DISTRIBUTION ROUTE OPTIMIZATION FOR MULTI-VEHICLE AGRICULTURAL MATERIALS CONSIDERING CARBON EMISSION COST

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考虑碳排放成本的多车型农资配送路径优化研究

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ABSTRACT

Agriculture is the foundation of the national economy, and agricultural materials are the basis of agricultural development. As the three rural issues (agriculture, countryside, and farmers) become increasingly important, the distribution of agricultural materials attracts extensive attention. Given the slow development of rural logistics, the traditional agricultural material distribution process encounters many problems, such as cumbersome distribution links, high distribution costs, and low profit for enterprises, which in turn cause high production costs and low income for farmers. In consideration of soft time window constraints, this study adopted the agricultural material distribution route as the study object and established an optimization model of the agricultural material distribution route with fixed, transportation, energy consumption, time window penalty, and carbon emission costs as the objective functions. With regard to the algorithm, the operation of differential update and chaotic disturbance was innovatively enhanced and applied to the improved ant colony algorithm to simulate the model and obtain the optimal distribution route optimization model. Results show that the traditional ant colony algorithm improved by differential updating and chaotic disturbance has the advantages of low distribution cost, reasonable route, small number of activated vehicles, and short convergence time. Compared with the traditional ant colony algorithm, the improved ant colony algorithm can converge to the global optimum faster. This study provides guidance and suggestions on route selection and vehicle configuration to reduce costs and increase efficiency and offers certain theoretical support to alleviate urban traffic pollution and implement carbon trading policies in the future.

摘要

农业是国民经济的基础, 而农业生产资料的支持是农业发展的基础，在"三农"问题愈发重要的今天，农业生产资料的配送问题也随之显得十分重要。由于农村物流发展缓慢, 传统的农资配送过程中存在着配送环节过多、配送成本过高、企业获得利润过少的问题, 同时也造成了农民生产成本过高、收入低的现象。基于此，本文以农资配送路径对象，以软时间窗约束为前提，以固定成本、运输成本、能耗成本、时间窗惩罚成本和碳排放成本为目标函数，建立了农资配送路径优化模型。在算法方面，创新性地改进了微分更新和混沌扰动的操作，将微分更新和混沌扰动应用于改进的蚁群算法对模型进行仿真求解，得到了最优分配路径优化模型。仿真结果表明：采用微分更新和混沌扰动对传统蚁群算法进行改求解模型，得到的分配成本更低，路线更好，激活车辆数量更少，算法收敛时间更短，并且与传统蚁群算法相比，改进蚁群算法可以更快地收敛到全局最优。研究结果也可以帮助企业对农资配送车辆路线的选择和车型配置决策提供指导和建议，帮助企业降本增效，并为未来缓解城市交通污染和碳交易政策的广泛实施提供一定的理论支持。

INTRODUCTION

As important agricultural inputs, agricultural materials are the bridge connecting industry and agricultural production and provide material guarantee and foundation for modern agriculture development (*Wang Xu et al., 2020*). Agricultural material logistics is an important link in the process of agricultural material sales, and in China, the distribution direction is from cities to the countryside, the distribution route is from trunk transportation to branch transportation, and the distribution scale is from large to small (diffused type). The different distribution types and obvious seasonality and regionality of agricultural material distribution increase the difficulty of the management, storage, and transportation of agricultural materials.

The problems of idle driving and secondary distribution also arise from improper planning and dispatching of agricultural material distribution vehicles (*Huo et al., 2017*). The relatively backward development of rural areas in China, the outdated infrastructures, the complex terrain, and poor traffic conditions have caused great difficulties in the distribution of agricultural materials (*Zhang, 2017*). Some distribution routes are unreasonable. Some problems, such as poor inventory management, untimely stocking, and information blocking of the strong demand for agricultural materials, also arise during busy farming seasons. As the main distribution tool, vehicles are particularly important and affect the circulation of agricultural materials (*Du and Chen, 2017*). Logistics distribution guarantees the smooth arrival of agricultural materials to farmers, and a discrepancy in it can affect the cultivation of crops and cause serious losses to farmers (*Wei et al., 2016*). This study qualitatively and quantitatively analyzed the problems in agricultural material logistics distribution, optimized the distribution route, and established an optimization model of agricultural material distribution. Moreover, the rural agricultural logistics distribution route was optimized, and distribution efficiency was enhanced. Through the optimization of the agricultural logistics distribution route, farmers can use reliable agricultural products at the minimum cost, enterprises can obtain increased profits, and vigorous and healthy agricultural development in China can be maintained. Exploring agricultural material logistics distribution is crucial to the development of agricultural material logistics and agriculture in China.

