Research on the distribution problem of electric logistics vehicle based on quantum whale algorithm considering charging strategy

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Abstract. With the continuous introduction of national carbon emission reduction policies, especially in the field of logistics and distribution, the use of electric vehicles can effectively reduce carbon emissions and the key factors are charging mode and time window constraints and the choice of charging piles, so this paper constructs an electric logistics vehicle distribution model that considers factors such as electric logistics vehicle charging mode and customer time window according to actual needs. In order to improve the problem that the traditional whale swarm algorithm has a low solution speed and is easy to fall into the local optimal solution, this paper uses the Grover quantum algorithm for quantum acceleration, and uses the variable neighborhood search algorithm to perform a variety of neighborhood searches, so that the algorithm can effectively jump out of the local optimal solution and obtain the global optimal solution. Finally, a study is used to verify the rationality of the model and the effectiveness of the algorithm.

Keywords: Electric logistics vehicles; Route planning; Hybrid charging mode; Quantum whale algorithm

1 Introduction

Compared with traditional cars, electric vehicles have many advantages such as environmental protection and energy saving, low cost and no noise, but there are also problems such as short mileage, difficult charging and slow charging, so how to carry out scientific planning of intelligent charging paths under the constraint of electric vehicles has become the biggest challenge at present. [1] Therefore, governments and enterprises have also begun to consider replacing traditional cars with electric logistics vehicles to complete logistics distribution [2] and actively promote the development of green logistics. On the issue of charging facility site selection and path planning, Wang Qiying et al. [3] studied the site selection of the substation under the soft time window. Han Zhibin [4] conducted a study on the path planning of electric vehicles for the law of electric energy consumption. Hu et al. [5] Considering the uncertainty of demand, use a robust method to study the vehicle path problem. In terms of algorithms to solve problems such as path planning, Fan Liyang [6] conducted research on the path problem of multi-energy vehicles by improving genetic algorithms. Jinying Lu[7] used the

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adaptive large neighborhood search algorithm to study the path optimization problem with time window. In this paper, a path planning model with soft time window considering charging strategy and soft time window is established, and the GVWOA algorithm is designed to improve the efficiency of whale algorithm using quantum computing and variable neighborhood algorithm, so as to achieve efficient processing and analysis of the problem and obtain the optimal solution.

2 Model description and establishment

2.1 Problem description

A distribution center has K homogeneous electric logistics vehicles, the maximum battery capacity is Q, the maximum load capacity is W, the customer point is n, the distribution center is only one, the demand for customer point i is qi, the time window constraint is $[E_i, L_i]$, and when the vehicle does not meet the time window constraint, it needs to pay the opportunity or penalty cost. After the vehicle is fully charged, it is limited by the power supply, and it may be necessary to select a charging pile in the middle of the way, and its power consumption is linear with the distance. The goal requires the selection of reasonable charging piles and distribution routes to meet demand and minimize costs.

2.2 Symbol description

Table 1. Symbol description

symbol	illustrate	symbol	illustrate
V	Loop customer point collection, $V \in \{1,2,\cdots,N\}$	WT_i^k	The time that the vehicle k waits at point i
V_0,V_{N+1}	0, N+1 is the distribution center	C_{ij}	Variable cost from i to j
V'	A collection of nodes	c_1	The cost per mile
K	Vehicle assembly	c_2	Fixed electricity costs
s_i	Customer point i service hours	A	Power consumption rate
$[E_i, L_i]$	Location i time window	P_{fast}	Fast charging price
t_{ik}^A	The time of the vehicle k to i	W	Maximum load capacity, unit:t
t_{ik}^L	The time at which the vehicle k leaves i	q_i^k	Vehicle k has the remaining capacity at customer point i

d_{ij}	The distance from i to j,unit:m	π_1, π_2	Penalty cost factor
Q	Maximum battery capacity, unit:kWh	X_{ijk}	Vehicle k has a value of 1 when it goes from i to j, 0 otherwise
q_i	Customer point i demand, unit:t	Y_{ijk}	When the vehicle is charged in path r, the value is 1, otherwise it is 0
F	Charging station collection		

