International Journal of Innovative Computing, Information and Control
ICIC International ©2019 ISSN 1349-4198
Volume **15**, Number **2**, April **2019**
pp. 773–782

DISTRIBUTION PATH OPTIMIZATION METHOD OF GAS CYLINDER BASED ON GENETIC-TABU HYBRID ALGORITHM

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Received June 2018; revised October 2018

Abstract. *In this paper, the problem of the distribution path optimization of gas cylinder in urban area is studied. A method of distribution route optimization is proposed, which combines genetic-tabu hybrid algorithm and the vehicle routing model with time windows constraint (VRPTW). The experimental results show that the proposed method of gas cylinder distribution reduces cost of distribution and balances the relationship between minimum distribution distance, minimum time cost and minimum number of vehicles.*
Keywords: Genetic-tabu hybrid algorithm, VRPTW, Distribution path, Optimization

1. **Introduction.** With the rapid development of modern economy, gas supply industry is becoming one of the most essential parts in supply chain networks [1]. Modern supply chain managers have widely considered the reduction of operation cost, the improvement of service quality and the awareness of environmental impacts as decision making objectives. Among other ways to achieve these goals, vehicle routing optimization has received significant attention and is valued as an important component of supply chain optimization [2]. Some of the related researches have focused on the optimization of distribution networks where vehicles simultaneously perform delivery and pickup activities [3,4]. In order to reduce the transportation costs, the gas filling stations are constantly seeking an optimal route to allocate the gas cylinder [5]. Extensive studies were also done on the vehicle routing model with time windows constraint (VRPTW) and their variants [6-8]. Existing algorithms for solving this problem mainly include genetic algorithm, tabu searching algorithm, simulated annealing algorithm, quantum-inspired evolutionary algorithm, etc. [9-12] proposed an improved tabu search algorithm with an adaptive neighborhood search strategy to assess time-dependent multi-zone multi-trip optimization solutions. These algorithms have obtained some results for this problem. However, when different types of gas cylinder cannot be transported together because of the chemical reaction and different types of vehicles have different shipping volume, the distributed problem is still a challenge in this field.

In this paper, a path optimization method is proposed to improve the efficiency of gas cylinder distribution path. Firstly, the components of the distribution path problem are analyzed and the optimization target is put forward. Secondly, the optimized model of VRPTW is discussed. Then, genetic-tabu hybrid algorithm is adopted to solve the

DOI: 10.24507/ijicic.15.02.773

problem of the distribution path optimization of gas cylinder. Finally, an experimental example is provided to verify the effectiveness of the proposed algorithm.

2. **Problem Statement and Preliminaries.**

2.1. **Problem statement.** VRPTW in distribution is to achieve certain distribution objectives. Under different constraints, such as the maximum load of the transport vehicle, the delivery time, the maximum distance of the transportation vehicle, vehicles for distribution will be arranged properly to meet customers' requirement.

2.2. **Components of distribution problem.** Distribution path model is a key point and difficult problem of the system. The difficulty lies mainly in the selection and optimization of distribution routes. The general distribution route problem is composed of the distribution center, vehicles, merchandise, customers, objective functions and constraints.

(1) Distribution center: It mainly refers to the gas cylinder warehouse.
(2) Vehicles: Constraints are vehicle type, maximum load, and maximum distance.
(3) Merchandise: The merchandise is mainly the gas cylinders. There are liquefied petroleum gas, oxygen, nitrogen, carbon dioxide, argon, acetylene and so on.
(4) Customers: The customers are divided into civil part and industrial part.
(5) Objective functions: The objective function is the lowest distribution cost.
(6) Constraints: They are the maximum load and the longest distribution of a vehicle.

2.3. **Goal of distribution routing optimization.** The goal of distribution routing optimization is to minimize the cost of distribution. In fact, the minimum delivery cost requires minimum delivery distance, minimum time cost and minimum number of vehicles. These three optimization objectives are shown as follows.

(1) Minimum distribution distance: The shorter distance means the lower cost.
(2) Minimum time cost: Customer satisfaction is converted into a penalty coefficient that deviates from the time window.
(3) The minimum number of vehicles: By reducing the vehicles for distribution, the total transport cost of distribution can be cut down.