The construction of logistics facilities in China's rural areas is relatively backward, which is mainly reflected in the level of roads, means of transport, communication, and commodity storage. Compared with the total size of the road network mainly composed of rural roads, the density of rural roads in China is only about one-fifth that of the United States, 1/8 that of the United Kingdom, and 1/15 that of Japan. Currently, 184 townships and more than 50,000 administrative villages are still without roads. The number of agricultural materials storage facilities in China is seriously insufficient, and the existing storage facilities are not fully functional and cannot play their due functions, resulting in a great loss of agricultural materials in storage. The use of Internet information means to optimize the logistics and transportation routes of agricultural commodities, provide digital and shared agricultural logistics supply and marketing services for agricultural commodities transport warehouses, goods, vehicles, routes, and network resources, optimize the county and village three-level distribution system, and solve the problems of agricultural products up and farmers' livelihood and production means down.

State of the art

The logistics industry is highly developed in developed countries, such as those in Europe, the United States, Japan, and South Korea, and many research achievements in logistics have been obtained for urban and rural areas. Particularly, the rural land in America is highly intensive, and the distribution, inventory management, and information integration of rural agricultural materials are highly developed. Studies on rural logistics in China have focused on the optimization of distribution networks, the location of storage and distribution facilities, and logistics systems. *Mardaneh et al.* studied the factors that influence agricultural logistics and established an agricultural logistics system in accordance with the characteristics of rural logistics *(Mardaneh et al., 2016)*. Chaudhuri et al. reduced the logistics cost by optimizing the vehicle route and proposed a logistics transportation system *(Chaudhuri et al., 2018)*. *Ferrag* achieved a major breakthrough by combining multivehicle path optimization and game theory *(Ferrag et al., 2020)*. *Liu* solved multivehicle problems with time windows by using a genetic algorithm *(Liu et al., 2022)*. According to Chandra et al., fuel consumption is influenced by driving distance and the actual operation process of vehicles *(Chandra et al., 2014)*. *Lin* discussed the carbon emission of freight vehicle routing, especially the influence of vehicle speed on carbon emission *(Lin et al., 2021)*. *Luo* explored the influence of road gradient on vehicle fuel consumption in a reverse logistics recovery path *(Luo et al., 2016)*.

In addition, vehicle route optimization was also used in reverse logistics. With the development of the Internet, Çeken applied the positioning system to vehicle positioning and 2D code scanning technology to goods delivery *(Çeken et al., 2019)*. Remarkable breakthroughs in distribution center location and express delivery have been achieved in the United States where unified government management is implemented *(Marinaki et al., 2016)*. This management method breaks through the traditional system of departments in charge and contributes to the development of logistics effectively. In addition, increased attention has been devoted to the training system of logistics talents. The logistics talent system plays a crucial role in the logistics industry *(Badia-Melis et al., 2018)*.

Similar to the development model of the United States, the development model of Europe entails unified supervision and control of the government and independent operation of enterprises.

Advanced science and technology have considerably changed the development of the European logistics industry, and the continuous development of the Internet era has driven the coordinated progress of the logistics industry and promoted the rapid development of the European logistics industry *(Dulebenets et al., 2016)*. The development of the logistics industry in Japan mainly depends on the construction of strong domestic logistics infrastructure, and outstanding results have been achieved in logistics distribution specialization *(Braekers et al., 2016)*.

Many scholars have conducted studies on agricultural logistics. They qualitatively analyzed the concept and development of agricultural logistics from a macro perspective and quantitatively studied the optimization of site selection, route optimization, and the whole logistics network. *Ji et al.* improved the Baumol–Wolf model, proposed a 0-1 mixed integer programming model, and established a decomposition filtering model *(Ji et al., 2020)*. *Fazayeli* analyzed the logistics network system of agricultural resources in China and proposed the logistics supply network model of agricultural products *(Fazayeli et al., 2018)*.

Voutos discussed rural logistics distribution on the basis of the realization of the road network and improved the clustering algorithm to solve the distribution problem by dealing with the clustering center and edge points *(Voutos et al., 2019)*. *Leleń* combined the genetic algorithm and the Tabu Search algorithm to solve the vehicle routing problem *(Leleń et al., 2019)*. Bortolini effectively solved the vehicle routing problem with time windows by combining hill climbing and genetic algorithms *(Bortolini et al., 2016)*. *Hu* proposed a heuristic algorithm based on the Tabu Search algorithm and obtained the optimal solution of the vehicle routing problem *(Hu et al., 2020)*. *Olkhova* transformed dynamic problems into static problems by setting time periods and time points and proposed new ideas for solving dynamic vehicle routing problems *(Olkhova et al., 2017)*. *Lakshmanna* combined the best customer insertion rule with the genetic algorithm and embedded the fuzzy optimization program to verify the effectiveness of the model *(Lakshmanna et al., 2018)*. *Rajyalakshmi* studied the road network property of service facilities and changed the coding mode to obtain the genetic algorithm when the vehicle is not fully loaded *(Rajyalakshmi et al., 2022)*. *Liu* put forward a deterministic search method, which took less time and obtained more accurate results. Also, an efficient genetic operator was designed to solve the dynamic random shortest route problem by using the topological characteristics of the network *(Liu et al., 2023)*.

