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A Novel Hybrid Method on VRP with Pickup and Delivery

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Abstract: In order to solve the vehicle routing problem with pickup and delivery (VRPPD), this paper proposed an improved quantum genetic algorithm based on different constraint conditions. Firstly, a mathematical model was established aiming at minimizing the dispatching time and the total cost. Secondly, the paper proposes the improved quantum genetic algorithm and non dominated sorting strategy. In order to obtain more optimal solutions, the non dominated sorting strategy is introduced. Finally, the proposed method is applied to the simulation example, and the effectiveness of the proposed method is evaluated through the convergence curves of comparison with the existing algorithms.

Keywords: Double chains quantum genetic algorithm, quantum genetic particle, vehicle routing problem.

1. INTRODUCTION

In the VRP with pickup and delivery, a heterogeneous vehicle fleet based at multiple terminals must satisfy a set of transportation requests. Each request is defined by a pickup point, a corresponding delivery point. The objective function(s) generally minimizes system costs. The early work on VRPPD was conducted for dial-a-ride scenarios [1]. It was first examined by Wilson *et al.* [2], Wilson and Weissberg [3], and was motivated by the demand-responsive transportation systems. A parallel insertion heuristic similar to that of Wilson *et al.* was proposed by Roy *et al.* [4] for the multiple VRPPD in the context of the transportation of disabled persons. Since a fair amount of requests are known in advance, these are used by means of time-spatial proximity criteria to create initial routes for all vehicles starting at the beginning of the day. Madsen, Ravn, and Rygaard [5] implemented a generalized version of this approach for a partly dynamic dial-a-ride problem. Their algorithm can minimize vehicle waiting time as well as introduce breaks. Local search for the VRPPD was first considered by Psarafits [6], who extended the ideas of Lin and Kernighan. A decade later, Bent R and Hentenryck presented another local search heuristic for the VRPPD [7]. The algorithm involves two phases, both using arc exchange procedures. In the construction phase, it tries to find an initial feasible route allowing infeasibility and penalizing the violation of restrictions in the objective function. The VRPPD has a variety of practical applications, including the transport of the disabled and elderly, sealift and airlift of cargo and troops, and pickup and delivery for overnight carriers or urban services. Perspectives on this growing field were offered by Solomon and Desrosiers, *et al.* [8].

This paper proposes an improved quantum genetic algorithm based on different constraint conditions at first. Then the non dominated sorting strategy is introduced to obtain more optimal solutions. The effectiveness is verified through the application to the CMT n X and CMT n Y. Here we extend the above efforts by reviewing important recent developments and offering our view for future directions.

2. MODEL OF VRPPD

Identify request i by two nodes, i and $n+i$, corresponding, respectively, to the pickup and delivery stops of request. It

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is possible that different nodes may represent the same geographical location. Next, denote the set of pickup nodes by $P=\{1, \dots, n\}$ and the set of delivery nodes by $D=\{n+1, \dots, 2n\}$. Further, define $N=P \cup D$. If request i consists of transporting d_i units from i to $n+i$, let $l_i=d_i$ and $l_{n+i}=-d_i$.

Let K be the set of vehicles. Because not all vehicles can service all requests, each vehicle k has a specific set $N_k=P_k \cup D_k$ associated with it, where N_k, P_k , and D_k are appropriate subsets of N, P , and D , respectively. For each vehicle k , define now network $G_k=(V_k, A_k)$. Set $V_k=N_k \cup \{o(k), d(k)\}$ as the set of nodes inclusive of the origin, $o(k)$, and destination, $d(k)$, depots for vehicle k , respectively. The subset A_k of $V_k \times V_k$ comprise all feasible arcs. The capacity of vehicle k is given by C_k , and its travel time and cost between distinct nodes $i, j \in V_k$, by t_{ijk} and c_{ijk} , respectively.

The mathematical model of VRPPD may be described as follows:

$$\min Z = \sum_{k=1}^K \sum_{j=1}^N f_k x_{ijk} + \sum_{k=1}^K \sum_{i=1}^N \sum_{j=1}^N p_k d_{ij} x_{ijk} \tag{1}$$

$$y_{ijk} = \begin{cases} 1 & \forall i, j = 1, 2, \dots, N; \quad \forall k = 1, 2, \dots, K; \\ 0 & \end{cases} \tag{2}$$

$$y_{ik} = \begin{cases} 1 & \forall i = 1, 2, \dots, N; \quad \forall k = 1, 2, \dots, K; \\ 0 & \end{cases} \tag{3}$$

$$\sum_{k=1}^K \sum_{i=1}^N x_{ijk} = 1, \forall j = 1, 2, \dots, N \tag{4}$$

$$\sum_{k=1}^K \sum_{i=1}^N x_{ijk} - \sum_{k=1}^K \sum_{i=1}^N x_{jik} = 0 \tag{5}$$

$$0 \leq U_{ik} - \sum_{j=1}^N X_{ijk} (q_i - p_i) \leq Q \tag{6}$$

$$0 \leq \sum_{j=1}^M q_j \left\{ \sum_{i=1}^N X_{ijk} \right\} \leq r \cdot Q \tag{7}$$

$$\sum_{i=1}^N v_i y_{ik} \leq V_k, k = 1, 2, \dots, K \tag{8}$$

$$P \leq \frac{\sum_{i=1}^N p_i \times y_{ik}}{\sum_{i=1}^N q_i \times y_{ik}} \leq 1 \tag{9}$$