To sum up, the distribution module is designed as the mathematical model of minimum total distribution cost as the objective function by balancing the optimization objectives.

3. **The Mathematical Model.** The VRPTW model is selected and used in this paper. The mathematical model of VRPTW can be described as a node set as $N = \{n|n = 0, 1, \ldots, |N|\}$. The transportation time between the two nodes is t_{ij}, $i, j \in N$, $(t_{ij} = t_{ji})$. The set of distribution vehicle is $K = \{k|k = 0, 1, \ldots, |K|\}$ where $|K|$ is the total number of the distribution vehicles. The fixed delivery cost of the distribution vehicle is $v_k \in R^+$. The maximum driving time of the distribution vehicle k is T_k. A collection of gas cylinder type is $P = \{p|p = 0, 1, \ldots, |P|\}$. The transportation cost of gas cylinder distribution per unit time is $h_k \in R^+$. The maximum number of P gas cylinders by the distribution vehicle k is Q_k^p, $p \in P$. The number of the P gas cylinders required by user i is q_i^p. The distribution time window for user i is $\{e_i, l_i\}$. The time for the delivery vehicle k to reach the address of the user i is t_{ki}. Time waiting cost is w_1. Time delay cost is w_2. If the distribution vehicle k passes through the line section (i, j), x_{ijk} will be set to 1. Otherwise $x_{ijk} = 0$. If the gas cylinder is required by user i and delivered by the vehicle k, y_{ipk} will be set to 1. Otherwise, $y_{ipk} = 0$. If the minimum cost of distribution is taken

as the objective function, the mathematical model of distribution routing problem is as follows:

$$\begin{aligned} Min \sum_{(i,j,k)} x_{ijk} t_{ij} h_k + w_1 \sum_{(i,j,k)} x_{ijk} \max\left(e_i - t_{ki}, 0\right) \\ + w_2 \sum_{(i,j,k)} x_{ijk} \max\left(t_{ki} - l_i, 0\right) + \sum_{(i=0,j,k)} x_{ijk} v_k \end{aligned} \tag{1}$$

Equation (1) is the objective function which is the model of minimum total delivery cost including transportation vehicle cost, time penalty cost and fixed delivery cost. The objective function is the sum of the minimum cost of distribution, the cost of waiting time for early arrival, the cost of compensation for delay and the fixed delivery cost of the distribution vehicles.

$$\sum_{i \in N \backslash \{0\}} y_{ipk} q_i^p \leq Q_K^P, \quad \forall k \in K, \quad p \in P \tag{2}$$

$$\sum_{i \in N} \sum_{j \in N} x_{ijk} t_{ij} \leq T_k, \quad \forall k \in K \tag{3}$$

Equation (2) and Equation (3) show that the constraint conditions are the maximum number of cylinders and the longest delivery time as for gas cylinders distribution vehicles.

$$\sum_{k \in K} y_{ipk} = 1, \quad \forall i \in N \backslash \{0\}, \quad p \in P \tag{4}$$

Equation (4) shows that any user's requirement for a type of gas cylinder can only be delivered by one vehicle, which means that the user's demand cannot be split and distributed.

$$\sum_{i \in N} x_{ijk} \geq y_{ipk}, \quad \forall j \in N \backslash \{0\}, \quad k \in K, \quad p \in P \tag{5}$$

Inequation (5) shows that service can be delivered to user when the arc (i, j) is able to drive.

$$\sum_{i \in N} x_{ijk} = \sum_{i \in N} x_{jik}, \quad \forall j \in N \backslash \{0\}, \quad k \in K \tag{6}$$

Equation (6) shows that number of vehicles entering and leaving on each routing is equal.

$$x_{ijk} + x_{jik} \leq 1, \quad \forall i \in N \backslash \{0\}, \quad j \in N \backslash \{0\}, \quad k \in K \tag{7}$$

Equation (7) shows no subcircuit on each routing

$$\sum_{j \in N \backslash \{0\}} x_{0jk} = \sum_{i \in N \backslash \{0\}} x_{0ik} = 1, \quad \forall k \in K \tag{8}$$

