Study on Post Transportation Vehicle Routing Problem Based on Taboo-Genetic Hybrid algorithm

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Abstract: To enhance the operational efficiency of post transportation network, a hybrid post transportation model with center location and vehicle routing problem is proposed. Some important factors, such as pick-up and delivery of packages and multi-type vehicles, are also considered in the presented model. The solution of the model is divided into two stages. In the first stage, the third-level post centers and their regions are determined. Moreover, the deliver tasks between the second-level and the third-level post centers are distributed. In the second stage, the vehicle scheduling problem of each post center is solved. The center distribution method and taboo-genetic hybrid algorithm are employed in second stages, respectively. Finally, the empirical analysis is performed with actual data of Guizhou Post. The results show that the proposed model and algorithm are valid and practical.

Key words: Location, vehicle routing problem, post, genetic, taboo search

INTRODUCTION

The network design of Guizhou Post generally includes two interrelated problems: Hub Location Problem (HLP) and Vehicle Routing Problem (VRP).

The first papers in HLP, presenting the first mathematical model and solution method, were due to efforts of O’Kelly (1986). Since then, many papers have been published over recent years with a significant increasing trend. For example, Alumur and Kara (2008) put their emphasis on network hub location models from a general aspect; some new trends need to be taken into account such as the implementation of reliability, sustainability, global logistics and multi-criteria decision making in HLP.

VRP were developed by Dantzig and Ramser (1959). A comprehensive review on VRP (variants, solutions and formulations) was found by Toth and Vigo (2002). The vehicle routing problem with simultaneous pick-up and delivery (VRPSPD) was introduced by Min (1989). The heterogeneous vehicle routing problem (HVRP) was introduced by Taillard (1999) and later studied extensively by many other researchers such as Subramanian et al. (2012) and Liu (2013).

Location Routing Problem (LRP) are characterized by the search for the optimal number and locations of centers, simultaneously with the vehicle schedules and distribution routes. Jacobsen and Madsen (1980) and Madsen (1983) described a practical LRP model for a newspaper delivery system. More recently, a number of studies for different combined LRP with capacitated depots and routes are discussed in the literature (Prins et al., 2006; Akca et al., 2009; Ting and Chen, 2013).

Therefore, we address an extended and more practical version of LRP, using the real-world data of Guizhou Post for the developed solution method for our problem of transportation network design:

- Number and location of post centers together with the service area allocation
- Consider the network design associated with simultaneous pick-up and delivery
- Consider a heterogeneous type of vehicles having various capacities and variable costs

PROBLEM DESCRIPTION

Model assumptions: In this study, we consider the optimal design of transportation network of Guizhou Post. Since, there is no first-level post center exists in Gouzhou, the logistic network is a three-level of post transportation system which includes one second-level center, p third-level centers and n country-level post.

Following are the assumptions:

- The anticipated quantity of import and export in every post center is known. The road distances between each two post centers are known

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Inventory cost is ignored

The numbers and types of vehicles are determined; each vehicle owned to one post center. Moreover, the vehicle started from a post center must return to the same center when finishing its task

The total vehicle load at any point of the route does not exceed the vehicle capacity

If the candidates of third-level post center are not checked, they are the county-level post

Since, all of post centers have already existed, their construction cost is ignored

**Model parameters:** The parameters and notations are as below:

- 0 = \{1\}: Second-level post center
- A = \{2, 3, \ldots, t\}: Candidates of third-level post
- B = \{1, 2, \ldots, p\}: Checked third-level post centers
- C = \{p+1, p+2, \ldots, p+n\}: County-level posts
- V = \{V_{1}^{m}, m = 1, 2, \ldots, M; k = 1, 2, \ldots, K\}: The set of vehicles owned by third-level center. m is the index of vehicle type, k is the number of the vehicle; l(\text{Bel}) is the index of third-level centers
- Q_{mk}: The capacity of the vehicle k (type m)
- n_{i}: Import of third-level post center i, \text{Bel}
- p_{i}: Export of third-level post center i, \text{Bel}
- q_{i}: Export of county-level post center i, \text{C}
- q_{i}^{m}, k: The actual capacity of vehicle k (type m) after passing post center i
- d_{ij}: The road distance between post center i and j
- B_{mk}: The fixed cost of vehicle k (type m)
- c_{ij}: The transportation unit cost of vehicle k (type m) when passing from post center i to j
- e: The punishment coefficient of empty loading
- ER = ((Q_{\text{Bel}}-q_{i}^{m,k})*L)/Q_{\text{Bel}} L is the travel distance of the vehicle
- Expense loss of empty-loading: BC = ER*e

**Decision variables:**

- x_{ij} = 1, if vehicle k (type m) passes from post center i to j
- x_{ij}^{m,k} = 1, if the vehicle k (type m) serves post i, \text{Bel}; m, keV, i \in \text{Bel} \cup \text{C}
- w_{i} = 1, if the candidate post i is checked, i \in A
- z_{i} = 1, if the country-level post j is allocated to the third-level post center i, i \in \text{Bel}, j \in \text{C}

