Hindawi Publishing Corporation
Mathematical Problems in Engineering
Volume 2016, Article ID 6153898, 7 pages
http://dx.doi.org/10.1155/2016/6153898

Research Article

Research on Medicine Distribution Route Optimization for Community Health Service Institutions

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Received 25 January 2016; Accepted 26 April 2016

Academic Editor: Zhimin Huang

At present, the optimization of medicine distribution route has become an urgent issue that needs to be solved in the unified medicine distribution for community health service institutions. Considering the characteristics of medicine distribution for community health service institutions, to minimize the overall cost (including refrigeration storage cost, vehicle fixed cost, and transportation cost) of medicine distribution in a certain region, a transport-distance-constrained local community medicine distribution route optimizing model is established. Then, a tabu-search-based algorithm originated from client direct arrangement ideology is put forward and MATLAB language is used to simulate the medicine distribution procedure. The simulated results show that the proposed algorithm is capable of obtaining an optimum distribution scheme cost with minimum transportation cost.

1. Introduction

Developing community health service is an effective method to optimize the allocation of medical health resource and to make medical services in China more affordable and accessible for ordinary people. Recent researches show that the exceedingly high logistics and distribution cost is one of the major causes contributing to soaring medical fees [1]. The distribution route is designed directly to affect the distribution cost and delivery speed of medicine and the quality of medical service. As medicare reform deepens continuously the community health service in China will step into a stage of large-scale development, which calls for a unified distribution for community medicine. Therefore, it provides with great theoretical and practical significance to design an optimal medicine distribution route for community health service institutions.

The community health service institutions, which undertake part of medicare function, are mainly oriented towards the disease prevention, health care, and health education. Therefore, the medical distribution for these institutions has its distinguishing characteristics. Compared to pharmacies and hospitals, they are prone to such logistics problems as small medicine demand, frequent delivery, widely and randomly distributed branches, and high logistics cost. On the other hand, they require more on temperature-sensitive medicines, like vaccines, insulin injections, and tincture. High temperature during delivery may lead to the deterioration of these medicines and make them become toxic. According to Zhao's research, community health service institution has developed its own new pharmaceutical supply chain, which is different from that of hospitals and pharmacies [2]. Wang established a medicine distribution model for community health service institution based on the system of logistic chain management in his doctoral thesis, but he failed to present detailed model algorithm due to its theoretical complexity [3]. J. Zhang and K. Zhang optimized the medicine distribution routing using ant colony algorithm [4]. Zheng et al. set up a model optimizing the dynamic medicine distribution route in urban areas by use of the Genetic Algorithm [5].

Through an overall review of current researches, it is found that while numerous researches have been done on medicine distribution for hospitals and pharmacies, few researches have been made specially on medicine distribution for community health service institutions and its distinguishing characteristics have failed to be taken into account. Therefore, compared with current researches, this paper has three different points. Firstly, this paper reflects the characteristics of community medicine distribution such as the precise time, the special vehicles, and the fixed branches. So the overall distribution cost includes three key elements in the objective function, which are fixed cost, transport cost, and refrigeration storage cost. Secondly, this paper constructs a model more flexible and adaptable for community medicine distribution. It can complete the optimal distribution route design according to different conditions on its own. Thirdly, this paper improves the tabu-search algorithm based on the idea of client-direct-arrangement and applies it into the model solution to seek the optimal distribution plan meeting all constraint conditions. The result should be contributed to provide some new insights into the design of optimal medicine distribution for community health service institutions and thus reduce the regional medicine distribution cost.

2. Problems Description in Community Medical Distribution Route

The characteristics of medicine distribution for community health service institutions can be described as follows: (1) strict requirements for the accuracy and time of delivery. For example, in Zhenjiang, Jiangsu Province, there are a total of 53 community health service centers and stations widely distributed within a region of 130 square kilometers. The long distance between scattered branches complicates the distribution. (2) The second characteristic is the high requirements for the control of temperature, humidity, exposure to light, and sanitary conditions during transit. Therefore, special vehicles are required for the task of delivery. (3) The third one is the basically fixed locations and clients. Community health service institutions mainly serve for middle-aged and elder citizens suffering from chronic diseases, children who need to be vaccinated, and patients with common diseases, which keeps their demand for medicine stable in quantity and variety [6] and makes it possible to conduct unified medicine distribution.