Equation (8) shows that gas cylinder distribution vehicles start from the gas filling station for distribution business, and then gas cylinder distribution is finished, they will eventually return to the gas filling station.

$$t_{oki} = t_{ok(i-1)} + t_{i(i-1)}, \quad \forall k \in K, \quad i \in N \backslash \{0\} \tag{9}$$

Equation (9) shows that the time for the distribution vehicle to reach the user's address.

$$\sum_{k \in K} \sum_{i \in N \backslash \{0\}} x_{ijk} = 1, \quad \forall j \in N \backslash \{0\} \tag{10}$$

Equation (10) shows that the distribution of the user i is only once, which means that once the distribution will complete all needs.

$$\sum_{p\in P} y_{ipk} = |P|, \quad \forall i \in N\backslash\{0\}, \quad \exists k \in K \tag{11}$$

Equation (11) shows that P is the number of types of distribution cylinders for all users.

4. Distribution Route Optimization Problem of Genetic-Tabu Hybrid Algorithm.

4.1. Genetic-tabu hybrid algorithm.

The advantage of genetic algorithm is that it has strong search ability. In general, genetic algorithm can be used to find the global optimization solution and it can be applied to large-scale optimization problems [13]. However, the disadvantages are "premature convergence" and the poor hill-climbing ability because of the defective mutation operation. These shortcomings of genetic algorithm lead to its weak local search ability.

Tabu search algorithm is very efficient in dealing with simple problems. In the search process, the hill-climbing ability is very strong. The disadvantages of tabu search algorithm are that search ability depends on the initial solution.

Motivated by the advantages of the two algorithms, the genetic-tabu hybrid algorithm is proposed. First, the global search is done by genetic algorithm. Then the current solution of genetic algorithm is used as the initial solution of tabu search algorithm, and tabu search is used to local search for individuals [14]. It not only preserves the global optimization ability of the genetic algorithm, but also improves the local search ability. The flowchart of the genetic-tabu hybrid algorithm is as shown in Figure 1.

4.2. Implementation of the algorithm.

4.2.1. *The description of chromosomes.* In order to facilitate the combination of genetic algorithm and tabu search, natural number coding is used to coding design. The order of delivery is the order of genes in chromosomes.

4.2.2. *The generation of the initial population.* Firstly, it needs to ascertain the number of distribution vehicles, and the first gene of vehicle K is 0, indicating the distribution center. Then a customer point is selected randomly to judge whether the distribution information of the customer point satisfies the constraints. Finally, if no one can meet the condition, the next vehicle will be selected until all customer points are selected.

4.2.3. *The fitness function.* The fitness function is $f_i = Z_{\min}$, where $Z_{\min}$ is the lowest cost chromosome in the same generation. The best result of fitness function is the delivery route plan with the lowest delivery cost.

4.2.4. *Selection of operators.* The larger fitness individuals in the current population are used for the crossover operation. In order to maintain the global searching ability, the best individual reservation and the roulette wheel selection are used to select individuals.

4.2.5. *Crossover operation.* Crossover operation requires two paths to be crossed and two new paths are obtained. The maximum reserved crossover method is used in this paper.

4.2.6. *Mutation operation.* For the distribution path planning problem, the mutation operation acts as a transformation path. In this paper, the mutation operation is done by arbitrarily determining two nonzero positions in chromosome genes and exchanging them.