To sum up, energy conservation and emission reduction have become global concerns, and low-carbon technology and low-carbon economy have elicited extensive interest. With high fuel consumption and carbon emissions, the logistics industry needs to consume considerable energy to ensure product quality. Agricultural logistics serves rural areas. Given that the rural logistics network is imperfect, it has high energy consumption and carbon emission, and its effect on the environment is obvious. Therefore, the reduction of the energy consumption of logistics and the realization of green and sustainable development are essential. A review of previous studies on vehicle route optimization and vehicle evaluation in logistics shows that vehicle system evaluation has seldom been studied, and the studies on vehicle route optimization in logistics have focused on a single distribution center and a single model. Considering the economy and sustainability of vehicles, this study established a green multivehicle agricultural material distribution routing model under the background of logistics and designed and solved an improved ant colony algorithm. The feasibility and effectiveness of the proposed model and algorithm were verified by examples. The study can provide decision support and method guidance for distribution and management.

MATERIALS AND METHODS

Problem Description

After agricultural material distribution centers receive customers' demand orders, agricultural material distribution operation is performed by agricultural distribution vehicles, which are fully charged in distribution centers and deliver agriculture materials to different customers. However, each customer can accept the service of only one agricultural distribution vehicle. After an agricultural distribution vehicle completes the distribution, it returns to the starting point, namely, the distribution center. When a power warning is received by a distribution vehicle in the distribution process, it cannot reach the next distribution point and must replenish its battery power in a nearby fast-charging pile. Certain restrictions are imposed on the weight of goods distributed by agricultural distribution vehicles, so customers' total medical needs should not exceed the maximum load of agricultural distribution vehicles. The coordinates of customer points and the time window of the customer's request service are known.

This study did not consider road congestion and assumed that the road is smooth and that the agricultural distribution vehicle can reach customers' locations smoothly within the specified time window and complete the delivery service.

In this study, with K agricultural distribution vehicles in a distribution center as the study objects, the agricultural material distribution route to N customers was optimized. In consideration of green logistics and the timeliness of the agricultural material cold chain, this study assumed that the traditional vehicle routing optimization problem increases the time window penalty cost and the carbon tax cost.

(1) The distribution center has enough agricultural distribution vehicles, and the quality of each vehicle is known. The vehicles can run normally with the same constant power.

(2) The distribution center has sufficient agricultural material inventory, and customer demand, customer location, and delivery time are known. Every customer has been and can only be served by one agricultural distribution vehicle once.

(3) Each agricultural distribution vehicle starts from the distribution center. Once it receives its instruction, it does not accept other tasks and returns to the distribution center after completing the task.

(4) Every customer has a time window requirement for delivery time. Deliveries that are performed later or earlier than the delivery time result in a corresponding time window penalty cost.

Modeling

The objective function of multivehicle agricultural material distribution route optimization that considers the carbon emission cost includes the following aspects.

Fixed cost of vehicles

The fixed costs of agricultural material distribution include vehicle maintenance and depreciation costs. The distribution center has K agricultural distribution vehicles, and the fixed cost of each vehicle is F.

Therefore, the fixed cost of agricultural distribution vehicles is:

$$C_1 = \sum_{k=1}^{K} \sum_{j=1}^{N} F x_{0j}^{k} \tag{1}$$

where, x_{0j}^{k} is the decision variable, $x_{0j}^{k} = 1$ indicates that vehicle K leaves the distribution center to go to customer j, otherwise $x_{0j}^{k} = 0$; N is the number of customers.

Vehicle transportation cost

Vehicle transportation cost can be approximately regarded as positively related to mileage. Transportation cost C_2 can be expressed as:

$$C_2 = \sum_{k=1}^{K} \sum_{i=1}^{N} \sum_{j=1}^{N} C_{ij} Q_{ij} d_{ij} x_{ij}^{k} \tag{2}$$

where C_{ij} is the transportation cost per unit agriculture material and distance, Q_{ij} is the transportation volume from customer i to customer j, d_{ij} is the distance between customers i and j, and $x_{ij}^{k} = 1$ is the decision variable indicating that agricultural distribution vehicle K travels from customer i to customer j (otherwise, $x_{ij}^{k} = 0$).

Energy consumption cost in transportation process

Energy consumption cost: The first item is energy consumption during transportation. The energy consumption (B) of vehicle transportation is expressed as:

$$B = \alpha \sum_{i=0}^{N} \sum_{j=0}^{N} \sum_{k=1}^{K} d_{ij} x_{ij}^{k} \tag{3}$$

The total energy consumption cost during transportation is the product of vehicle transportation energy consumption and unit price δ of fuel.

$$C_3 = \delta B = \delta \alpha \sum_{i=0}^{N} \sum_{j=0}^{N} \sum_{k=1}^{K} d_{ij} x_{ij}^{k} \tag{4}$$

Time window penalty cost

Each customer has an acceptable service time range. Any delivery that exceeds this time range incurs a time window penalty cost. In accordance with customer satisfaction, time windows can be classified as hard, soft, and mixed. A hard time window requires the agriculture material to be delivered within the specified time, and early or late delivery is not allowed. A soft time window allows deliveries outside the specified time, but a penalty is imposed.