In view of the characteristics described above, the optimization of medicine distribution route can be simplified into a mathematic subject: given a fixed distribution center and k number of medicine delivering vehicles with refrigerating devices. Let the load capacity of each vehicle be Q, and let the maximum traveling distance of each vehicle once a time be L. Suppose that there are n numbers of branches around that need medicine (with exactly known location), and the requested amount of medicine for the ith institution is q_i. Suppose that the starting point and destination for each vehicle are the distribution center, the fixed operating cost for each vehicle is c_0, transportation cost per kilometer is c_1, and the cost for cooling per hour is c_2. With all these parameters known, an optimized distribution scheme needs to be given to reduce the cost for a unified distribution.

3. Model Assumptions and Constraints

3.1. Assumptions

(1) The amount and location of community health service institutions are constant.

(2) There is a distribution center with fixed location and adequate distributing capacity.

(3) The demand for medicine in each community health service branch can be satisfied readily.

(4) The usage of vehicles is fixed; after delivery is done, vehicle should return to the distribution center.

(5) In order to avoid overload issues, the amount of each delivery should not exceed the overall requested amount each time.

(6) One-to-one rule is applied, which means that one vehicle only serves one certain route.

3.2. Constraints

(1) Load on vehicles: the overall amount of medicine requested by branches along certain route should not exceed the load capacity of the vehicle.

(2) Maximum distribution distance: the overall distance of a certain route should not exceed the maximum distribution distance of the vehicle.

(3) One-way rule: a vehicle only follows one direction along a certain route, which means that the vehicle cannot turn back and each branch only can be served by one vehicle once.

4. Construction of Community Medicine Distribution Route Optimization Model

Based on the assumptions and constraints described above, the model is established as follows:

$$\min \quad Z = m \cdot c_0 + c_1 \cdot \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{m} L_{ij} \cdot x_{ijk} + c_2 \cdot \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{m} t_{ij} \cdot x_{ijk}, \tag{1}$$

$$\text{s.t.} \quad \sum_{i=0}^{n} q_i \cdot y_{ik} \le Q \quad k = 1, 2, \ldots, m; \tag{2}$$

$$\sum_{i=0}^{n} \sum_{j=0}^{n} L_{ij} \cdot x_{ijk} \le L \quad k = 1, 2, \ldots, m; \tag{3}$$

$$\sum_{k=1}^{m} y_{ik} = 1 \quad i = 0, 1, \ldots, n; \tag{4}$$

$$\sum_{i=0}^{m} x_{ijk} = y_{jk} \quad j = 0, 1, \ldots, n;\ k = 1, 2, \ldots, m; \tag{5}$$

$$\sum_{j=0}^{n} x_{ijk} = y_{ik} \quad i = 0, 1, \ldots, n;\ k = 1, 2, \ldots, m; \tag{6}$$

$$y_{ik} = \begin{cases} 1, & \text{the } i\text{th client is served by vehicle } k, \\ 0, & \text{others;} \end{cases} \tag{7}$$

$$x_{ijk} = \begin{cases} 1, & \text{vehicle } k \text{ drives from client } i \text{ to client } j, \\ 0, & \text{others} \end{cases} \tag{8}$$

in which L_{ij} is the distance between client i and client j, L is the maximum distance traveled by a vehicle each time, t_{ij} is the time a vehicle takes to drive from client i to client j, $i = 0$ means distribution center, and the amount of medicine requested is 0 ($q_0 = 0$). Other parameters are the following: m is the number of delivery vehicles, c_0 is the fixed operating cost of vehicles, c_1 is delivery cost per distance unit of vehicle, and c_2 is cooling cost per unit time. The meanings for each expression shown above are as follows.

Expression (1): overall cost of community medicine distribution cost includes fixed operating cost of vehicles, delivery cost per distance unit of vehicle, and cooling cost; Expression (2): vehicles are not overloaded; Expression (3): the overall distance of one certain route does not exceed the maximum delivery distance of vehicle; Expression (4): each vehicle only serves one client once; Expressions (5)-(6): the route for each vehicle is closed: logistic center—one or more community health service institutions—logistic center; Expressions (7)-(8): they reflect integer constraints.