**Model formulation:** The mathematical model is given as follows:

\[
\min \sum_{l, m, k} \sum_{i, j} (c_{ij} + ER* e) x_{ij}^{m,k} d_{ij} + \sum_{i} \sum_{m, k} \sum_{l} c_{ij} x_{ij}^{m,k} d_{ij} + \sum_{l} \sum_{m, k} B_{mk} \times \max(x_{ij}^{m,k})
\]

Subject to the following constraints:

\[
\sum_{m,k} \sum_{i \in A} x_{ij}^{m,k} - \sum_{i \in B} x_{ij}^{m,k} = 0, \forall i \in \text{B}
\]

\[
\sum_{m,k} \sum_{i \in B} x_{ij}^{m,k} - \sum_{i \in C} x_{ij}^{m,k} = 0, \forall i \in \text{B}
\]

\[
\sum_{m,k} \sum_{i \in C} x_{ij}^{m,k} = 0, \forall i \in \text{B}
\]

\[
\sum_{i} \sum_{k} x_{ij}^{m,k} = \sum_{i} \sum_{k} x_{ij}^{m,k} \leq 1, \forall i \in \text{B}
\]

\[
\sum_{i} \sum_{k} x_{ij}^{m,k} = \sum_{i} \sum_{k} x_{ij}^{m,k} \leq 1, \forall i \in \text{B}
\]

\[
\sum_{i} \sum_{k} x_{ij}^{m,k} \leq |S|-1, \forall i, j \in \text{B} \text{ or } i, j \in \text{C}
\]

\[
\sum_{i} \sum_{k} x_{ij}^{m,k} \leq |S|-1, \forall i \in \text{B}
\]

\[
q_{i}^{m,k} = q_{i}^{m,k}-p_{i}+q_{i}, \forall i \in \text{B} \cup \text{C}, m, keV
\]

\[
Q_{\text{Bel}} > q_{i}^{m,k}, \forall i \in \text{C}, m, keV
\]

\[
\sum_{j} z_{i} = 1, \forall i \in \text{C}
\]

\[
\sum_{i} z_{i} \leq w_{i}, \forall i \in \text{B}, j \in \text{C}
\]

The objective function 1 comprises the transportation cost of distribution between the second-level and third-level post centers, the transportation cost of distribution between the third-level post centers and the county-level post and the fixed cost of vehicle. Constraint (2) ensures a vehicle can only serve a post once a period. Constraint (3) and (4) ensures that if a vehicle serves a post, it just happened once. Constraint (5) and (6) ensures each vehicle should set out from a post center and then back to it. Constraint (7) ensures that the solution which isn't integrated is ruled out. Constraint (8) and (9) are the balance equation for import and export for post parcel between third-level and county-level post. Constraint (10) shows that the capacity changes of vehicle k (type m) after passed post i, i-1 is the former node of i. Constraint (11) guarantees the vehicle capacity is respected. Constraint (12) assures that each country-level post is assigned to one third-level post center. Constraint (13) means if a candidate third-level post is unchosen, there is no country-level post belongs to it.
SOLUTION METHODOLOGY

The solution of the model is divided into two stages: First is to determine the third-level post centers and their regions, then to execute the deliver tasks between second-level and third-level post centers; second is to solve the vehicle routing problem of each center. The center distribution method and taboo-genetic hybrid algorithm are employed in the two stages, respectively.

Stage 1: Center distribution: Here we use binary code to represent the location decision variable. \( \omega_i = 1 \), \( i \in A \) means the candidate third-level post center \( i \) is checked, or else it is opposite. It can be illustrated as follows:

Step 1: Set \( \omega_i = 0 \), \( i \in A \): it means all the candidate third-level post centers are unchecked, therefore only the second-level post center \( O \) should execute the deliver tasks, all the country-level post in \( C \) belong to \( O \). Then execute the stage 2, gain total cost \( TC \) of the model.

Step 2: Count the number \( n \) of the third-level post centers; select post \( i \) of \( A \) randomly, set \( \omega_i = 1 \), then \( i \) is selected and belongs to \( B \), set \( n = n+1 \). Initialize swap variables: \( SN \) is swap time, \( SN_{max} \) is maximum swap time, set \( SN = 1 \).

Step 3: Insert post \( O \) into the top of \( B \). Then to determine the regions of third-level post center: set a critical value \( \rho \) at first, compute \( r(i) \) of post \( i \) in \( C \)

\[
r(i) \text{ is distance between post } i \text{ and the nearest center } t_i \text{ in } B,\text{ } \quad d_{ij} = \frac{d_{ij}}{d_{ij}}
\]

Step 4: Execute stage 2, gain the vehicle routing cost of each third-level post center and total cost \( TC \).

Step 5: If \( TC < TC \), set \( TC = TC \), update the optimal solution, then turn to step 6, otherwise, turn to step 6 straightaway.