$$C_4=\sum_{k=1}^{K}\sum_{i=1}^{N}H_i\left(t_i^k\right)\max\{\left(E_i-t_i^k\right),\left(t_i^k-L_i\right),0\}y_k^i \tag{5}$$

where: C_4 is the time window cost, and if the agricultural material delivery vehicle exceeds the customer's required time window, there will be a penalty cost;

$H_i\left(t_i^k\right)$ is the loss cost coefficient function caused by early or late delivery, which can be expressed as:

$$H_i(t_i^k)=\begin{cases}\infty, & t_i^k<e_i\cup t_i^k>l_i\\ \gamma, & e_i\leq_i^k<E_i\\ 0, & E_i\leq t_i^k\leq L_i\\ \mu, & L_i<t_i^k\leq l_i\end{cases} \tag{6}$$

where: L_i is the latest arrival time of agriculture material in the hard time window [E_i, L_i], y_k^i means that customer i is served by vehicle k. [e_i, l_i] represents the soft time window, which are the earliest and latest arrival time of agricultural material acceptable to customers. γ is the penalty cost of arriving earlier than the required time, and μ is the penalty cost of arriving later than the required time.

Carbon tax cost

Carbon emission cost = carbon tax price × carbon emission. Carbon emission = total energy consumption (B) × carbon dioxide emission coefficient (σ). Carbon tax cost is computed as:

$$C_5=\omega\sigma B=\omega\sigma\alpha\sum_{i=0}^{N}\sum_{j=0}^{N}\sum_{k=1}^{K}d_{ij}x_{ij}^k \tag{7}$$

where, ω is the carbon tax price and σ is the carbon dioxide emission coefficient.

Optimization model setting

On the basis of the analysis of fixed, transportation, and fuel costs in the distribution process, time window penalty cost, and carbon tax cost, the following model is established:

$$minC=C_1+C_2+C_3+C_4+C_5 \tag{8}$$

The constraints are as below:

$$\sum_{k=1}^{K}y_i^k=\begin{cases}1, & i=1,2,3,\cdots,N\\ k, & i=0\end{cases} \tag{9}$$

$$\sum_{k=1}^{K}\sum_{j=1}^{N}x_{0j}^k=K \tag{10}$$

$$\sum_{k=1}^{K}\sum_{j=1}^{N}x_{0j}^k=N \tag{11}$$

$$\sum_{j=1}x_{0j}^k=\sum_{j=1}x_{j0}^k\ ,,\ 1,k=1,2,3,\cdots,k \tag{12}$$

$$\sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{K}\gamma_i^kQ_{ij}\leq Q \tag{13}$$

$$t_j^k=t_{ij}+max\{t_i^k,E_i\}+t_{si} \tag{14}$$

$$W,,\ Q_{ij}\leq W_1 \tag{15}$$

where: Q is the maximum cargo capacity of agricultural distribution vehicles or the maximum transport capacity and W_1 is the minimum transport capacity.

Formula (8) yields the total cost of minimizing the objective function. Formulas (9) and (10) indicate that the number of refrigerated vehicles assigned by the distribution center does not exceed K, and each customer can only be served by one vehicle once. Formula (11) indicates that N customers accept service. Formula (12) shows that each agricultural distribution vehicle returns to the distribution center immediately after finishing the assigned task. Formula (13) indicates that the demand of N customers is less than or equal to the maximum cargo capacity of delivery vehicle K. Formula (14) presents the continuity of service time points for two customers. Formula (15) shows that the freight volume of the vehicle is greater than the minimum traffic volume and less than the maximum traffic volume.

ALGORITHM DESIGN

The location of goods was obtained using the scanning method, and polar coordinates represented the locations of goods. The area for warehouse entry and exit operations was selected as the starting point, and its angle was set to 0°. The equipment nodes were segmented with the maximum carrying capacity of the robot as the constraint condition, and several subregions that met the carrying capacity constraints were obtained.

Algorithm Improvement

(1) Improvement of the initial pheromone concentration. The initial pheromone concentration of the basic ant colony algorithm is similar in all routes. The first search of each iteration is blind search without direction guidance. As a result, the pheromone concentration of irrelevant routes is high, the search time is prolonged, and the algorithm is likely to be introduced into the local optimal solution. Therefore, in this study, the initial pheromone concentration was set as follows to guarantee the directionality of the algorithm at the initial search stage:

$$\tau_{ij}(0) = \frac{Q}{d_{0i} + d_{0j}}, i \neq j \tag{16}$$

where: Q is the total amount of pheromones released by ants for each search, d_{0i} is the actual distance between demand point i and the distribution center, and d_{0j} is the actual distance between demand point j and the distribution center.

(2) Improvement of the pheromone updating strategy (differential updating and chaotic disturbance). Pheromone update in the basic ant colony algorithm is likely to increase pheromone concentration errors in non-optimal routes, resulting in locally optimal solutions. This study used the ant cycle system in global route updating. In this system, after an iteration is completed, the selected route is given the same pheromone increment: the quotient of the total pheromone amount and total route length.

