives to reduce carbon emissions and shorten delivery time for enterprises. Cimen M et al[5] studied the influence of random vehicle speed and environmental problems on carbon emissions, constructed an uncertain vehicle routing optimization model, and expanded the research of vehicle routing problem. The research on vehicle routing problem at home and abroad has been quite rich. Based on the reference of many existing research data, this paper establishes a vehicle routing model suitable for FX enterprises to solve the actual logistics distribution routing problem.

2. Model Establishment

2.1. Problem Description and Assumptions

The green transformation problem of logistics distribution path planning can be described as a vehicle routing problem considering carbon emission costs. This paper mainly studies the problem of dispatching multiple vehicles of the same model to multiple fixed customer points under a certain time window constraint for a single distribution center, and seeks the vehicle distribution path scheme with the minimum total distribution cost. In order to further improve the feasibility of the research question, the following hypotheses are proposed:

(1) Considering only a single distribution center problem, each distribution vehicle starts from the distribution center and returns to the distribution center after completing the distribution task.

(2) Know the location coordinates of the distribution center and customer points, the demand of each customer point and the acceptable delivery time range and the best delivery time range;

(3) The maximum load of each delivery vehicle is the same and known. Each customer point is only served by one delivery vehicle. Each vehicle can serve multiple customer points, and the demand for delivery does not exceed the maximum load of the delivery vehicle.

(4) Do not consider the traffic conditions and vehicle speed in the distribution process, and do not consider that the distribution vehicle has other assignment tasks beyond the planned path during the distribution process.

2.2. Symbols and Decision Variables

n : represents the number of customer points, $i=0$ represents the distribution center, $i, j=1,2...,n$ represents the customer point with distribution demand;

K : the number of delivery vehicles, k is the serial number of delivery vehicles, $k=1,2...,K$;

f_k : represents the fixed cost per participating vehicle;

d_{ij} : represents the distance from customer point i to j ;

α : represents the transportation cost per unit distance;

p : represents the unit price of the product;

Q_{ij} : represents the demand from the customer point i to j ;

t_{0j}^k : represents the delivery time of vehicle k from distribution center to customer point j ;

w_j^k : represents the loading and unloading waiting time of vehicle k at customer point j ;

e_1 : represents the product damage rate per unit time during delivery;

e_2 : represents the cargo damage rate per unit time of the product during loading and unloading;

C_e : represents the unit cost of carbon emissions;

e : represents the carbon emission coefficient of vehicle fuel consumption;

Q : represents the maximum load of the vehicle;

$[ET_i, LT_i]$: represents the best time range to indicate customer acceptance of delivery;

$[et_i, lt_i]$: represents the time range that represents the customer's acceptable delivery;

λ_1: represents the penalty coefficient for early delivery of goods;

λ_2 : represents the penalty coefficient for delay in delivery of goods;

t_i^k : represents the time point when the goods arrive at customer point i ;

$$S_{jk} = \begin{cases} 1, & \text{Distribution center dispatch vehicles } k \\ 0, & \text{Distribution center does not dispatch vehicles } k \end{cases}$$

$$x_{ij}^k = \begin{cases} 1, & \text{Delivery vehicle } k \text{ through customer point } i \text{ to } j \\ 0, & \text{Delivery vehicle } k \text{ does not pass customer point } i \text{ to } j \end{cases}$$

$$y_j^k = \begin{cases} 1, & \text{Distribution vehicle } k \text{ service customer point } j \\ 0, & \text{Distribution vehicle } k \text{ has not served customer point } j \end{cases}$$

2.3. Cost Analysis

(1) Vehicle fixed costs (C_1)

The fixed cost of the vehicle generally refers to the relatively fixed cost of the vehicle during transportation, including the driver's salary, vehicle depreciation fee and vehicle management fee. This cost is not affected by the vehicle load and delivery distance, and is only related to the number of delivery vehicles. The total fixed cost is expressed as:

$$C_1 = \sum_{k=1}^{K} \sum_{j=0}^{n} S_{jk} f_k \tag{1}$$

(2) Transportation cost (C_2)

Transportation cost refers to the expenditure of fuel, maintenance and tolls generated during the distribution of vehicles. The transportation cost increases with the increase of transportation mileage, which is generally positively correlated. The total transportation cost is expressed as:

$$C_2 = \sum_{k=1}^{K} \sum_{i=0}^{n} \sum_{j=0}^{n} \alpha d_{ij} x_{ij}^k \tag{2}$$

(3) Goods damage cost (C_3)

