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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (24): 8500-8504, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.8500.8504

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
- $V = \{V_i^{mk} | m = 1, 2 \ldots M; k = 1, 2 \ldots K\}$: The set of vehicles owned by third-level center. m is the index of vehicle type; k is the number of the vehicle; $l(l \in B)$ is the index of third-level centers
- Q_{mk}: The capacity of the vehicle k (type m)
- m_i: Import of third-level post center i, $i \in B$
- n_i: Export of third-level post center i, $i \in B$
- p_i: Import of county-level post i, $i \in C$
- q_i: Export of county-level post i, $i \in C$
- $q_i^{m,k}$: The actual capacity of vehicle k (type m) after passing post center i
- d_{ij}: The road distance between post i and j
- $B_{m,k}$: The fixed cost of vehicle k (type m)
- $c_{ij}^{m,k}$: The transportation unit cost of vehicle k (type m) when passing from post center i to j
- e: The punishment coefficient of empty loading
- $ER = ((Q_{mk} - q_i^{mk}) * L)/Q_{mk}$, L is the travel distance of the vehicle
- Expense loss of empty-loading: $EC = ER * e$

Decision variables:

- $x_{ij}^{m,k} = 1$, if vehicle k (type m) passes from post center i to j
- $x_i^{m,k} = 1$, if the vehicle k (type m) serves post i, $l \in B$; m, $k \in V$; $i \in B \cup C$
- $w_i = 1$, if the candidate post i is checked, $i \in A$
- $z_{ij} = 1$, if the country-level post j is allocated to the third-level post center i, $i \in B$, $j \in C$

Model formulation: The mathematical model is given as follows:

$$\min \sum_{m,k \in V} \sum_{i \in O} \sum_{j \in B} (c_{ij}^{m,k} + ER \times e) \times x_{ij}^{m,k} \times d_{ij} + \sum_{l \in B} \sum_{m,k \in V} \sum_{i,j \in l \cup C} (c_{ij}^{m,k} + ER \times e) \times x_{ij}^{lm,k} \times d_{ij} + \sum_{l \in B} \sum_{m,k \in V} B_{mk} \times \max(x_i^{m,k}) \quad (1)$$

Subject to the following constraints:

$$\sum_{m,k \in V} \sum_{i,j \in O \cup B \cup C} x_{ij}^{m,k} = 1, \forall l \in B \quad (2)$$

$$\sum_{m,k \in V} \sum_{i \in l \cup B \cup C} x_{ij}^{m,k} = x_j^{m,k}, \forall l \in B, j \in C \quad (3)$$

$$\sum_{m,k \in V} \sum_{i \in O \cup B \cup C} x_{ij}^{m,k} = x_j^{m,k}, \forall j \in B \quad (4)$$

$$\sum_{m,k \in V} \sum_{i \in C} x_{ij}^{m,k} = \sum_{m,k \in V} \sum_{u \in C} x_{iul}^{m,k} \le 1, \forall l \in B \quad (5)$$

$$\sum_{m,k \in V} \sum_{i \in B} x_{ij}^{m,k} = \sum_{m,k \in V} \sum_{u \in C} x_{ij}^{m,k} \le 1, \forall 0 \in O \quad (6)$$

$$\sum_{m,k \in V} x_{ij}^{m,k} \le |S| - 1, \forall i, j \in B \text{ or } i, j \in C \quad (7)$$

$$w_i m_i \ge \sum_{j \in C} z_{ij} \times p_i, \forall i \in B \quad (8)$$

$$w_i n_i \ge \sum_{j \in C} z_{ij} \times q_i, \forall i \in B \quad (9)$$

$$q_i^{m,k} = q_{i-1}^{m,k} - p_i + q_i, \forall i \in B \cup C, m, k \in V \quad (10)$$

$$Q_{m,k} \ge q_i^{m,k} \forall i \in O \cup A \cup C, m, k \in V \quad (11)$$

$$\sum_{i \in B} z_{ij} = 1, \forall j \in C \quad (12)$$

$$\sum z_{ij} \le w_i, \forall_i \in B, j \in C \quad (13)$$

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 country-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 country-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 unchecked, 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, therefor 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 ρ at first, compute r(i) of post i in C($r(i) = d_{it_1}/d_{it_2}$, d_{it_1} is distance between post i and the nearest center t_1 in B, d_{it_2} is distance between post i and the next-nearest center t_2 in B), if $r(i) \geq \rho$, post i is a critical post, otherwise, post i is a noncritical post. The assignation of critical post mainly based on distance, the assignation of the noncritical post mainly based on their demand. Then to compute the deliver cost between the second-level and third-level post centers

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 $SN \leq SNmax$, 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 $i(i \in B)$ has one vehicle of type 1, two vehicle 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:

$$F = \sum_m \sum_k \sum_i pv \times g(Q_{mk}, q_i^{mk})$$

pv is penalty value, $g(Q_{mk}, q_i^{mk}) = q_i^{mk}$, if $\sum_i q_i^{mk} > Q_{mk}$, otherwise, 0

- **Selection operator:** Firstly, copy the best chromosome to next generation; then use the