On this basis, the pheromone concentration is updated differently by highlighting the advantages and disadvantages of the route, that is:

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \Delta\tau_{ij} + \Delta\tau_{ij}^{*} \tag{17}$$

$$\Delta\tau_{ij} = \sum_{g=1}^{G} \Delta\tau_{ij}^{g} \tag{18}$$

$$\Delta\tau_{ij}^{g} = \begin{cases} \frac{Q}{L_g}, Z_g \leq Z_{ave}, & (i,j) \text{ is the selected route} \\ 0, Z_g > Z_{ave} \end{cases} \tag{19}$$

$$\Delta\tau_{ij}^{*} = \begin{cases} \frac{Q}{L_{best}}, (i,j) \in \text{the points in the optimal route} \\ 0, (i,j) \notin \text{the points in the optimal route} \end{cases} \tag{20}$$

where: $\tau_{ij}(t)$ is the pheromone concentration on the route between demand points i and j in iteration t; ρ is the volatilization rate of the pheromone on the route after each iteration; $\Delta\tau_{ij}$ is the change amount of the pheromone between points i and j in each iteration; $\Delta\tau_{ij}^{g}$ is the value of the contribution of ants in group g to the pheromone changes of points i and j in the iteration; $\Delta\tau_{ij}^{*}$ is the extra reward to the optimal route, the pheromone on which is further strengthened; L_g is the total length of the route selected by the ants in group g;

L_{best} is the total length of the optimal route currently obtained; and G is the total number of ant groups. If the total distribution cost of the route selected by the ants in group g is less than the average distribution cost, the pheromone will be increased accordingly; otherwise, the value will be zero. The pheromone of the route that is worse than the average level of the iteration will decrease in this iteration because of pheromone-volatilization. $\Delta\tau_{ij}^{*}$ guarantees and emphasizes the pheromone concentration of the current optimal route.

However, as the number of iterations increases, the optimal route no longer changes, which means that the algorithm is trapped in a local optimal solution. Therefore, when the obtained optimal route does not change frequently, the chaotic disturbance mechanism is introduced to make the algorithm jump out of the current local optimal solution.

The settings are as follows:

$$\tau_{ij}(t+1)=(1-\rho)\cdot\tau_{ij}(t)+\xi F_{ij}(t) \tag{21}$$

$$F_{ij}(t+1)=\upsilon F_{ij}(t)[1-F_{ij}(t)] \tag{22}$$

where ξ is the adjustable coefficient, which is a constant; $F_{ij}(t)$ is the chaotic variable; υ is the control variable, the value of υ is in the range of [3.56, 4.0]. When υ =4 and $0 \le F_{ij}(t) \le 1$, the variable is in a chaotic state completely.

(3) Improvement of the transfer rule. The transfer rule of the basic ant colony algorithm only includes random search, which cannot highlight the best choice of pheromone and heuristic function to some extent, resulting in a low search speed. Therefore, this study combined deterministic search and random search to determine the choice of the next demand degree (j), and the specific settings are as follows:

$$j=\begin{cases}\arg\max\{\tau_{ij}^{\alpha}(t)\cdot\eta_{ij}^{\beta}(t)\}, q<q_0\\ P_{ij}^{k}(t), q..q_0\end{cases} \tag{23}$$

$$P_{ij}^{k}(t)=\begin{cases}\dfrac{\tau_{ij}^{\alpha}(t)\cdot\eta_{ij}^{\beta}(t)}{\sum\limits_{s\ e\ allow_k}\tau_{is}^{\alpha}(t)\cdot\eta_{is}^{\beta}(t)},\ j\in allow_k\\ 0,\ j\notin allow_k\end{cases} \tag{24}$$

where q, $q_0 \in (0,1)$, q_0 is a set constant, q is a random variable in the interval of (0,1), and α is the importance degree of pheromone concentration. The more important the pheromone concentration is, the greater its value is. b indicates the importance of the heuristic function, and $allow_k$ is the set of points that ants can go to when they are at point i. When random number $q < q_0$, a deterministic search is selected; when $q..q_0$, random search is used, and the next destination is selected in accordance with its probability.

Basic Steps of Algorithm

In this study, the improved ant colony algorithm was used to solve the minimum cost model of product distribution in distribution center. The approximate steps are as follows:

(1) Input related data matrix, parameter initialization, total iteration $TNC = 0$, ant group number $NC = 0$, pheromone concentration initialization, construct heurist function matrix;

(2) $NC=NC+1$, $k=0$, place the NC group of ants in the distribution center;

(3) $k=k+1$, the k-th ant leaves and it delivers the products to stores according to the rules. Repeat (3) until the products have been delivered to all stores, and record relevant data;

(4) Return to (2) until $NC=NC_{max}$. Compare the results of NC group and update the pheromone concentration according to the rules;

(5) $TNC=TNC+1$, $NC=0$, return to step (2) until $TNC=TNC_{max}$. The optimal distribution route with the lowest distribution cost is obtained.