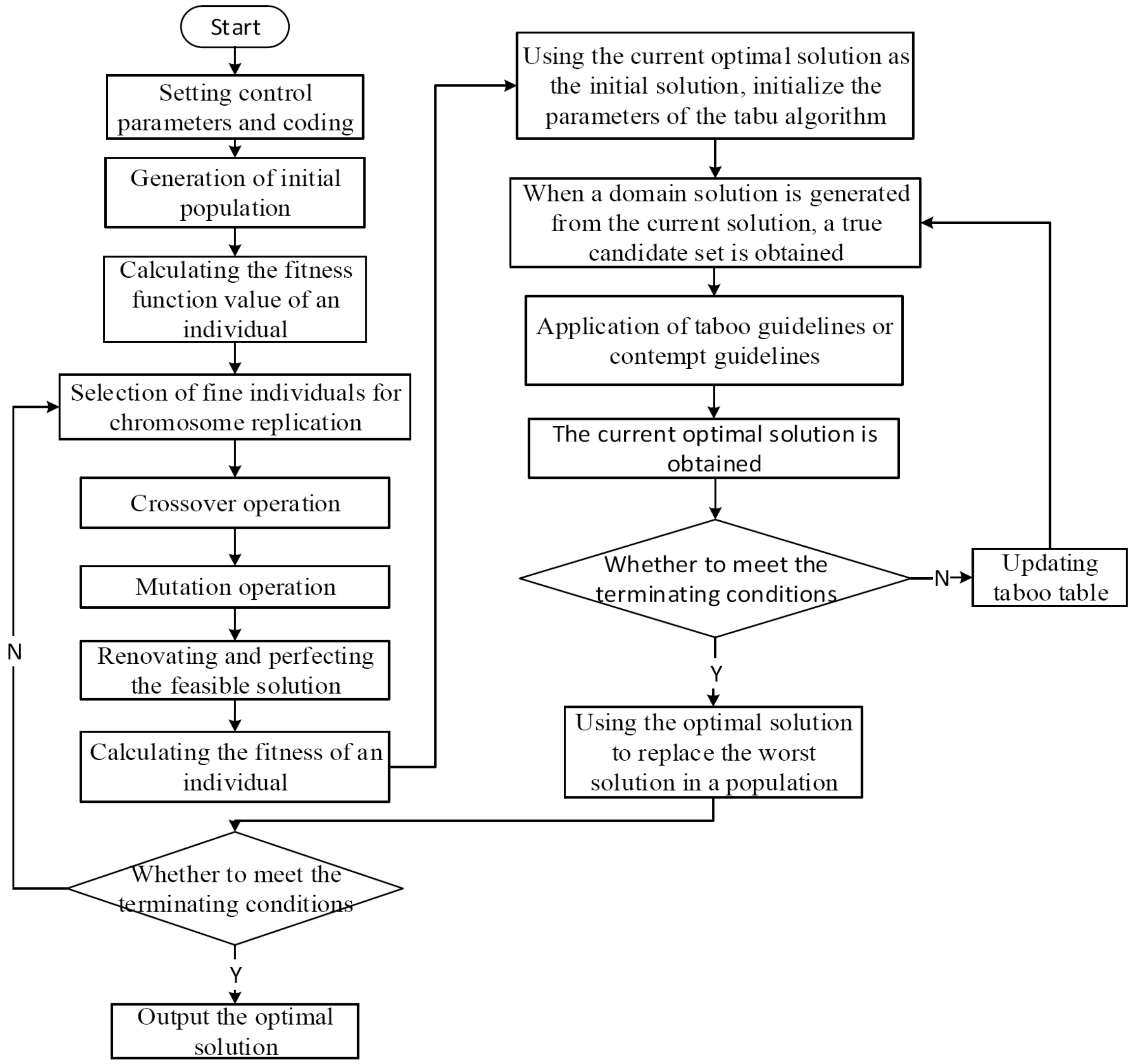

FIGURE 1. Genetic-tabu hybrid algorithm flow chart

4.2.7. *Parameters and terminating conditions.* Practically, a population size of around 30-100 individuals is quite frequent [15]. The intermediate termination condition is that the algorithm reaches 400 generations or the chromosome is best kept for 20 generations.

4.2.8. *Neighborhood structure.* The random selection of two customer points to execute the exchange strategy is vertex exchanging, 2-opt and exchanging the "tail".

4.2.9. *Taboo table.* The taboo table of this algorithm is determined by the neighborhood structure and recorded by a matrix $(n+1) \times (n+1)$. If two points i, j carry vertex swap, the tabu condition is stored in the matrix element (i, j).

4.2.10. *Termination criterion and release criterion.* The terminating criterion is described as: within N times iterations, if the current optimal solution is continuously M times without change, it is considered that it is meaningless to continue to circulate. Otherwise, the program continues to loop until the M times iterations are completed. According to experience, N is selected as 500 and M is selected as 25 in this paper [16].

The release criterion used in this algorithm is that the solution obtained after the current solution changed is better than all the solutions obtained before.