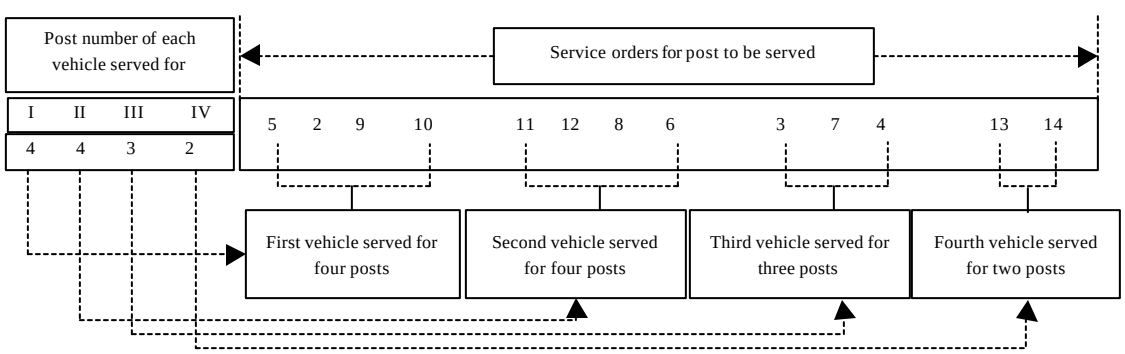

Fig. 1: Coding rule of chromosome

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 use a length T taboo list to record the fitness value of 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 chromosome, if the fitness of α is less than EV, choose α into the next generation; otherwise, choose the better one of the two parent chromosome
- **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

Table 1: Vehicle message

Type	Capacity (t)	Fixed cost (yuan)	Variable cost (yuan km^{-1})	e (yuan km^{-1})
I	5	165	2.4	1.20
II	8	185	2.7	1.35
III	10	215	30	1.50

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 show that the total cost in the best solution is 65214 Yuan; the city-level post

Table 2: Import and export demand of every post

No.	City	Import	Export	No.	City	Import	Export	No.	City	Import	Export
1	Guiyang	-	-	29	Anlong	2015	775	57	Sinan	4743	760
2	Liupanshui	54173	10192	30	Ziyun	4996	4379	58	Dejiang	3329	781
3	Zunyi	40080	25995	31	Shuicheng	1800	900	59	Yanhe	3789	1029
4	Tongren	40439	11703	32	Weining	7092	1872	60	Huangping	3593	509
5	Xingyi	48918	10085	33	Hezhang	2586	444	61	Shibing	2408	672
6	Bijie	37984	7244	34	Nayong	4903	974	62	Taijiang	265	189
7	Anshun	39664	14634	35	Liuzhi	4709	816	63	Jianhe	419	265
8	Kaili	27047	4551	36	Zhongshan	7824	926	64	Sanhui	3509	373
9	Duyun	24347	7820	37	Panxian	10938	1035	65	Tianzhu	4346	791
10	Xiuwen	2427	390	38	Zunyi	3237	1169	66	Jinping	2877	375
11	Kaiyang	4071	1076	39	Tongzi	6247	647	67	Leishan	3089	604
12	Xifeng	2960	1027	40	Suiyang	4109	566	68	Rongjiang	3449	698
13	Luodian	2780	461	41	Zhengan	4313	709	69	Liping	4633	658
14	Fuquan	3276	605	42	Daozhen	4125	574	70	Congjiang	3659	788
15	Huishui	2895	478	43	Jinsha	6363	3121	71	Dauzhai	2661	414
16	Changshun	2822	556	44	Meitan	4505	794	72	Majiang	4535	1201
17	Longli	2950	365	45	Fenggang	3682	664	73	Zhenyuan	3613	1119
18	Guiding	3018	548	46	Wuchuan	3845	732	74	Cengong	2862	829
19	Qingzhen	4108	1678	47	Yuqing	2626	529	75	Pingba	6252	2227
20	Qianxi	3744	220	48	Renhuai	3517	934	76	Zhenning	5752	4923
21	Dafang	5273	1248	49	Xishui	6043	1049	77	Guanling	3862	2676
22	Wengan	4560	815	50	Chishui	4024	625	78	Qinglong	3121	1774
23	Sandu	2344	307	51	Songtao	4818	695	79	Puan	3308	593
24	Dushan	3398	4456	52	Wanshan	1564	328	80	Zhijin	4003	699
25	Pingtang	2815	351	53	Yuping	7151	750	81	Puding	4368	3840
26	Libo	2231	529	54	Jiangkou	2370	571	82	Zhenfeng	2705	749
27	Ceheng	2214	566	55	Shimo	4269	779	83	Xingren	3901	428
28	Wangmo	2605	495	56	Yinjiang	3701	801				

Table 3: Parameters of the solution

ρ	Population no.	Generations	P_c	P_m	T	Neighborhood	Taboo length
0.7	50	200	0.8	0.1	50	20	3

Table 4: Distribution program of per post center

Center No.	Charged country-level post and the distribution program	Distribution cost (yuan)	Distribution cost of STT (yuan)
1	II-15-17-20-10-II, II-6-21-19-, II-11-12-19-II	4016	-
3	I-46-42-41-I, I-49-50-48-I, II-59-45-44-II, II-57-56-58-II, III-43-III, III-38-40-III, III-39-III	9845	6227
7	I-35-76-I, I-37-79-I, II-30-16-II, II-28-27-29-5-II, II-36-31-II, II-81-80-II, II-32-2-II, III-33-34-III, III-75-III, III-83-82-III, III-78-77-III	14313	6790
8	I-51-54-55-47-I, I-63-4-52-53-74-I, II-61-73-60-II, II-66-65-64-62-II, III-67-71-III	8058	6246
9	II-18-22-14-II, II-25-24-26-23-II, II-69-70-68-II, III-13-72-III	5780	3939

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.

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