Optimization Model of Vehicle Scheduling for Postal Region Transportation

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Abstract — Postal regional transportation vehicle scheduling problem (VSP) plays an important role in the transportation network. In order to save the cost of ordinary mail transport network, a model is built according to the actual situation of a branch of China Postal services. A hybrid algorithm based on gene and taboo search is presented to optimize the model. The actual data of Zunyi Postal Company in China is fed into the model and simulation tests were performed. The results show that our schedule scheme is better than the existing one of Zunyi Postal service, which confirms that the proposed model is valid and practical.

Keywords - Transportation Network; Optimization; VSP; Genetic Algorithm

I. INTRODUCTION

In recent years, logistics in China have been increasingly developed. The transportation network has spread from urban to rural areas and played an important role in delivery service. How to integrate vehicle resources and optimize the vehicle scheduling in a city region is attracting more and more interests of researchers and engineers. Some researches on VSP have been done and some schemes have been presented. Dantzig G. presented that vehicles start from one center and come back to it [1]. Chen and Alvarenga set up a model to solve the problem on the total delivery distance of vehicle on VSP [2, 3]. The model of multi-center VSP is presented, which consider the effect of delivery cost and vehicle capacity [4]. The VSP based on product recycle is proposed by AliDiabat [5]. To solve this model, a genetic algorithm combined with artificial immune method is presented [6]. For the problem of multi-depot and multi-type vehicle scheduling, some models are established to simulate its operation in recent years [7-12]. However, few models are established and tested according to actual condition of delivery companies and their operation data. In this paper, a model for VSP based on China Postal is proposed, which includes single-center, multi-type vehicle and many demand points. The purpose of this model is lowering the operation cost in a postal area.

The rest of this paper is organized as follows. The VSP model for a postal area is described in Section 2. In section 3, a taboo-genetic hybrid algorithm is presented to solve this model. Experiments are performed in Section 4. Finally, Conclusions are drawn in Section 5.

II. MODEL DESCRIPTION

A. Model assumption

The model for a postal area can be described as a system with one center and N demand points. Here, the demand point is corresponding to a county-level postal point. All the vehicles started from post center and provide service to demand points. When the vehicle is full loaded, it will come back to the center. According to the actual condition of a postal area, we give the following assumptions.

(1) The types, numbers and capacities of vehicles are determined. Each vehicle started from the postal center and return to it. Each vehicle has its own route.

(2) The total packages in one route do not exceed the sum of vehicle capacity in the same route.

(3) The demands of import and export are determined and the distances between any pair of points are known.

(4) The center and the demand points own their inventory with enough space to contain parcels. The pickup and delivery service for each demand point is provided.

(5) The difference of road conditions is not considered.

B. Notations

To the convenience of description, the following variables are given:

- \( O \) : The postal center, \( O = \{1\} \).
- \( N \) : The set of country-level postal points, \( N = \{1,2,\ldots,n\} \).
- \( V = \{V^{mk} | m = 1,2,\ldots,M; k = 1,2,\ldots,K\} \) : The set of vehicles, \( m \) is the index of vehicle type; \( k \) is the id of the vehicle.
- \( Q_{mk} \) : The maximum load capacity of vehicle \( k \) of type \( m \).
- \( P_i \) : The import demand of the country-level postal point \( i \in N \).
- \( q_i \) : The export demand of the country-level postal point \( i \in N \).
The actual capacity of vehicle $k$ of type $m$ after passing postal point $i$. $j$ is the node after $i$.

d$_{ij}$: The distance between postal points $i$ and $j$.

$\alpha_{mk}$: The fixed cost of vehicle $k$ of type $m$.

$\beta_{ij}^m$: Transportation cost rate of vehicle $k$ of type $m$.

$L$: The running distance of vehicle.

e: Penalty coefficient when vehicle is in empty running.

$ER$: Empty running rate. $ER = ((Q_{mk} - q_{mk}^i) * L)/Q_{mk}$.

$EC$: The loss of empty running: $EC = ER * e$.