Time window is not taken into account in this model, considering the fact that the delivery time requested by each branch is almost the same, generally before 8 a.m. Therefore, as long as the shortest route is achieved, the least time for distribution can be assured. In addition, for the sake of saving energy, after distribution is done, cooling devices on vehicles are suggested to be turned off on the way back to the distribution center.

5. Algorithm Design

Tabu search, TS for short, is a metaheuristic algorithm proposed by Glover in 1986. It is actually extension of local neighborhood search [7]. Through simulating the memory mechanism of human intelligence, TS algorithm introduces an agile storage structure and corresponding tabu criteria to avoid circuitous search. It can achieve a global optimum by remitting some tabooed good status according to remitting criteria [8–10]. Being different from genetic algorithm and simulated annealing algorithm, tabu search algorithm is an intelligent random algorithm, which can overcome the defection of precocious convergence during the search process and finally achieve a global optimum [11]. Now, it has been applied to solve classic issues like traveling businessmen issue, siting issue, and route optimization problem [12–14]. In order to find out an optimized route for community medicine distribution, this paper improves the traditional tabu search algorithm mainly based on the idea of customer straight arrangement [10].

5.1. Key Elements Analysis

5.1.1. Initial Solution. The choice of initial solution affects the search efficiency and convergence speed of TS algorithm. Generally, the traditional tabu search algorithm generates initial solution randomly. But it has large probability of randomly generated infeasible initial solution in the community medicine distribution route optimization, because of too many conditions of satisfaction and infeasible solutions. So, we construct the initial solution based on the idea of customer straight arrangement and divide the initial solution into feasible solutions which satisfy the constraint conditions by the method of greed segmentation. We prevent the problem that random initial solution is infeasible as far as possible.

5.1.2. Evaluation Function. The meaning of evaluation function is a method of determining the solution evaluation. It determines complexity and performance of the algorithm implementation. The method of edge-directed solution arrangement is much used for evaluation function construction in the existing literature, but it has its deficiency such as being time-consuming, search-inefficient, and convergence-slow. In this paper, we design the evaluation function of TS algorithm also based on the idea of customer straight arrangement. It reduces the number of infeasible solutions, narrows the search scope, and improves the search efficiency. Therefore, it provides the possibility for the improvement of the whole performance of TS algorithm.

The evaluation function for tabu algorithm is designed following the ideology: take the route optimization of one distribution center and 6 communities in one certain region, for example. Set logistic center as zero, current solution S equals 342156, and constraints are the maximum load capacity and maximum traveling distance of vehicle for each single delivery. Firstly, add client 3 as the 1st client into route 1; then judge whether it can satisfy the constraints, namely, to judge whether the amount of medicine requested by client 3 and the whole distance of route 0-3-0 can satisfy the constraints. If it does, add the client 4 as the 2nd one into this route, and go on with next calculation. If not, end calculation for route 0-3-0, add client 4 into route 2, and go on with the calculation. Assume that 3 routes are derived, 0-3-0, 0-4-2-1-0, and 0-5-6-0. L_0 is the sum of the distance of these 3 routes. The evaluation function of current solution can be calculated by $f(x) = 3c_0 + L_0 * c_1$.

5.1.3. Neighborhood and Candidate. Neighborhood structure design is very important to ensure the efficiency of TS algorithm and the solution of the overall situation. Combined with the characteristics and requirement of community medicine distribution route optimization problem, we adopt the SWAP operation to build the neighborhood structure, namely, to exchange the positions of two random elements in solution. The number of neighborhood solutions is C_n^2 produced by SWAP operation. According to the characteristics of the problem, the candidate solutions are preferential selected in the field of current state.