2.3 Model building

In order to effectively solve the path planning and charging pile selection, this paper considers the influencing factors such as load capacity and soft time window to construct a path planning model considering the reconnection point strategy and the mathematical model is as follows:

$$\min Z = \left(\sum_{k\in K}\sum_{i\in V'}\sum_{j\in V'} C_{ij}\cdot x_{ij}^{k} + \sum_{k\in K}\sum_{j\in V'} c_2 \cdot x_{0j}^{k} \right) + \left[\sum_{k\in K}\sum_{i\in V}\sum_{j\in F} t_{fast}\cdot Y_{ijk}\left(P_{fast}+\pi\right) \right] + \sum_{k\in K}\sum_{i\in V} S\left(t_{ik}^{A}\right) \tag{1}$$

s.t.

$$\sum_{k\in K}\sum_{j\in V_{N+1}\cup V\cup F, i\neq j} x_{ij}^{k} = 1, i\in V \tag{2}$$

$$\sum_{k\in K}\sum_{j\in V_{N+1}\cup V\cup F, i\neq j} x_{ij}^{k} \leq 1, i\in F \tag{3}$$

$$\sum_{k\in K}\sum_{i,j\in V', i\neq j} x_{ij}^{k} = \sum_{k\in K}\sum_{i,j\in V', i\neq j} x_{ji}^{k} \tag{4}$$

$$\sum_{k\in K}\sum_{i,j\in F} x_{ij}^{k} = 0 \tag{5}$$

$$0 \leq \sum_{j\in V, i\neq j} q_j \sum_{i\in V_0\cup V\cup F} x_{ij}^{k} \leq Q, k\in K \tag{6}$$

$$t_{ik}^{L} = t_{ik}^{A} + WT_{i}^{k} + s_i, i\in V', k\in K \tag{7}$$

$$t_{jk}^{A} = \sum_{i\in V'}\sum_{j\in V', i\neq j} x_{ij}^{k}\left(t_{ik}^{L} + t_{ij}\right), k\in K \tag{8}$$

$$WT_{i}^{k} = \max\left[0, \left(E_i - t_{ik}^{A}\right)\right], i\in V \tag{9}$$

$$0 \leq q_j \leq Q - A\cdot d_{ij}\cdot x_{ij}^{k}, i\in F\cup V_0, j\in V\cup V_{N+1}\cup F, k\in K, i\neq j \tag{10}$$

$$0 \le q_j \le q_j - A \cdot d_{ij} \cdot x_{ij}^k + Q\left(1 - x_{ij}^k\right), i \in V, j \in V \cup V_{N+1} \cup F, k \in K, i \ne j \tag{11}$$

$$S\left(t_{ik}^A\right) = \begin{cases} \pi_1\left(E_i - t_{ik}^A\right), & t_{ik}^A < E_i \\ 0, E_i \le t_{ik}^A \le L_i \\ \pi_2\left(t_{ik}^A - E_i\right), & t_{ik}^A > L_i \end{cases} \tag{12}$$

The objective function (1) represents the minimum of the total cost of the logistics distribution process; Equation (2) means that each customer is required to be delivered at least once; Equation (3) means that the vehicle k can not pass through the charging station; Equation (4) indicates conservation of flow and the number of vehicles entering the customer point is always equal to the number of vehicles leaving the point; Formula (5) means that the vehicle k is prohibited from continuing to drive from one charging station to another charging station; Formula (6) means that the loading capacity of the vehicle does not exceed the maximum capacity; Equation (7) represents the calculation of the time to leave i; Equation (8) represents the calculation of the time to reach j; Equation (9) represents the waiting time at the customer's point. Formula (10), (11) respectively represents the power constraint of vehicle k arriving at j from the charging station or distribution center when charging, and the power constraint from customer point i to point j when the electric vehicle is not charged, to ensure that the vehicle will not run out of power during driving; Equation (12) represents the cost of punishment.