The decision variables are defined as below:

\[ x_{ij}^m = \begin{cases} 1, \text{if vehicle } k \text{ of type } m \text{ goes from } i \text{ to } j \\ 0, \text{otherwise} \end{cases} \]

\[ y_{ji}^m = \begin{cases} 1, \text{if vehicle } k \text{ of type } m \text{ serves the post } i \\ 0, \text{otherwise} \end{cases} \]

C. Model formulation

The optimization object is minimizing the total cost of the whole transportation network. The model is defined as follows:

\[
\min f(i, j, m, k) = \sum_{m, k \in \mathcal{M}} \sum_{i \in \mathcal{N}} \alpha_{mk} \cdot \max(x_{ij}^m) + \sum_{m, k \in \mathcal{M}} \sum_{i, j \in \mathcal{N}} (\beta_{ij}^m + ER \cdot e) \cdot x_{ij}^m \cdot d_{ij}
\]  

s.t.

\[
\sum_{m, k \in \mathcal{M}} \sum_{i \in \mathcal{N}} x_{ij}^m = 1; \forall j \in \mathcal{O} \cup \mathcal{N} 
\]  

\[
\sum_{m, k \in \mathcal{M}} \sum_{i \in \mathcal{N}} y_{ij}^m = y_{ji}^m; \forall j \in \mathcal{N} 
\]  

\[
\sum_{m, k \in \mathcal{M}} \sum_{i \in \mathcal{N}} x_{ij}^m = \sum_{m, k \in \mathcal{M}} \sum_{i \in \mathcal{N}} x_{ji}^m \leq 1; \forall l \in \mathcal{O} 
\]  

\[
\sum_{m, k \in \mathcal{M}} x_{ij}^m \leq |S| - 1; \forall i, j \in \mathcal{N} 
\]  

\[
\sum_{m, k \in \mathcal{M}} \max(y_{ij}^m) \leq V^m 
\]  

\[
q_{oi}^m = \sum_{i \in \mathcal{N}} y_{oi}^m \cdot p_i; m, k \in \mathcal{V} 
\]  

\[
q_{i0}^m = \sum_{i \in \mathcal{N}} x_{i0}^m \cdot q_i; m, k \in \mathcal{V} 
\]  

\[
q_{ij}^m = q_{(j-i)k} - p_i; \forall i \in \mathcal{O} \cup \mathcal{N}; m, k \in \mathcal{V} 
\]  

\[
Q_{mk} \geq q_{ij}^m; \forall i \in \mathcal{O} \cup \mathcal{N}; m, k \in \mathcal{V} 
\]  

Eq.(1) is the objective function, which consists of the transportation cost of vehicles, the punishment cost of empty loading and the fixed cost of vehicle. Constraints (2) and (3) ensures one postal point must be served only once by one vehicle; Constraint (4) means that each vehicle starts from the center and finally returns to it; Eq. (5) is a sub-tour breaking constrain; Constraint (6) ensures the number of all possible routes must be smaller or equal to the total number of vehicles; Constraint (7) and (8) are the relationship between the center and all the postal points, i.e. the import and export of parcels between center and points must keep balance; Constraint (9) shows the capacity changes of vehicle when passing node $i$ ($j$ is the node before $i$); Constraint (10) ensures the capacity can’t exceed the total capacity of all vehicles.

III. ALGORITHM DESIGN

Due to the complexity of model, it is difficult to get its analytical solution. Thus, a genetic algorithm with taboo search is presented. To obtain the feasible solution of the model efficiently, taboo search is designed in the crossover and mutation operator according to model traits. The details of algorithm are described as below.

A. Coding Rule

According to the model traits, the natural number coding is used here, which consists of two parts. The first part describes the vehicle type and the number of postal points served by this vehicle. The second part describes the route of each vehicle. An example is shown in Fig.(1). Here, there are four vehicles and three vehicle types in this example. The first two vehicles are in type I and type II, respectively. The two remain vehicles are in type III. The corresponding numbers of points served by vehicles are 3, 2, 4, and 3, respectively.
B. Fitness Function

A fitness function is used to evaluate how close a given design solution is to achieving the set aims. Here, the fitness function is designed in Eqs. (11) and (12).

\[ F = f + P \]  
\[ P = \sum_{m,k \in \mathbb{N}} \sum_{i} w \cdot h(Q_{mk}, q_{i}^{mk}) \]  

Where \( f \) means vehicle transportation cost and \( P \) is penalty value, \( w \) is the punishment coefficient and

\[ h(Q_{mk}, q_{i}^{mk}) = \begin{cases}                         
q_{i}^{mk}, & \text{if } q_{i}^{mk} > Q_{mk} \\
0, & \text{otherwise} 
\end{cases} \]

1) Selection Operator

Elitist strategy is employed here. The first 10% best individuals are directly copied to the next generation. Then, we continue selecting individuals according to the probability of fitness value calculated by roulette wheel selection method.