The significance of symbol in the mathematical model is as follows:

x is a path, y is a path state, f_k is the fixed cost of vehicle k , p_k is the travel cost of vehicle k in per km, M is the number of customers, K is the number of vehicles which are providing the service, d_{ij} is the distance between customer i and customer j , Q is the maximum loads of vehicles, q_i is the delivery quantity for the customer i , p_i is the pickup

quantity for the customer i , v is the ratio between goods volume and the maximum load when the vehicle is to leave the distribution center, U_{ik} is the load of vehicle k after leaves the customer i , P is ratio between pickup and delivery.

Eq. (1) is the objective function including the fixed cost and travel cost for the vehicle, $\sum_{k=1}^K \sum_{j=1}^N f_k x_{ijk}$ is the total fixed cost and $\sum_{k=1}^K \sum_{i=1}^N \sum_{j=1}^N p_k d_{ij} x_{ijk}$ is the total travel cost.

Eq. (2) is the leaving of vehicle k from i to j . Eq. (3) indicates that vehicle k is serving the customer i . Eq. (4) indicates that the customer i can be served only by vehicle k . Eq. (5) indicates that any customer can be served only once at most. Eq. (6) indicates that the total load of vehicle k can not exceed its capacity of Q . Eq. (7) indicates that the initial loading rate of vehicle k should be less than 1 to reserve some space for pickup. Eq. (8) indicates that the total volume of the goods in vehicle k can not exceed the upper limit. Eq. (9) indicates that the pickup service should be executed in the completion of a certain amount of delivery service, so as to minimize the cost of cargo handing.

3. IMPROVED QUANTUM GENETIC ALGORITHM

Quantum genetic algorithm (QGA) realized the diversity and parallelism of the population through replacing the chromosome coding with quantum bits probability amplitude and searching with the quantum gates. This paper proposed improved double chains quantum genetic algorithm (IDCQGA) because of there being shortcomings of complex encoding and decoding with QGA.

3.1. Double Chains Quantum Genetic Algorithm

This paper introduces a new compensation factor γ ($\gamma \geq 1$) on the basis of probability amplitude coding, if π is a quantum chromosome, then the coding scheme of the i^{th} chromosome is as follows:

$$p_i = \left[\begin{array}{c} |\alpha_{i1}| |\alpha_{i2}| \dots |\alpha_{im}| \\ |\beta_{i1}| |\beta_{i2}| \dots |\beta_{im}| \end{array} \right] = \left[\begin{array}{c} |\cos(\gamma t_{i1})| |\cos(\gamma t_{i2})| \dots |\cos(\gamma t_{im})| \\ |\sin(\gamma t_{i1})| |\sin(\gamma t_{i2})| \dots |\sin(\gamma t_{im})| \end{array} \right] \tag{10}$$

In which the normalization condition should be met for α and β , that is to say, $|\alpha|^2 + |\beta|^2 = 1$ and $t_{ij} = 2\pi \times rad$, rad is the random number in $(0,1)$; $i=1,2,\dots,n$; $j=1,2,\dots,m$; n is the size of the population, m is the number of the qubit. γ makes the cycle from 2π into multi-cycle to improve the convergence efficiency of the algorithm. Each chromosome consists of two parallel gene chains, and one is the vehicle selecting chain, the other is goods sequencing chain.

The gene chain represents that the sequence number of the elected vehicle with the goods of $\{G1\ G2\ G3\ G4\ G5\ G6\ G7\}$ is 3-1-2-3-4-3-1, that is to say, the G1 can select any vehicle from the set of V1, V2, V3 and V4, and it can be known that 3 represents the 3rd vehicle with the name of V3 is selected. G6 can select any vehicle from the set of V1, V3 and V4, and the 3 represents the 3rd vehicle with the name of V4.

The gene chain represents the sequence of the goods, that is to say, if the numbers of goods are 2-1-4-3-7-5-6, then the corresponding sequence is G2 G1 G4 G3 G7 G5 G6.

3.2. Non Dominated Sorting

A sorting method of non dominated is proposed and the method realizes the classification depending on the parameters N_p and n_p of individual p in population S , the specific steps are as follows:

Step 1: Initialize the parameter set N_p which includes all the individuals dominated by p and make $N_p = \emptyset$;

Step 2: Initialize the variable n_p and n_p means the number of individuals which can dominate p ;

Step 3: Calculate dominance relationship, $p, q \in S$, if p can dominate q , then $N_p = N_p \cup \{q\}$, else if q can dominate p , then $n_p = n_p + 1$; if $n_p = 0$, then p is a non-dominated individual, denoted as $p_r = 1$, and p joins R_i , that is to say $R_i = R_i \cup \{p\}$;

Step 4: Q means the set of residual individuals, making $i=1$, when $R_i \neq \emptyset, Q = \emptyset$. If $q \in N_p$, then $n_q = n_q - 1$; else if $n_q = 0$, then $q_r = i + 1$; $Q = Q \cup \{q\}$, $i = i + 1, R_i = Q$;

Step 5: Judge whether R_i is empty or not, if it is empty, the calculation will stop, otherwise, it will turn to Step 4.