Cargo damage cost refers to the quality damage or quantity loss of goods in the process of transportation, loading and unloading, which is generally related to the length of service time of goods. The average cargo damage rate of goods in the process of logistics transportation in China is higher than 2%. Cargo damage cost is still an important part of logistics distribution cost. The cost of cargo damage is expressed as:

$$C_3 = p \sum_{j=0}^{n} \sum_{k=1}^{K} y_j^k Q_j \left(t_{0j}^k e_1 + w_j^k e_2 \right) \tag{3}$$

(4) Green cost (C_4)

In this paper, the carbon emission cost of distribution vehicles is described as green cost. According to the research of Duro J A, Demir E et al[6,7], the carbon emission and fuel consumption of vehicles can be known, and the fuel consumption of vehicles is affected by the driving distance and vehicle load during transportation. Usually, fuel consumption is converted into a fixed constant of carbon emissions, which is called carbon emission coefficient, that is, carbon dioxide emissions per liter of fuel consumption. The cost of carbon emissions is to monetize carbon emissions. Since China's carbon emissions trading market has been developed, monetization can be achieved according to the pricing mechanism of the carbon trading market. The specific accounting methods of carbon emission costs are as follows:

$$C_4 = C_e \sum_{k=1}^{K}\sum_{i=0}^{n}\sum_{j=0}^{n} e\rho_{ij}^k d_{ij}^k Q_{ij}^k x_{ij}^k \tag{4}$$

Among them, ρ_{ij}^k is the fuel consumption of the vehicle from the customer point i to j, and the calculation method of the fuel consumption of the delivery vehicle is shown in Formula (5):

$$\rho_{ij} = \rho_0 + \frac{\rho^* - \rho_0}{Q} Q_{ij} \tag{5}$$

In the formula, ρ_{ij} is the fuel consumption from customer point i to j; ρ_0 is the fuel consumption per unit distance under no-load condition; ρ^* is the fuel consumption per unit distance under full load; Q is the maximum load of the vehicle; Q_{ij} is the demand from customer point i to j.

(5) Punishment cost (C_5)

In real life, customers have certain requirements for the time of product delivery. If the product is not delivered within the required time range, the enterprise needs to bear the corresponding penalty cost, that is, the penalty cost of the vehicle in the delivery process. In general, the delivery time agreed between the enterprise and the customer has a flexible space, and there is an acceptable time range and an optimal time range. The function diagram of the penalty cost changing with time is as shown in Figure 1:

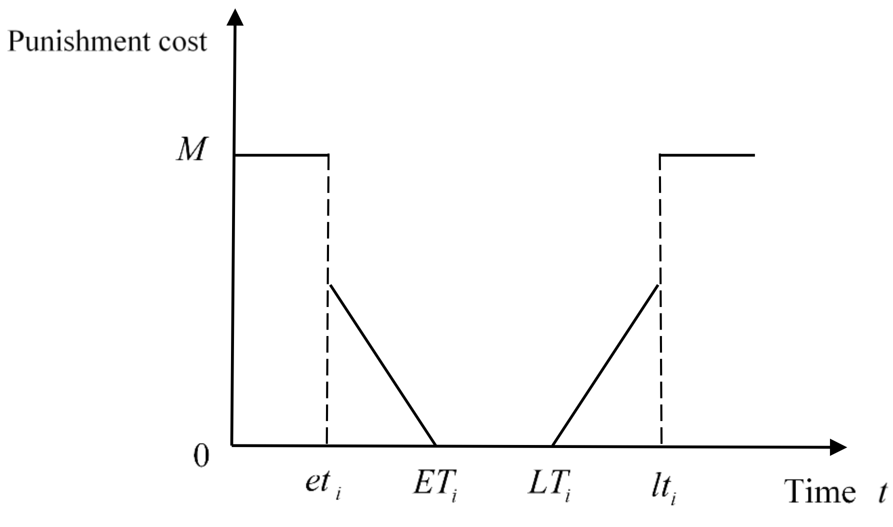

Figure 1: Penalty cost function diagram

Among them, $[ET_i, LT_i]$ represents the best time range for customers to accept delivery, and the delivery of goods within this time range will not generate additional compensation, and the penalty cost is 0; $\left[et_i, lt_i\right]$ represents the time range of the customer's acceptable delivery. When the delivery time of the goods is within the acceptable time range of the customer, but not within the optimal time range, the enterprise needs to compensate for the breach of contract according to the compensation method negotiated by both parties. When the delivery time of the goods is not within the acceptable range of the customer, whether it is delivered early or late, even if the customer cannot receive the goods due to their own reasons or the customer does not receive the goods within the agreed time, the penalty cost is a fixed constant M , usually M represents an infinite number. Therefore, the accounting method of penalty cost in the distribution process is different in different situations. The specific representation is as follows:

$$C_5 = \sum_{i=0}^{n}\sum_{k=1}^{K}\begin{cases} M, t_i^k < et_i \\ \lambda_1\left(ET_i - t_i^k\right), et_i < t_i^k < ET_i \\ 0, ET_i < t_i^k < LT_i \\ \lambda_2\left(t_i^k - LT_i\right), LT_i < t_i^k < lt_i \\ M, t_i^k > lt_i \end{cases} \tag{6}$$