SIMULATION

Introduction to the Simulation

This study described an agricultural material logistics distribution model. The data of the case model used to test the validity of the proposed model and algorithm are shown in Table 1. The main contents are as follows. Agricultural distribution vehicles provide delivery services to 25 evenly distributed customer points with known time window constraints in a certain area, and every customer point can only be served by one delivery truck.

In the distribution process, various agricultural distribution vehicle models with different approved volumes are used. The information on the agricultural distribution vehicle is shown in Table 2. The following assumptions were applied: the fixed cost F of each agricultural distribution vehicle is 1,000 yuan/time, the vehicle speed is 40 km/h, the fuel consumption of the vehicle is 0.08 L/km without refrigeration, the unit transportation cost of unit goods is 2 yuan/(t·km), the waiting time for unloading is 1.5 h, the fuel price is 8 yuan/L, the penalty coefficient for early delivery is 5 yuan/h, the penalty coefficient for late delivery is 10 yuan/h, the carbon tax price is 0.3 yuan/kg, and the carbon dioxide emission coefficient is 2.3 kg/L.

Table 1

Customer information

Customer	Coordinate (X) km	Coordinate (Y) km	Demand volume (T)	Time window (min)	Service time (min)
0	40	50	0	(0,1236)	0
1	46	68	0.2	(912,967)	90
2	49	70	0.6	(825,870)	90
3	50	66	0.2	(65,146)	90
4	42	68	0.2	(727,782)	90
5	47	65	0.2	(15,67)	90
6	40	69	0.4	(621,702)	90
7	40	66	0.4	(170,225)	90
8	38	68	0.4	(255,324)	90
9	38	70	0.2	(534,605)	90
10	35	66	0.2	(357,410)	90
11	35	69	0.2	(448,505)	90
12	25	85	0.4	(652,721)	90
13	32	75	0.6	(30,92)	90
14	22	85	0.2	(567,620)	90
15	30	80	0.8	(384,429)	90
16	30	85	0.8	(475,528)	90
17	18	75	0.4	(99,148)	90
18	10	75	0.4	(179,254)	90
19	15	80	0.2	(278,345)	90
20	30	50	0.2	(10,73)	90
21	20	52	0.4	(914,965)	90
22	28	52	0.4	(812,883)	90
23	38	55	0.2	(732,777)	90
24	25	50	0.2	(65,144)	90
25	25	52	0.8	(169,224)	90

Table 2

Information on agricultural distribution vehicles

Truck model	Model 1	Model 2	Model 3	Model 4
Size	4000x2000x3000mm	4100x2040x3000mm	5600x2050x3000mm	8600x2050x3000mm
Self-mass	2t	3t	4t	5t
Number of tires	4	6	8	12
Swept volume	3000mL	3200mL	4000mL	4000mL
Fuel	#92	#92	#92	#92
Mileage	Unlimited	Unlimited	Unlimited	Unlimited
Rated load mass	3t	4t	6t	10t

The parameters involved in the algorithm were as follows: number of iterations MAXGEN = 100, number of ants m = 50, pheromone importance factor alpha = 1, heuristic function importance factor beta = 3, waiting time importance factor gamma = 2, time window span importance factor delta = 3, r0 is the parameter used to control the transfer rule and equals 0.5, pheromone volatilization factor rho = 0.85, and pheromone concentration update constant Q=5. MATLAB2022a was used to realize and run the algorithm, and the optimization model of the agricultural material distribution route that considers carbon emissions was solved in accordance with the specific data of the examples above.

RESULTS AND ANALYSIS

In this study, the route optimization model of agricultural material distribution was solved using the improved ant colony algorithm. The maximum number of iterations was set to 200, and the agricultural distribution vehicle start-up cost was 1,000 yuan. A satisfactory solution, that is, three agricultural distribution vehicles are needed to complete the agricultural material distribution task, was obtained by solving the model. The total travel distance of the agricultural distribution vehicle was 322.238 km, and the total cost was 3,322.215 yuan. The algorithm was run for 259.292 s. The improved ant colony algorithm route diagram is shown in Fig. 1. The convergence curve of the improved ant colony algorithm is shown in Fig. 2, and the calculation results are listed in Table 3.