5. **Experiment Result.**

5.1. **Data selection.**

5.1.1. *Position information.* In reality, the staff will collect the number and the type of gas cylinders and the location and time of delivery when they receive the order. The customer's distribution address needs to be obtained through the map in the system.

5.1.2. *Customer information.* The experimental data is the requirement of customers at a certain filling station in Guangyuan. The customer information is shown in Table 1. No. means number. T/Q means type and quantity. A and B mean two types of cylinders.

Table 1. Customer information

No.	T/Q		Position coordinates		Time window	No.	T/Q		Position coordinates		Time window
	A	B	x	y			A	B	x	y	
1	0	0	105.8321	32.4273	–	16	6	0	105.8278	32.4256	10:00-12:00
2	1	0	105.8361	32.4263	8:00-12:00	17	0	2	105.8295	32.4247	13:00-17:00
3	0	3	105.8372	32.4268	8:00-10:00	18	3	0	105.8314	32.4223	10:00-12:00
4	3	0	105.8358	32.4281	8:00-10:00	19	0	1	105.8299	32.4212	13:00-16:00
5	0	5	105.8358	32.4281	8:00-10:00	20	4	0	105.8287	32.4237	8:00-10:00
6	1	0	105.8330	32.4260	14:00-16:00	21	0	3	105.8287	32.4237	8:00-10:00
7	3	0	105.8309	32.4262	12:00-15:00	22	5	0	105.8269	32.4200	14:00-16:00
8	3	0	105.8389	32.4315	10:00-12:00	23	0	1	105.8336	32.4305	10:00-14:00
9	3	0	105.8279	32.4290	10:00-12:00	24	5	0	105.8268	32.4235	9:00-11:00
10	4	0	105.8289	32.4266	8:00-10:00	25	3	0	105.8281	32.4216	10:00-12:00
11	0	1	105.8307	32.4281	12:00-17:00	26	6	0	105.8322	32.4226	8:00-10:00
12	5	0	105.8353	32.4315	10:00-12:00	27	0	5	105.8337	32.4324	10:00-11:00
13	0	2	105.8353	32.4315	10:00-15:00	28	3	0	105.8297	32.4274	15:00-17:00
14	0	1	105.8265	32.4265	12:00-17:00	29	4	0	105.8346	32.4238	9:00-11:00
15	5	0	105.8287	32.4326	8:00-12:00	30	0	2	105.8346	32.4238	9:00-12:00

5.1.3. *Terminating conditions.* The termination conditions of the algorithm are as follows.
(1) The number of iterations of the algorithm is 500.
(2) The optimal state of chromosomes remains unchanged for 25 generations.
(3) The average value of chromosome fitness of one generation is 85% of the total number of chromosomes of the generation.

5.1.4. *Control parameters.* According to the genetic-tabu hybrid algorithm the mathematical model of the distribution path problem and the constraint conditions, the appropriate control parameters are selected and shown in Table 2, Table 3 and Table 4.

Table 2. Introduction of control parameters

Type	Par	Value	Type	Par	Value
Population size	n	60	Number of vehicle	K	8
Number of iterations	N	500	Transportation cost in unit time	h_k	30
Crossover probability	P_c	0.6	Cost of time waiting	w_1	10
Mutation probability	P_m	0.02	Cost of time delay	w_2	30
Length of tabu table	L	5	Maximum driving time for a vehicle	T_k	8
Order number	No.	29			

TABLE 3. Delivery vehicle loading

Type of gas cylinder	Type of vehicle/loading			Type of gas cylinder	Type of vehicle/loading		
	X	Y	Z		X	Y	Z
A	30	25	20	B	20	18	15

TABLE 4. The cost of distribution vehicles

Cost	Type of vehicle/cost			Cost	Type of vehicle/cost		
	X	Y	Z		X	Y	Z
Fixed cost/RMB	230	220	200	Unit transport cost/RMB	160	150	110

5.2. **Simulation analysis.**

5.2.1. *The shortest path model.* In this section, we provide a simulation example which uses the genetic-tabu hybrid algorithm and the shortest path model to solve the problem of the distribution path optimization of gas cylinder. The path map of the shortest path model is shown in Figure 2. Based on the shortest path model, we carry out the simulation and get the simulation result as shown in Figure 3.