2.4. Objective Function Construction

According to the research hypothesis and cost, a logistics distribution path planning model with the goal of minimizing the total distribution cost is established. The target planning model is expressed as:

$$\min C = C_1 + C_2 + C_3 + C_4 + C_5 \tag{7}$$

$$s.t.\begin{cases} \sum_{j=1}^{n} x_{ij}^k = \sum_{j=1}^{n} x_{ji}^k \le 1 & i = 0, k \in \{1, 2, \dots K\} \\ \sum_{j=0}^{n}\sum_{k=1}^{K} x_{ij}^k = 1 & i \in \{1, 2, \dots n\} \\ \sum_{i=0}^{n}\sum_{k=1}^{K} x_{ij}^k = 1 & j \in \{1, 2, \dots n\} \\ \sum_{i=0}^{n}\sum_{j=0}^{n} Q_{ij}^k x_{ij}^k \le Q & k \in \{1, 2, \dots K\} \end{cases} \tag{8}$$

Among them, the total distribution cost includes vehicle fixed cost, transportation cost, cargo damage cost, green cost and penalty cost, with the minimum total distribution cost as the goal, and through the constraints to ensure that the starting point and end point in the distribution process are the distribution center; ensure that each customer point is accessed and one vehicle is accessed only once and that the maximum vehicle load is not exceeded.

3. Algorithm Design

The basic idea of ant colony algorithm comes from the behavior of ant colony in the process of foraging. The ant colony will release ' pheromone ' to transmit information to its peers in the process of foraging. The ants in the ant colony have certain perception ability to food and pheromone. If the ants find the food location within the perception range, they will start from it. Otherwise, it will go to the place with more pheromones, but not all move to the direction with more pheromones, which will reduce the error probability of each ant and find the food location accurately. After a period of search, the walking path with higher pheromone concentration is finally obtained, and the whole ant colony will reach the food source along the shortest path.

In the ant colony algorithm, there is a positive feedback mechanism for the foraging behavior of ants. Through the accumulation of pheromones, the search process continues to converge and gradually approaches the optimal solution, so that the algorithm continues to evolve in the process of finding the optimal solution. Since each ant is an independent individual and the pheromone concentration in the initial stage is the same, each ant will not affect each other in the process of finding the optimal solution, which enhances the stability and global search ability of the algorithm. At the same time, the ant colony algorithm has strong robustness. Because the initial requirement of the ant colony algorithm is low and the parameter setting is small, it can be easily combined with other algorithms to solve the problem and improve the performance of the algorithm. The specific steps of ant colony algorithm are:

Step 1: Parameter initialization. Set the number of ants, the number of cities, pheromones, heuristic functions, volatile factors, and maximum number of iterations.

Step 2: Put each ant on different cities, and use roulette to select the next city to arrive until each ant has visited all cities.

Step 3: Update the pheromone. When all ants complete a cycle, the path length of each ant is calculated, and the historical optimal solution in the current iteration number is recorded, that is, the shortest path; at the same time, the pheromone concentration on the connection path between cities is updated in real time.

Step 4: Determine whether the termination condition is reached. If the number of iterations does not reach the maximum number of iterations, it is necessary to empty the path record table and return to the first step for calculation. If the maximum number of iterations is reached, the calculation is terminated and the optimal solution is output.

4. Example Analysis

4.1. Known Conditions

According to the data provided by FX company, there are 8 vehicles in its distribution center that can participate in the daily distribution process. The maximum load of each vehicle is 50, and the fixed cost of the vehicle is 100 RMB. It is assumed that the vehicle starts from the distribution center at a constant speed on the road and returns to the distribution center after completing the task. The coordinate position, demand and optimal delivery time of each customer point are shown in Table 1.

4.2. Results and Analysis

By designing an ant colony algorithm suitable for the problem studied in this paper, MATLAB software is used to substitute known data into the designed algorithm for coding operation. The importance of pheromone is set to 1, the relative importance of heuristic factor is 5, the dilution degree of pheromone is 0.35, the amount of pheromone is 5, the number of ants is 50, and the maximum number of iterations is 300. After running many times, the optimal results are obtained, and the iterative curve graph (figure 2) and the optimal path graph (figure 3) of the objective function are obtained. The optimal solution of the objective function tends to be stable around 140 iterations, and the total distribution cost is 3319.5 RMB under the optimal condition.