2) Taboo-Crossover Operator

A taboo table with size \( L \) is used to record the fitness value of each individual in this operator. The average fitness value of the last generation is regarded as the expected value. In the process of crossover, the fitness value of new generated individual is compared with the expected value. If it is smaller than the expected value, the taboo is broken and the new generated individual is employed in the next generation. Otherwise, the generated individual is accepted as new one in the next generation when taboo is not broken; or the best individual in current generation is selected as the individual in the next generation when the new generated individual is taboosed. As mentioned in section 3.1, the genetic code of individual has two parts. Single-point crossover and cycle crossover are performed on the first part and the second part, respectively. In the single-point crossover, a cross-point is randomly selected and the codes of two parent individuals are exchanged at this cross-point. In the cycle crossover, the cross-point \( k \) and crossing width \( l \) are determined firstly. Then, the codes of two parent individuals are exchanged by a cycle way according to \( k \) and \( l \). An example as shown in Fig.2 is given for the convenience of understanding.

![Figure 2. The example of taboo-crossover operator.](image)

3) The taboo-mutation operator

In the taboo-mutation operator, the solution \( x \) is initialized by mutation probability. Then, the orientation of neighborhood search is determined by fitness function and a new solution \( x' \) is generated under the control a taboo table. The best solution in the taboo table is chosen an individual in the next generation, when the maximum iteration is finished. Here, two position in the code are randomly selected and exchange them. An example of mutation operation is illustrated in Fig.(3).

![Figure 3. The example of taboo-mutation operator.](image)

4) Adjustment of Infeasible Solution

In the presented model, the total number of postal points is fixed. For any individual, the sum of postal points in its gene code must be equal with the total number. However, these two numbers are probably not the same after crossover and mutation, which means that the individual is not a feasible solution. Thus, the adjustment is needed and the corresponding formula is defined as follows:

5) Adjustment of Infeasible Solution

In the presented model, the total number of postal points is fixed. For any individual, the sum of postal points in its gene code must be equal with the total number. However, these two numbers are probably not the same after crossover and mutation, which means that the individual is not a
feasible solution. Thus, the adjustment is needed and the corresponding formula is defined as follows:

\[ r = \text{Round}(N \times P_i / \text{Sum}(P_i)) \] (13)

Where \( r \) is the adjustment actor, \( N \) is the total number of postal points in the model and \( P_i \) is the first part of code. Function \( \text{Round}(x) \) returns an integer not greater than \( x \) and function \( \text{sum}(x) \) return the sum of \( x \).

6) **END RULE**

The end rule of the algorithm is that no further promotion is done in the two neighbor generations. The sum of fitness values for the top ten individuals is calculated and saved. Then, the next 1 generation is produced. If the ratio \( SV \) of sum of fitness values for the top ten individuals in these two generations is very small, which means that the solution is stable, the calculation is ended.

IV. EXPERIMENT RESULTS AND ANALYSIS

A. DATA and PARAMETER SET

To verify our model and algorithm, the actual data of Zunyi Postal in March, 2014 is collected. The data on vehicles in Zunyi Postal is shown in Table 1. The distance between each pair of postal points is given in Table 2 and the import and export parcels of each postal point are listed in Table 3.

B. EXPERIMENTAL RESULTS

The control parameters of the algorithm are set in Table 4 and the results is obtained by our algorithm. The total cost in solution is 6807 Yuan and 5 routs are shown in Table 5.

C. COMPARISON ANALYSIS

The model is solved by traditional genetic algorithm and shown in Table 6. Another result based on current scheme of Zunyi Postal is obtained and also shown in Table 6. Furthermore, our result is also listed in Table 7 for the convenience of comparison. The comparison results indicate that our scheme is better.