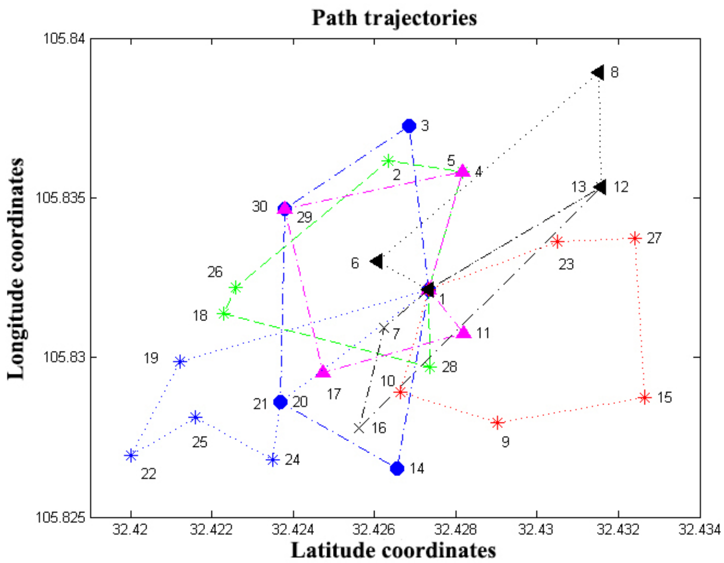

FIGURE 2. The shortest path model

In Figure 2, "1" indicates the gas filling station. The rest of the numbers represent the coordinates of the customer points. The convergence rate of the model is faster in the earlier stage in Figure 3. However, the time to get the optimal solution is longer, and the later search ability is weak. Finally, the optimal solution is obtained in the 149 generations.

5.2.2. *The minimum cost model.* Next, we give a simulation example which uses the genetic-tabu hybrid algorithm and the minimum cost model to solve the problem of the distribution path optimization of gas cylinder. The path map of the minimum cost model is shown in Figure 4. According to the minimum cost model, simulation analysis is carried out to get the simulation diagram of the optimization process, as shown in Figure 5.