3 Quantum whale optimization algorithm

The basic whale optimization algorithm is a heuristic optimization algorithm that simulates the hunting behavior of humpback whales, which mainly includes three important stages of shrinking and encircling prey, spiral bubble net attack and random search for prey.[8] By constantly updating the position of the whale, the global optimal solution is finally obtained. However, the whale algorithm has the disadvantages of slow convergence speed and low accuracy, easy to fall into local extremums, etc., so this paper uses double qubit coding and uses The Grover quantum computing method and the variable neighborhood algorithm to jump out of the local optimality, which improves the population diversity, optimization performance, convergence speed and solution quality of the algorithm.

The GVWOA algorithm optimizes the algorithm by changing the way the update position is located. Let $\overrightarrow{QX}(t)$ be the updated position of the whale, N elements, after the $\sqrt{N}$ sub-G operator iteration to obtain the target quantum state, $|\varphi\rangle$ is the initial uniform superposition state, as shown in equation (13). Symmetrical projection based on initial φ in two-dimensional Hilbert space, equation (14). Each G-transform can be rotated 2θ and after the k-g-transform is shown in Equation (15). Thus an updated formula for WOA can be obtained as shown in Equation (16).

$$|\varphi\rangle = \frac{1}{\sqrt{N}} \sum_{x=0}^{N-1} |x\rangle \tag{13}$$

$$G = H^{\otimes n}\left(2|0\rangle\langle 0| - I\right)H^{\otimes n} = \left(2|\varphi\rangle\langle\varphi| - I\right)O \tag{14}$$

$$G^k|\varphi\rangle = \sin\left(2k+1\right)\theta|\alpha\rangle + \cos\left(2k+1\right)\theta|\beta\rangle \tag{15}$$

$$\overrightarrow{QX}(t) = \sin\left(2k+1\right)\theta\overrightarrow{X}(t) + \cos\left(2k+1\right)\theta\sqrt{1-\overrightarrow{X}(t)} \tag{16}$$

The WOA-Grover algorithm flowchart is shown in Figure 1.

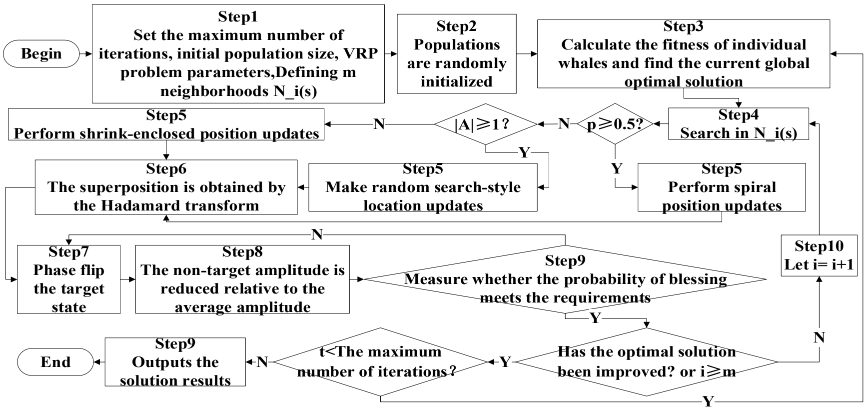

Fig. 1. WOA-Grover algorithm flowchart

4 Experimental cases

This example considers the 0 and 20 demand points of the distribution center, uses Euclidean geometric coordinates to represent the locations of each point and generates the average demand and the upper and lower bounds of the time window, as shown in Table 2.