Step 6: If \( n = Tn \) (\( Tn \) is total number of candidate third-level post centers), then turn to step 8; otherwise, turn to step 7.

Step 7: If \( SN < SN_{max} \), select two post of \( A \) which \( \omega_i = 1 \) and \( \omega_j = 0 \) randomly; exchange their value: set \( \omega_i = 1, \omega_j = 1 \), so post \( j \) belongs to \( B \), post \( i \) belongs to \( C \), set \( SN = SN + 1 \) and then turn to step 3. Otherwise, turn to step 2.

Step 8: Output the final solution.

Stage 2: Taboo-Genetic hybrid algorithm: The solution of vehicle scheduling problem for each post center is the core of the methodology. Here we design a taboo-genetic hybrid algorithm; the main strategies are described as follows:

- **Coding rule**: We use the binary coding and each chromosome contains two parts. Assume that post center \( i \in B \) has one vehicle of type 1, two vehicles of type 2 and one vehicle of type 3, as shown in Fig. 1. The first part of the chromosome is the vehicle's type and the number of country-level post of each vehicle served for; the second part of the chromosome is the service order for the country-level post to be served.

- **Fitness function**: Here, the fitness function is formed by adding a penalty value to the original objective function:

\[
F = \sum_{a} \sum_{b} \sum_{p} \sum_{q} \sum_{m} p_{av} \times g(Q_{a}, q_{ms})
\]

\( p_{av} \) is penalty value, \( g(Q_{a}, q_{ms}) = q_{ms}^{-1} \), if \( \sum_{a} q_{ms} > Q_{ave} \), otherwise, 0.

- **Selection operator**: Firstly, copy the best chromosome to next generation; then use the
selection strategy based on roulette to determine the survival probability of each chromosome according to the fitness value.

- **Taboo-crossover operator:** The taboo-crossover operator uses a length T taboo list to record the fitness value of each chromosome. Take the mean fitness value of parent population as Expected Value (EV). Assume that α is a child chromosome produced by the crossover of two parent chromosomes, if the fitness of α is less than EV, choose α into the next generation; otherwise, choose the better child of the two parent chromosomes.

- **Taboo-mutation operator:** First to determine the initial solution R of the taboo-mutation operator based on the mutation probability p_m, then execute the taboo search with R. Determine the orientation of the neighborhood search with the fitness function, finally to determine the mutation result based in accordance with the fitness value of neighborhood solution and the taboo list.

### EMPIRICAL ANALYSIS

The model of Guizhou Post can concretely describe as follows: Take Guiyang as the second-level post center, take the eight city-level post as candidate third-level post centers, to finish the transportation tasks of the seventy-four country-level post.

#### Data sets

According to Guizhou Post, Table 1 provides the vehicle message of Guiyang and other city-level post centers; Table 2 provides the import and export demand of every post in March 2013.

#### Parameters of the algorithm

Parameters of the solution are set based on the scale of our model, as shown in Table 3.

#### Computational results

The result shows that the total cost in the best solution is 65214 Yuan; the city-level post.

<table>
<thead>
<tr>
<th>Table 1: Vehicle message</th>
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<tbody>
<tr>
<td>Type</td>
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<tr>
<td>------</td>
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<tr>
<td>I</td>
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<td>II</td>
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<td>III</td>
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<th>Table 2: Import and export demand of every post</th>
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<td>No.</td>
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<td>1</td>
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<td>2</td>
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<th>Table 3: Parameters of the algorithm</th>
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<tr>
<td>ρ</td>
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<tr>
<td>0.7</td>
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Table 4: Distribution program of per post center

<table>
<thead>
<tr>
<th>Center No.</th>
<th>Charged country-level post and the distribution program</th>
<th>Distribution cost (yuan)</th>
<th>Distribution cost of STT (yuan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>II-15-17-20-10-II, II-6-21-19, II-11-12-19-II</td>
<td>4016</td>
<td>-</td>
</tr>
</tbody>
</table>

3, 7, 8 and 9 is selected as the third-level post centers; the number of vehicles is 32. Table 4 shows the regionalism, distribution program and distribution cost of per selected center in the best solution; it also shows the cost of the distribution task from the second-level to third-level post center (STT).

**CONCLUSION**

This study considered a hybrid transportation vehicle scheduling problem of post which include center location, vehicle routing problem, pick-up and delivery of packages, multi-center and multi-type and constructed the corresponding mathematical model simultaneously. Then it design a two-stage algorithm to solve the problem under the constraints, such as adjust the regionalism, minimize the traveling distance, minimize the number of vehicle, pick-up and delivery of post packages, the capacity of vehicle, etc. then it makes an optimization of the transportation network of Guizhou post with the model and algorithm; Finally, based on the principle of minimum cost, obtains an optimal distribution program of post vehicle schedule with the product data of Guizhou Post.

The results show that, the optimized effect of post cost is obvious. It provides an idea for the optimization of Guizhou post transportation network, also for other post in our country.

**REFERENCES**