5.1.4. Tabu Table and Termination Criterion. This paper uses the queue storage structure (FIFO: first in and first out) to update tabu table: when a new feasible solution is generated, its reverse move will be inserted to the bottom of the tabu list, and the first tabu element will be shifted out from the top; then the other tabu elements are moving up one unit. For the algorithm performance, too overloaded value of length of tabu list could increase the search cost, and too short value of length of tabu list could let the algorithm fell into local circulation. Generally, two equally effective ways could be used to set length of tabu list, which are static setting and dynamic setting. This paper adopts static setting to determine the length of tabu list in order to be convenient for calculation and solving. The static length of tabu list should be less than $\mathrm{TabuL} = \mathrm{round}(\sqrt{n(n-1)/2})$ according to literature research, and n is the number of search points (namely, the number of community health service institutions in Section 6).

In addition, this paper uses the specified maximum iteration step length method as the termination criterion of TS algorithm. Maxnum represents the number of feasible solutions, also used as the largest iterative steps. The search algorithm is ended when the total number of the detecting feasible solutions reaches to Maxnum. Then, we save and output the current best solution as the optimal solution.

5.2. Steps of Tabu Search Algorithm. According to the basic theory of tabu search algorithm, steps for searching an optimized solution are as follows.

Step 1. Use a computer to generate an element collection randomly, and use greedy segmentation method to decompose it into a number of subsets which satisfy the constraint conditions, set it as the initial solution S_0, and make the tabu table $H = \Phi$; at the same time make the algorithm iterate counter Num = 0.

Step 2. Use customer straight alignment method and evaluation function to construct the evaluation value $f(x)$ of the algorithm, and make the current optimal solution as BSF = S_0.

Step 3. Use pairwise interchange to conduct local neighborhood operation: exchange the positions of two elements in current solution randomly, and save it as a new current solution in alternative solution set Candidate (the number of elements in this solution set does not exceed $n * (n-1)/2$).

Step 4. Select one solution S_1 from the set Candidate as current solution, and make a comparison between its evaluation value $f(S_1)$ and the evaluation value of current optimum solution $f(\mathrm{BSF})$; if $f(S_1) < f(\mathrm{BSF})$, then let BSF $= S_1$; otherwise, go to Step 3, continue to select a new solution from Candidate set for comparison, and then update the tabu table H.

Step 5. Determine whether Num $\leq$ Maxnum is valid; if it is valid, return to Step 3 to continue the search; otherwise, terminate the algorithm and output current optimal solutions BSF.

6. Application

We choose Jingkou District of Zhenjiang City in Jiangsu Province as the application area. The community medicine distribution is unified and entrusted to a specific company by the medicine distribution center. However, the decision-making of this company about the required number of vehicles and the actual distribution path depends on too much experience. Moreover, this company is short of initiative for optimization of the community medicine distribution. Therefore, this paper tests and verifies the effectiveness of the optimization model by means of logical data processing. At the same time, we hope that the conclusion could contribute to the improvement of the actual operation efficiency of community medicine distribution.

There are one medicine distribution center, two community health service centers, and sixteen community health service stations in Jingkou District. So the total number of community health service institutions is 18; namely, $n = 18$. And the medicine distribution center has several vehicles with 8-ton load capacity. We set the coordinate of the distribution center as $(0, 0)$ and get the corresponding coordinate of each community health service institution referring to $(0, 0)$. The coordinates and the amount of medicine requested by each community health service institution are shown in Table 1.

In MATLAB 6.5, the parameters of tabu search algorithm are set as follows.

Table 1: Coordinates (km) and the amount of medicine requested by each community health service institution.

Delivery destination	Service center 1	Service center 2	Service station 1	Service station 2	Service station 3	Service station 4
Coordinates	(13, 15)	(−40, −60)	(60, 48)	(49, 23)	(−72, 80)	(−51, −39)
The amount of medicine requested	3	2	0.1	0.3	0.2	0.1
Delivery destination	Service station 5	Service station 6	Service station 7	Service station 8	Service station 9	Service station 10
Coordinates	(38, −58)	(60, −45)	(73, 69)	(−65, 70)	(20, 25)	(30, −20)
The amount of medicine requested	0.4	0.5	1	0.6	0.3	0.8
Delivery destination	Service station 11	Service station 12	Service station 13	Service station 14	Service station 15	Service station 16
Coordinates	(40, −18)	(50, 35)	(−25, 60)	(−15, −10)	(92, 42)	(−20, −35)
The amount of medicine requested	0.2	1	1.2	0.2	0.5	0.6

Table 2: Results of tabu algorithm.