Table 2. Study data

Customer point	Abscissa /km	Ordinate /km	Average demand /t	Time window nether /h	Time window upper bound /h
0	55	113	0.00	0	0
1	2	1	0.70	10.1	12.3
2	146	71	0.19	8.5	10.6
3	15	92	0.05	14.8	19
4	13	41	0.08	14	15.2
5	107	163	0.60	14.2	11.6
6	127	177	0.10	9.8	13.4
7	199	61	0.62	13.6	18.2
8	143	23	0.04	15.1	12.6
9	133	163	0.58	10.5	17.9
10	130	143	0.67	12.3	21.4
11	142	49	0.64	11.2	13.6
12	86	23	0.01	15.5	21.4

13	182	63	0.68	11.5	14.5
14	171	94	0.52	13.2	14.6
15	77	199	0.52	12.2	14.6
16	7	16	0.57	12.1	14.5
17	96	182	0.06	13.5	15.6
18	104	153	0.35	16	22
19	173	99	0.13	15	18
20	114	155	0.39	9.2	16.6

Assuming that the electric logistics vehicle model of the distribution center is the same, the maximum mileage is 200km, the maximum load capacity is 2.5t, the average speed is 80km/h, the unit mileage cost is 0.14 yuan, the unit time opportunity cost of the vehicle arriving early is 25 yuan /h, the unit penalty cost for late arrival is 45 yuan / hour, the fixed travel cost of the vehicle is 150 yuan / car, the electricity is 0% to 100% Fast charging requires 0.75h, and slow charging takes 4h.

By using the algorithm proposed in this paper, the optimal route, charging pile and charging mode selection of this case are obtained, namely 0-2 (charge) -13 (charge) -7-8-12 (charge) -0, 0-20-6-9-10 (charge) -0, 0-11-14-19 (charge) -0, 0-15-17-5-18 (charge) -0, 0-1-16-4 (charge)-3-0. The locations of the charging stations are points 2, 4, 10, 12, 13, 18 and 19. This is shown in Figure 2.

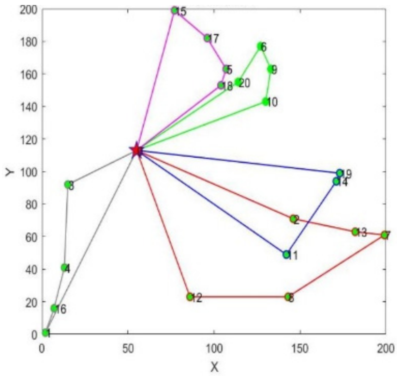

Fig. 2. Vehicle distribution roadmap

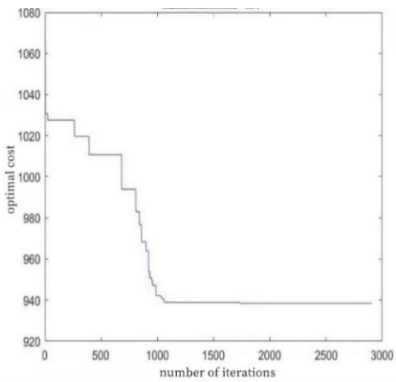

Fig. 3. GVWOA-Grover iteration curve

Through Figure 3, it can be seen that the total driving cost is 938.384 yuan, and convergence is achieved at the 1092nd iteration, in order to further verify the solution efficiency of the proposed algorithm, the genetic algorithm, the simulated annealing algorithm, and the particle swarm algorithm have the CPU time of 7.46s, 9.78s, 10.23s, 8.76s, and the cost is 938.38, 956.22, 1002.34, 980.67, so the indicators of the solution are optimal. It can be concluded that the proposed algorithm is feasible and efficient in solving such problems.

5 Conclusion

In this paper, a two-stage model of path planning and pile site selection is established by considering factors such as mixed charging mode and uncertain demand. In this paper, the WOA-Grover algorithm is proposed, which uses the Grover quantum algorithm for acceleration and adopts the neighbor operator to avoid falling into local optimality. In order to verify the effectiveness of the model and the efficiency of the algorithm, a study is constructed, and different algorithms are compared, and the algorithm of this paper is feasible and efficient in solving such problems, so the model and algorithm of this paper have certain practical value and can provide certain reference value for related industries.

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