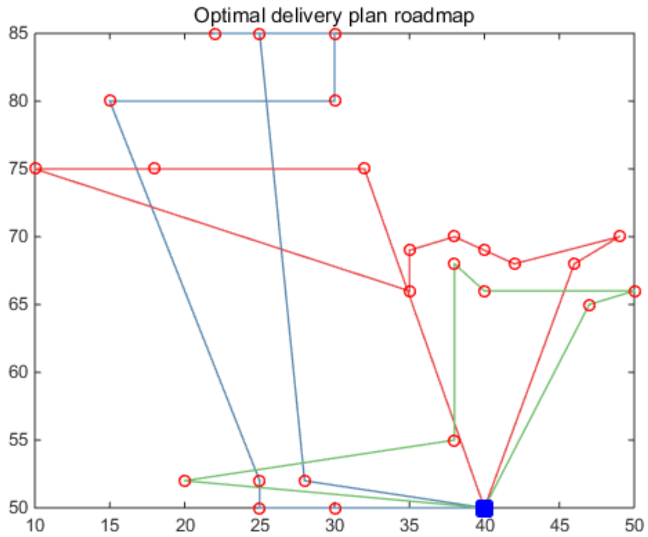

Fig. 1- Route diagram of improved ant colony algorithm

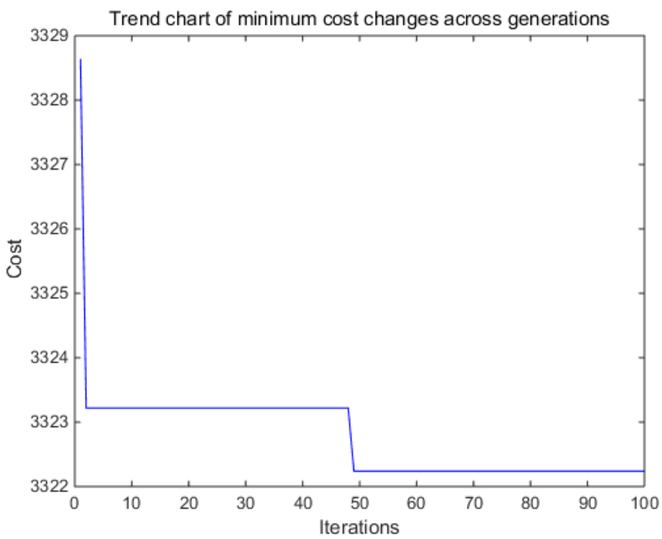

Fig. 2 –Convergence curve of improved ant colony algorithm

Based on the vehicle information in "Table 2 Information on agricultural distribution vehicles" and combined with the actual situation of optimizing the distribution path, select the vehicle. Here, a 4-ton vehicle with the lowest total cost was chosen to be used.

Table 3

Optimal service route

Service route	Model	Total distance	Convergence time	Total cost
0->20->24->25->19->15->16->14->12->22->0	4T	322.2386	259.292	3322.215
0->13->17->18->10->11->9->6->4->2->1->0	4T			
0->5->3->7->8->23->21->0	4T			

This study also designed a traditional ant colony algorithm solution model to further verify the effectiveness of the improved ant colony algorithm. Under the constant initial cost and parameters, four agricultural distribution vehicles were needed to solve the optimization model of the agricultural material route, and the total distance of an agricultural distribution vehicle was 346.048 km. The total cost was 4,346.109 yuan, and the algorithm was run for 304.661 s. The route diagram of the traditional ant colony algorithm is shown in Fig. 3, the convergence curve of the traditional ant colony algorithm is given in Fig. 4, and the calculation results are presented in Table 4.