Table 1: Basic information of customer points

customers point	x-coordinate	y-coordinate	magnitude of demand	The best delivery time window	Unloading waiting time
0	70	62	0		
1	80	39	15	4:30-5:00	20
2	50	76	17	5:10-5:40	20
3	90	30	23	5:20-6:40	25
4	90	50	21	6:30-7:30	25
5	100	83	8	5:30-6:30	10
6	95	32	4	8:10-9:45	10
7	35	30	10	6:30-9:30	15
8	53	27	15	7:00-9:30	20
9	74	75	9	7:30-9:30	10
10	75	55	11	5:00-7:30	15
11	20	36	14	7:00-8:00	15
12	53	81	19	6:00-7:30	25
13	65	75	11	8:00-9:30	15
14	25	45	6	7:00-7:30	10
15	82	82	5	5:30-9:30	10
16	30	15	20	7:30-8:50	25
17	81	51	14	8:00-10:00	15
18	65	36	6	7:00-8:00	10
19	90	61	11	8:00-8:30	15
20	25	75	7	9:05-10:10	10

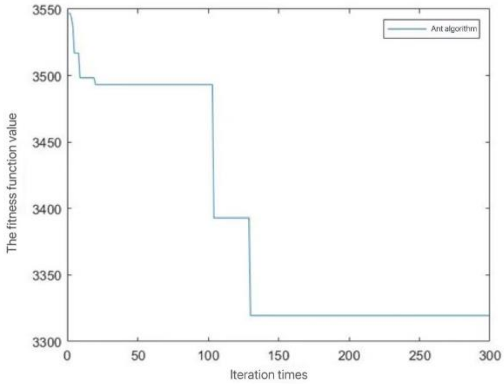

Figure 2: Iteration curve of objective function

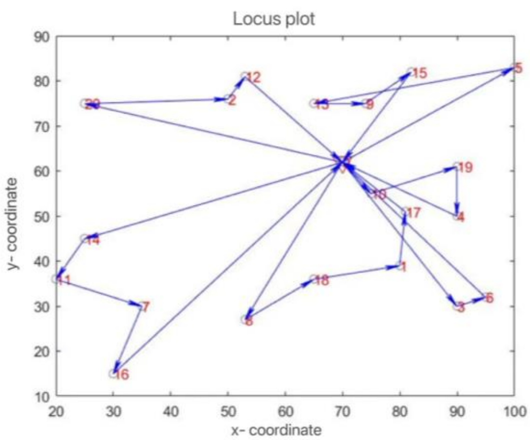

Figure 3: Optimal path graph

Table 2: Distribution vehicle route and cost

serial number	driving route	fixed cost	transportation cost	goods damage cost	green cost	punishment cost
1	0→8→18→1→17→0	100	193.6	2.9	208.6	29.5
2	0→10→19→4→0	100	118.2	3.5	230.4	11.6
3	0→3→6→0	100	164.3	2	191.4	0
4	0→5→13→9→15→0	100	231.1	2.3	260.2	0
5	0→14→11→7→16→0	100	291.7	4.1	286.5	17.4
6	0→20→2→12→0	100	206.4	3.7	231.3	28.8

According to the distribution path in Figure 3, it can be seen that only 6 distribution vehicles are needed in the best distribution scheme, and the detailed distribution cost of each vehicle can be calculated by software. The specific driving route and detailed cost of each vehicle are shown in Table 2.

The ant colony algorithm is used to study the logistics distribution path problem of FX company, and the distribution path is planned with the lowest total distribution cost. The results show that the number of distribution vehicles required in the optimized scheme is two less than usual. Due to the new addition of green cost in the total distribution cost, it is different from the company's daily accounting cost structure, so it is not compared for the time being, but the addition of green cost in the study provides reference for the company to carry out the green transformation of logistics distribution path in the future, which is helpful to the sustainable development of the company.

5. Conclusion

This paper studies the vehicle routing problem considering vehicle load, time window and carbon emissions, converts carbon emissions into green costs and adds them to the study of total distribution costs. On the basis of meeting customer needs, an algorithm model is constructed to solve the distribution path with the minimum total cost, and the driving tasks of distribution vehicles in logistics centers are reasonably planned. The green transformation of logistics distribution path should first take vehicle carbon emissions into account in daily distribution activities. On the basis of protecting customers ' rights and interests, economic benefits and environmental protection goals should be taken into account to enable enterprises to achieve sustainable development. The research in this paper provides a reference for enterprises to carry out the green transformation of logistics distribution path in the future. Whether it is the opening of the carbon emission trading market or the possible coming carbon tax policy, green transformation is the choice that every enterprise will face in the future and the only way for enterprise development.

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