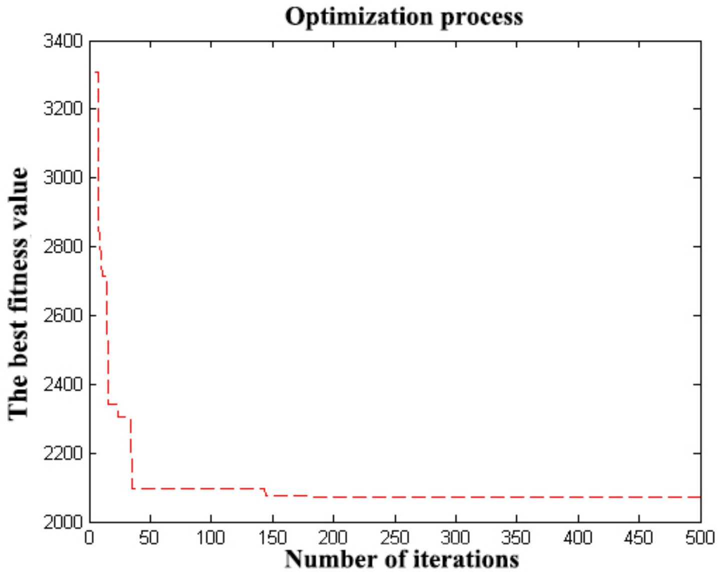

FIGURE 3. The optimization process of the shortest path model

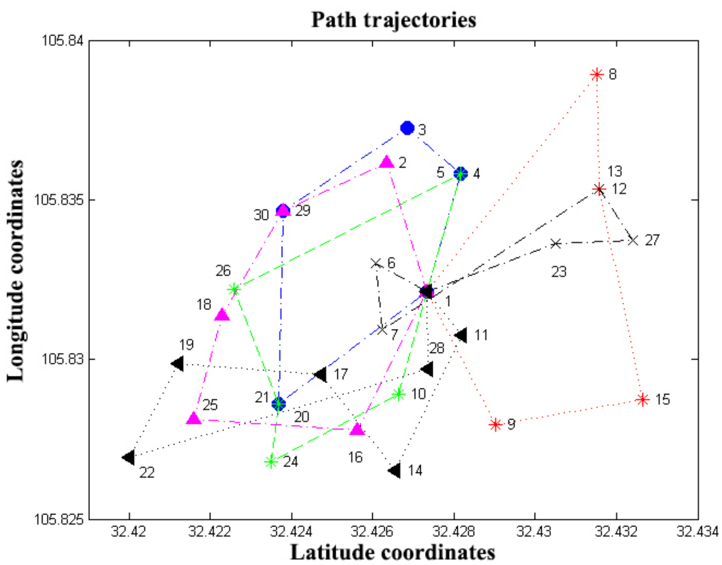

FIGURE 4. The minimum cost model

In Figure 4, the path planning is the simulation based on the minimum cost model. The model adds the limit of the distribution time window, and thus the mathematical model is more complex and with more constraint conditions. In Figure 5, it shows that the algorithm has faster convergence speed when it is applied into the minimum cost model. It indicates that the minimum cost model is more reasonable and the parameters are selected appropriately.

5.3. **Comparison of models.** The results are sorted out, and the experimental data of the two models are shown in Table 5.

It can be seen that the shortest path model has no time window and the customer punctuality is poor. The total distance of delivery is shorter, and the cost is lower. And the convergence time of the algorithm is longer and the number of iterations is large. Although the total cost of the minimum cost model with time window is larger,

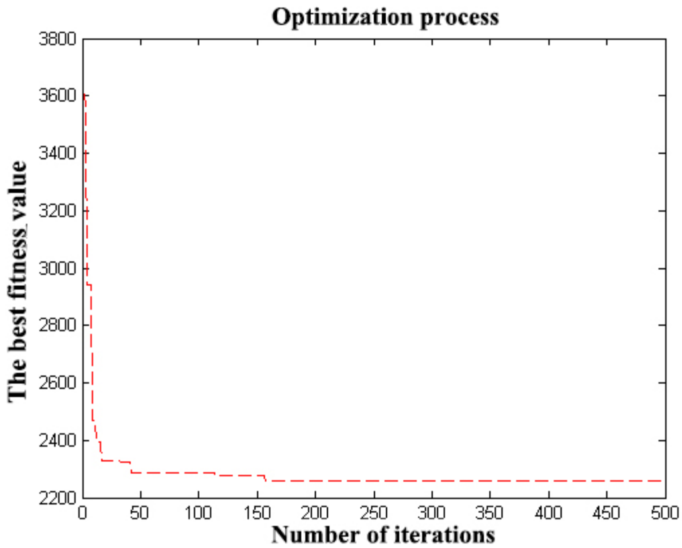

FIGURE 5. The optimization process of the minimum cost model

TABLE 5. Data comparison between two models

Type	Population size	Running time (s)	Average number of iterations	Mileage (km)	Minimum cost (RMB)	Punctuality
VRP	60	16.94	156	106.0293	2059.38	69.2%
VRPTW	60	11.21	149	120.2608	2257.70	86.7%

the punctuality is higher. And the running time of the algorithm is shorter. The most important point is that the punctuality has reached 86.7%, which is conducive to long-term development of enterprises. The data comparison shows that the performance of the minimum cost model is better than the shortest path model. The minimum cost model is selected in this paper.

6. **Conclusions.** In this paper, time cost is added to the objective function to improve the punctuality. Considering the chemical reaction between cylinders, they are divided into two types of A and B and cannot be distributed together. The different loading capacity of the distribution vehicle is also the constraint condition in this paper. Different vehicles are arranged according to the quantity of each distribution. In order to solve the problems of gas cylinder distribution with time window in the single distribution center of the gas filling station, the minimum cost model and the genetic-tabu hybrid algorithm are provided in this paper. Comparison experiments are provided to illustrate the validity of the method. Furthermore, how to optimize the parameters is also a significant task in the future work.

Acknowledgment. The research work was supported by the Xinjiang Uygur Autonomous Region Natural Science Foundation (Grant No. 2018D01A49).

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