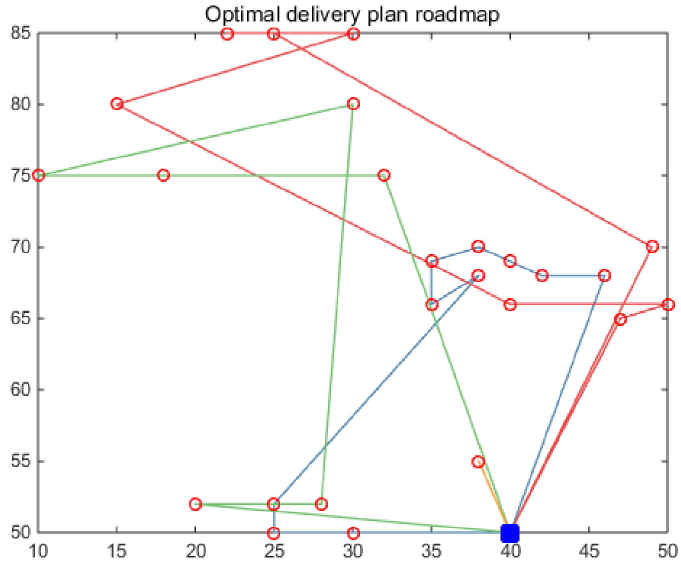

Fig. 3 - Route diagram of traditional ant colony algorithm

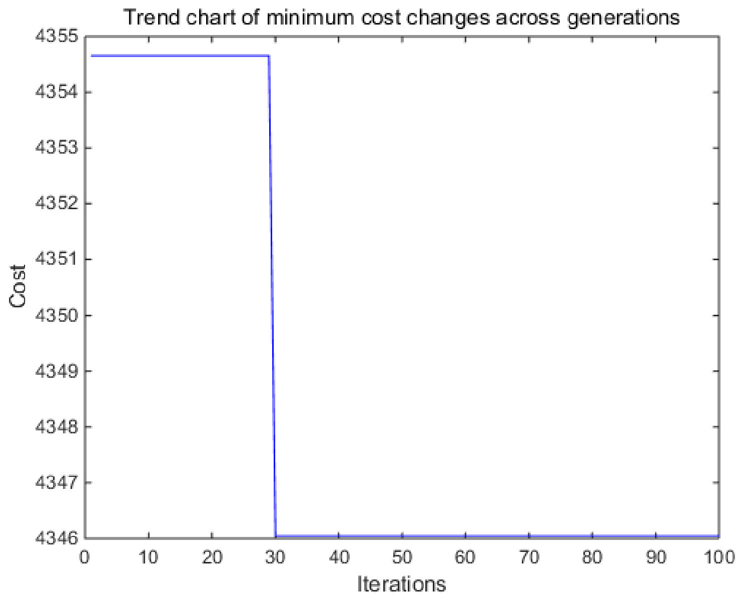

Fig. 4 - Convergence curve of traditional ant colony algorithm

Based on the vehicle information in "Table 2 Information on agricultural distribution vehicles" and combined with the actual situation of optimizing the distribution path, select the vehicle. Here, a 3-ton vehicle with the lowest total cost was chosen to be used.

Table 4

Traditional ant colony route

Service route	Model	Total distance	Convergence time	Total cost
0->20->24->25->8->10->11->9->6->4->1->0	3T	346.048	304.661	4346.109
0->5->3->7->19->16->14->12->2->0	3T			
0->13->17->18->15->22->21->0	3T			
0->23->0	3T			

The calculation results show that the improved ant colony algorithm has a lower distribution cost but more reasonable route compared with the traditional ant colony algorithm. The number of activated vehicles is small, and the convergence time of the algorithm is short. Compared with the traditional ant colony algorithm, the improved ant colony algorithm can converge to the global optimum faster with a lower distribution cost. In the multivehicle distribution route optimization model that considers carbon emissions, under the same conditions of driving distance, vehicle weight, traffic control, and others, the four-ton truck has obvious advantages, and it has the lowest total cost and the largest cost advantage. The existing agricultural material logistics distribution process is relatively complicated, and it involves many demand distribution points and freight types.

In terms of the total distance traveled by vehicles, the improved ant colony algorithm reduces by 7.39% compared to the traditional ant colony algorithm. In terms of algorithm convergence time, the improved ant colony algorithm improves by 17.50% compared to traditional ant colony algorithms. In terms of total cost, the improved ant colony algorithm reduces 30.82% compared to traditional ant colony algorithms. The traffic routes of vehicles are complex, and customers have strict requirements for agricultural material quality. Against the background of the market economy, competitive demands in the agricultural material market have increased. Therefore, for medical supplies with strict time requirements, the model that adopts a soft time window constraint and a loss function is suitable for actual situations. It decreases the cost resulting from transportation delays, improves customer satisfaction, and plays an important role in promoting the development of the modern logistics industry.

CONCLUSIONS

While ensuring the economic benefits of agricultural material distribution enterprises, it is also necessary to consider the environmental costs in the economic development of enterprises, in order to achieve a win-win situation between the logistics industry and ecological civilization development. This article mainly starts from the perspective of energy conservation and emission reduction, and takes into account the cost of converting low-carbon environmental protection into carbon emissions in the model. Under constraints such as vehicle load capacity and time window, the model considers the fixed cost of vehicle delivery, carbon emissions cost, vehicle transportation cost, and time window penalty cost as the objective functions for optimizing the agricultural material delivery path of multiple vehicle models. Using improved ant colony algorithm to study agricultural material enterprises with a single distribution center, the basic ant colony algorithm is improved from three aspects: initial pheromone concentration, pheromone update strategy, and transfer rules. By comparing the results under different parameter values, reasonable parameters are determined. And comparing the results of the improved ant colony algorithm with the basic ant colony algorithm, it is found that the improved ant colony algorithm has made some progress in the average value of the lowest delivery cost obtained. The research results of this article provide a reference for agricultural material distribution companies to propose multi vehicle logistics distribution path methods under the conditions of reducing energy consumption and increasing efficiency, making the company's development more suitable for the needs of building green logistics and developing green operations. The following conclusions were obtained from the analysis:

(1) Given the timeliness of some agricultural products, vehicle routing has a time limitation and a time constraint. A time window can be introduced to solve the multivehicle routing problem, and the traditional ant colony algorithm is usually adopted for the time constraint problem. Differential update and chaotic disturbance can be utilized to improve the traditional ant colony algorithm and make it conducive for future research on

multivehicle distribution under high agricultural demands. Such an improvement can avoid delays in the farming season and can boost the growth of crops.

(2) The improved ant colony algorithm has good sensitivity in solving large-scale calculation problems. In actual cases, the distribution from the distribution center to each demand point has good extensibility. The improved ant colony algorithm can be practically applied to the vehicle routing problem. In this study, the improved ant colony algorithm was compared with the traditional ant colony algorithm. The proposed algorithm shortens the response time and provides users with results faster compared with the traditional algorithm. With regard to the distribution route results, the distribution distance is short, and minimal fuel is consumed. The improved ant colony algorithm is environmentally friendly and decreases the transportation cost, thus benefiting farmers.

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