3.3. Description of Improved Algorithm

Step 1: Generate $popu/10$ initial solutions on the basis of chaotic theory ($popu$ is the size of swarm);

Step 2: Map the initial solution as the quantum individual and initialize the remaining individual to generate the probability amplitude of all quantum and obtain all quantum individual;

Step 3: Non-dominated sort and calculate crowded distance towards the quantum individual;

Step 4: Select two individuals randomly and compare their level of non inferior solution, if the level is different, the individual with lower level should be selected, and otherwise, the individual with smaller crowded density will be selected;

Step 5: Generate the new particle swarm $P1$ to ensure that all the state should occur with the same probability in the early;

Step 6: Calculate the fitness of each quantum individual and compare the result with the existing elite quantum individuals, then select and save the K quantum individuals whose fitness is the highest;

Step 7: Calculate the rotation angle of the individual qubits and generate the newly initial particle swarm $P(t+1)$;

Step 8: If it meets the convergence condition or has reached the maximum number of iterations, turn to Step 9, otherwise, make the iteration add one (+1) then turn to Step 2;

Step 9: Output the current optimal solution and the corresponding fitness value.

4. ANALYSIS AND VERIFICATION

In order to evaluate the effectiveness of proposed method, this paper adds some convergence curves. Fig. (1) shows the different convergence speed of obtaining the optimal solutions. The proposed method is compared with some existing algorithms, such as IA (Insert Algorithm) [9], TVN (Tabu and variable neighborhood algorithm) [10], and TS (Hybrid tabu search) [11]. The results are shown in Fig. (1), in which it can be known that the optimal solution of 45 can be obtained with IDCQGA within 100 iterations. However, the optimal solution of 68 can be obtained with TVN and TS. The method of IA is relatively poor with the solution of 120. From another perspective, the optimal solution can be obtained with IDCQGA in the 22nd iteration, and it can be obtained with TS in about 34th iteration, the convergence effectiveness of other algorithms are significantly worse.

The comparison of convergence curves are as follows:

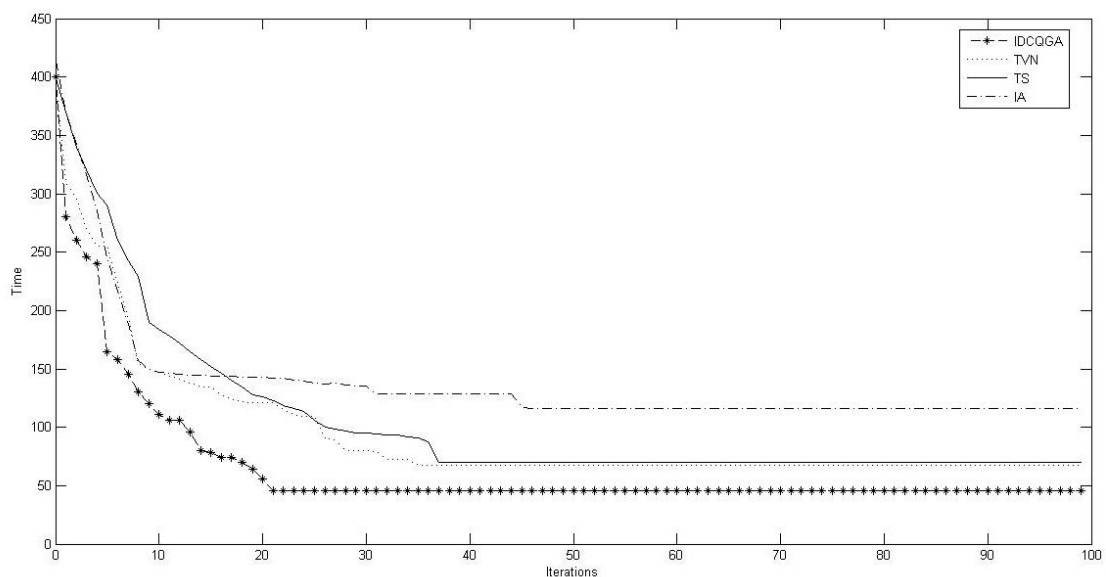


Fig. (1). Comparison of convergence curves.

CONCLUSION

A multi-objective VRPPD mathematical model is established as per different constraints at first. Next, the double chains quantum genetic algorithm is proposed to generate vehicle chain and goods chain in the early stage of the algorithm. Lastly, In order to obtain more optimal solutions the non dominated sorting strategy is introduced. The comparison results of convergence curves demonstrate that the proposed method can improve the efficiency of iterative search and obtain more non-dominated solutions than the existing algorithms. The above discussion verified the effectiveness of the proposed method.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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