<table>
<thead>
<tr>
<th>Population size</th>
<th>Generations</th>
<th>Pc</th>
<th>Pm</th>
<th>T</th>
<th>N</th>
<th>L</th>
<th>SV</th>
<th>l</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>500</td>
<td>0.8</td>
<td>0.1</td>
<td>50</td>
<td>40</td>
<td>4</td>
<td>0.01</td>
<td>7</td>
<td>15</td>
</tr>
</tbody>
</table>

TABLE I. VEHICLE INFORMATION

<table>
<thead>
<tr>
<th>Type</th>
<th>Number</th>
<th>Capacity(ton)</th>
<th>Fixed cost(Yuan)</th>
<th>Transportation Cost (Yuan/km)</th>
<th>Punishment coefficient (Yuan/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>2</td>
<td>5</td>
<td>165</td>
<td>2.4</td>
<td>1.2</td>
</tr>
<tr>
<td>II</td>
<td>5</td>
<td>8</td>
<td>185</td>
<td>2.7</td>
<td>1.35</td>
</tr>
<tr>
<td>III</td>
<td>5</td>
<td>10</td>
<td>215</td>
<td>3</td>
<td>1.5</td>
</tr>
</tbody>
</table>

TABLE II. DISTANCE BETWEEN EACH PAIR OF POSTAL POINTS

<table>
<thead>
<tr>
<th>Distance (km)</th>
<th>Zunyi</th>
<th>Zunyi</th>
<th>Tongzi</th>
<th>Suiyang</th>
<th>Zhengang</th>
<th>Meitan</th>
<th>Fenggang</th>
<th>Wuchuan</th>
<th>Yuqing</th>
<th>Renhuai</th>
<th>Xishui</th>
<th>Chishui</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zunyi</td>
<td>0</td>
<td>371</td>
<td>442</td>
<td>434</td>
<td>536</td>
<td>754</td>
<td>461</td>
<td>499</td>
<td>587</td>
<td>496</td>
<td>444</td>
<td>532</td>
</tr>
<tr>
<td>Zunyi</td>
<td>371</td>
<td>0</td>
<td>75</td>
<td>67</td>
<td>169</td>
<td>216</td>
<td>94</td>
<td>163</td>
<td>220</td>
<td>186</td>
<td>77</td>
<td>165</td>
</tr>
<tr>
<td>Tongzi</td>
<td>442</td>
<td>75</td>
<td>0</td>
<td>73</td>
<td>174</td>
<td>319</td>
<td>125</td>
<td>168</td>
<td>225</td>
<td>258</td>
<td>133</td>
<td>144</td>
</tr>
<tr>
<td>Suiyang</td>
<td>434</td>
<td>67</td>
<td>73</td>
<td>0</td>
<td>103</td>
<td>150</td>
<td>82</td>
<td>96</td>
<td>154</td>
<td>179</td>
<td>126</td>
<td>209</td>
</tr>
<tr>
<td>Zhengang</td>
<td>536</td>
<td>169</td>
<td>174</td>
<td>103</td>
<td>0</td>
<td>51</td>
<td>141</td>
<td>125</td>
<td>87</td>
<td>239</td>
<td>227</td>
<td>256</td>
</tr>
<tr>
<td>Meitan</td>
<td>754</td>
<td>216</td>
<td>319</td>
<td>150</td>
<td>51</td>
<td>188</td>
<td>75</td>
<td>91</td>
<td>280</td>
<td>275</td>
<td>333</td>
<td>223</td>
</tr>
<tr>
<td>Fenggang</td>
<td>461</td>
<td>94</td>
<td>125</td>
<td>82</td>
<td>141</td>
<td>188</td>
<td>0</td>
<td>42</td>
<td>119</td>
<td>99</td>
<td>153</td>
<td>262</td>
</tr>
<tr>
<td>Wuchuan</td>
<td>499</td>
<td>163</td>
<td>168</td>
<td>96</td>
<td>125</td>
<td>175</td>
<td>42</td>
<td>0</td>
<td>78</td>
<td>114</td>
<td>222</td>
<td>305</td>
</tr>
<tr>
<td>Yuqing</td>
<td>587</td>
<td>220</td>
<td>225</td>
<td>154</td>
<td>87</td>
<td>91</td>
<td>119</td>
<td>78</td>
<td>0</td>
<td>192</td>
<td>280</td>
<td>363</td>
</tr>
<tr>
<td>Renhuai</td>
<td>496</td>
<td>186</td>
<td>258</td>
<td>179</td>
<td>239</td>
<td>280</td>
<td>99</td>
<td>114</td>
<td>192</td>
<td>0</td>
<td>252</td>
<td>339</td>
</tr>
<tr>
<td>Xishui</td>
<td>532</td>
<td>165</td>
<td>144</td>
<td>209</td>
<td>256</td>
<td>333</td>
<td>262</td>
<td>305</td>
<td>363</td>
<td>339</td>
<td>92</td>
<td>0</td>
</tr>
<tr>
<td>Chishui</td>
<td>516</td>
<td>249</td>
<td>314</td>
<td>393</td>
<td>359</td>
<td>323</td>
<td>433</td>
<td>474</td>
<td>424</td>
<td>549</td>
<td>201</td>
<td>92</td>
</tr>
</tbody>
</table>