Iteration	Distribution route	Time for each iteration (s)	Numbers of vehicle/m	Overall cost/c
1	0 → 16 → 18 → 6 → 2 → 8 → 17 → 9 → 3 → 14 → 4 → 13 → 12 → 0 0 → 1 → 11 → 7 → 15 → 5 → 10 → 0	37.14	2	8790.6
2	0 → 1 → 11 → 16 → 18 → 6 → 2 → 8 → 12 → 0 0 → 10 → 5 → 15 → 7 → 9 → 17 → 3 → 14 → 4 → 13 → 0	28.46	2	8998.5
3	0 → 18 → 2 → 6 → 10 → 5 → 15 → 1 → 16 → 0 0 → 11 → 7 → 9 → 17 → 3 → 14 → 4 → 8 → 13 → 12 → 0	38.5	2	8553.4
4	0 → 1 → 16 → 18 → 2 → 6 → 10 → 5 → 15 → 0 0 → 11 → 7 → 9 → 17 → 3 → 14 → 4 → 8 → 13 → 12 → 0	35.02	2	8466.6
5	0 → 11 → 4 → 14 → 3 → 17 → 9 → 7 → 15 → 5 → 10 → 0 0 → 1 → 12 → 13 → 8 → 2 → 6 → 18 → 16 → 0	34.38	2	8358.7
6	0 → 18 → 2 → 6 → 16 → 7 → 9 → 17 → 3 → 14 → 4 → 12 → 13 → 8 → 0 0 → 1 → 11 → 15 → 5 → 10 → 0	39.34	2	8929.4
7	0 → 1 → 15 → 5 → 10 → 6 → 2 → 18 → 16 → 0 0 → 11 → 7 → 9 → 17 → 3 → 14 → 4 → 8 → 13 → 12 → 0	33.25	2	8217.6
8	0 → 6 → 2 → 8 → 13 → 12 → 4 → 14 → 3 → 17 → 9 → 7 → 11 → 0 0 → 1 → 15 → 5 → 10 → 18 → 16 → 0	29.92	2	9042.7
9	0 → 1 → 11 → 16 → 18 → 6 → 2 → 8 → 12 → 0 0 → 10 → 5 → 15 → 7 → 9 → 17 → 3 → 14 → 4 → 13 → 0	27.41	2	8998.5
10	0 → 18 → 2 → 6 → 16 → 11 → 7 → 15 → 5 → 10 → 0 0 → 1 → 14 → 3 → 9 → 17 → 4 → 8 → 13 → 12 → 0	36.95	2	9046.7

The length of tabu table is $\text{TabuL} = \text{round}(\sqrt{n(n-1)/2}) = 12$, the number of candidate solutions is 144, the largest iterative step is Maxnum = 500, fixed operating cost of vehicles $c_0 = 500$ RMB, transportation cost $c_1 = 10$ RMB/km, cooling cost for medicine $c_2 = 20$ RMB/hour, average velocity of vehicles $v = 60$ km/hour, maximum distribution distance in one single time $L = 500$ km, and maximum load capacity $T = 8$ t. Run the calculation 10 times randomly; we can get result as shown in Table 2.

According to Table 2, it can be seen that the average distribution cost is 8740.3 RMB, numbers of vehicles are 2 sets, average iteration time is 34 s, minimum distribution cost is 8217.6 RMB, and optimum route is the 1st route, 0 → 1 → 15 → 5 → 10 → 6 → 2 → 18 → 16 → 0, and the 2nd route: 0 → 11 → 7 → 9 → 17 → 3 → 14 → 4 → 8 → 13 → 12 → 0. The search procedure and optimum route are shown in Figures 1 and 2.

From Figure 1, it can be seen that the improved tabu search algorithm converged rapidly and could locate optimum solution after 20 iterations, which means that this algorithm is quite effective in seeking an optimum route for community health service medicine distribution. In addition, according to the simulation results, after the calculation is converged, the search procedure remained stable, which means that this algorithm is reliable and stable.