TABLE III. IMPORT and EXPORT PARCELS of POSTAL POINTS

<table>
<thead>
<tr>
<th>No.</th>
<th>Cityname</th>
<th>Import parcels</th>
<th>Export parcels</th>
<th>No.</th>
<th>Cityname</th>
<th>Import parcels</th>
<th>Export parcels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Zunyi</td>
<td>3237</td>
<td>1169</td>
<td>7</td>
<td>Fenggang</td>
<td>3682</td>
<td>664</td>
</tr>
<tr>
<td>2</td>
<td>Tongzi</td>
<td>6247</td>
<td>647</td>
<td>8</td>
<td>Wuchuan</td>
<td>3845</td>
<td>732</td>
</tr>
<tr>
<td>3</td>
<td>Suiyang</td>
<td>4109</td>
<td>566</td>
<td>9</td>
<td>Yuqing</td>
<td>2626</td>
<td>529</td>
</tr>
<tr>
<td>4</td>
<td>Zhengang</td>
<td>4313</td>
<td>709</td>
<td>10</td>
<td>Renhuai</td>
<td>3517</td>
<td>914</td>
</tr>
<tr>
<td>5</td>
<td>Dazhouen</td>
<td>4125</td>
<td>574</td>
<td>11</td>
<td>Xishui</td>
<td>6043</td>
<td>1049</td>
</tr>
<tr>
<td>6</td>
<td>Meitan</td>
<td>4505</td>
<td>794</td>
<td>12</td>
<td>Chishui</td>
<td>4024</td>
<td>625</td>
</tr>
</tbody>
</table>

TABLE IV. PARAMETERS

B.

C.

D.

E.

F.

G.

H.

I.

J.

K.

L.

M.

N.

O.

P.

Q.

R.

S.

T.

U.

V.

W.

X.

Y.

Z.
TABLE V. TRANSPORTATION SCHEDULING

<table>
<thead>
<tr>
<th>Rout no.</th>
<th>Transportation rout</th>
<th>Travel distance (Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type I—Xishui—Chishui—Huaien—Type I</td>
<td>572</td>
</tr>
<tr>
<td>2</td>
<td>Type I—Wuchuan—Daozhen—Zhengan—Type I</td>
<td>480</td>
</tr>
<tr>
<td>3</td>
<td>Type II—Yuqing—Fenggang—Meitan—Type II</td>
<td>404</td>
</tr>
<tr>
<td>4</td>
<td>Type III—Tongzi—Type III</td>
<td>101</td>
</tr>
<tr>
<td>5</td>
<td>Type III—Suyang—Zunyi—Type III</td>
<td>137</td>
</tr>
</tbody>
</table>

TABLE IV. COMPARISON RESULTS

<table>
<thead>
<tr>
<th>Results</th>
<th>Our Scheme</th>
<th>Traditional Genetic Algorithm</th>
<th>Current Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cost (Yuan)</td>
<td>6807</td>
<td>8865</td>
<td>10669</td>
</tr>
<tr>
<td>Number of vehicle</td>
<td>5</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Total distance (km)</td>
<td>1694</td>
<td>2220</td>
<td>3758</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

The vehicle scheduling model with one center and some postal points is proposed based on the actual condition of China Postal. Some important factors such as multi-type vehicles, pick-up and delivery of packages, and empty loading are considered in the presented model, which make it more suitable for practical application. A taboo-genetic algorithm is specially designed for this model. Finally, the actually data in Zunyi postal is input into the model and the corresponding result are calculated and compared with other models. The test results show that our scheme is better than the existing scheme of Zunyi Postal, which indicate that the proposed model is valid and practical. It can be used as a good reference to managing transportation network.

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