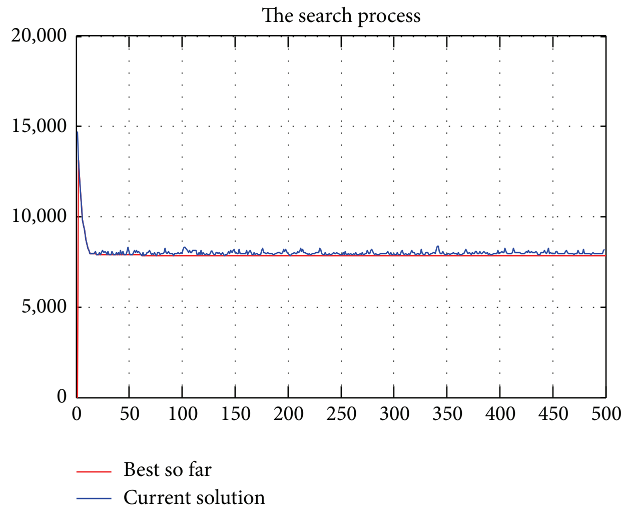

FIGURE 1: Procedure of tabu algorithm.

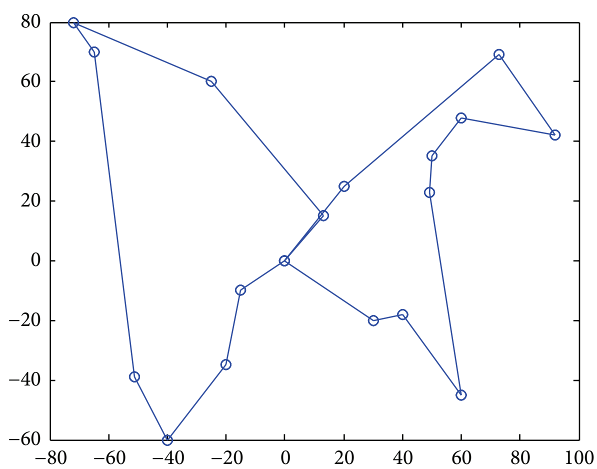

FIGURE 2: Optimum route.

From Figure 2, it can be found that in order to finish this distribution we need 2 vehicles in one time or use 1 vehicle to deliver two times. Also, there are no intersections in these two routes, which means that these two routes are intuitively preferable.

7. Conclusion

Unified and professional medicine distribution for communities can effectively integrate and allocate the already scarce medical resources and thus is of great significance to provide more affordable and easily accessible medical and health services to citizens. Considering the special characteristics of community medicine distribution, the paper establishes a model to optimize the community medicine distribution route, with the objective of minimizing the overall distribution cost (including storage cost, vehicle consuming cost, and transportation cost) and with the load capacity of vehicles and the maximum transport distance each time as constraint conditions. Then, a tabu-search-based algorithm originated from costumer direct arrangement ideology is put forward and MATLAB language is used to simulate the medicine distribution procedure. The simulated results show that the proposed algorithm can effectively solve the medicine distribution route optimization issues with uncertain number of vehicles and provide a scheme with minimum distribution cost for community health service institution. Compared to conventional distribution scheme which depends on experience and intuition, the proposed algorithm can reduce the overall distribution distance and delivery time, thus lowering the overall cost and improving the quality of medicare service. In addition, the algorithm can adjust the route readily to the changes in initial values, constraint conditions, and the amount of medicine requested by community health service institutions, so it has good adaptability in practice. It is believed that the advantage of the optimized distribution route will stand out with the increasing expansion of the community health service institutions. However, the road conditions, traffic jams, and weather are not considered in this study, which will become the focus of future research.

Competing Interests

The authors declare that they have no competing interests.

Acknowledgments

The financial support from National Natural Science Foundation of China (Grant no. 71573109 for Professor Zhiqiang Ma), Social Sciences Foundation of Jiangsu Province in China (Grant no. 13GLB009 for Professor Zhiqiang Ma), the Doctoral Program of Higher Education Research Foundation from Education Ministry of China (Grant no. 20123227110023 for Professor Zhiqiang Ma), and the Innovation Research Foundation for Graduate Students of Jiangsu Province in China (Grant no. KYZZ_0282 for Dr. Zhao Li) is acknowledged.

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