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Research Article

Synthetic Optimization Model and Algorithm for Railway Freight Center Station Location and Wagon Flow Organization Problem

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The railway freight center stations location and wagon flow organization in railway transport are interconnected, and each of them is complicated in a large-scale rail network. In this paper, a two-stage method is proposed to optimize railway freight center stations location and wagon flow organization together. The location model is present with the objective to minimize the operation cost and fixed construction cost. Then, the second model of wagon flow organization is proposed to decide the optimal train service between different freight center stations. The location of the stations is the output of the first model. A heuristic algorithm that combined tabu search (TS) with adaptive clonal selection algorithm (ACSA) is proposed to solve those two models. The numerical results show the proposed solution method is effective.

1. Introduction

In the past decade, China railway has invested many railway freight center stations, which are equipped comprehensive transportation facilities and logistics facilities for the purpose of centralized transportation. At the same time, most of the stations with small transport demand were closed. Those center stations can help to centralize transport demand and gain economic of scale, while the transport demand of closed stations may be lost, if the transport cost of the railway is higher than the other transport modes such as road and water transport. In order to attract the transport demand, railway must improve the wagon flow organization to provide service with high level.

The center station location and wagon flow organization are interacted and interconnected. In order to organize products with high level of service, the amount of goods must meet the train size limitation. Otherwise, long waiting time may be caused. At the same time, the efficiency of wagon flow organization can decide the operation efficiency of stations. For example, the limited storage capacity of station will be occupied, if there is no suitable train to serve the demand.

In order to solve the complicated station location and wagon flow organization problem, a two-stage method is proposed to optimize station location and wagon flow organization together. This paper is organized as follows. Section 2 briefly reviews the relevant literature. Section 3 introduces the optimal models in a two-stage method. In Section 4, a heuristic algorithm is proposed to solve the models. Finally, a numerical example is provided to illustrate the application of the models and algorithm.

2. Literature Review

The location of railway freight center stations is similar to hub location problem, which is among the most critical management decisions. Many models have been proposed such as set covering problem (SCP), p-center problem, and p-median problem [1–5].

The SCP model was presented by Caprara et al. [5] and solved by a heuristic method based on Lagrangian relaxation. Campbell [6] came up with formulations for the multiple and single allocation p-hub median problem with two heuristic methods. Besides, Campbell et al. [7] concluded that there are two types of hub location problem: single allocation and multiple allocation. Skorin-Kapov et al. [8] studied the uncapacitated multiple and single allocation p-hub median problems. O'Kelly [9] analyzed the models for both single-hub and two-hub problems. And O'Kelly [10] presented a quadratic integer program for the hub location. The model is linearized and solved by a heuristic algorithm. Furthermore, O'Kelly and Bryan [11] proposed a reliable model by considering the scale economies effect of traffic. Racunica and Wynter [12] studied the location problem in a hub-and-spoke network, aiming to increase the share of rail in intermodal transport.

Recently, fuzzy theory and dynamic environment were introduced into the location problem. Batanović et al.'s study [13] concerned the uncertain parameters in maximum covering location problem, which were modeled by fuzzy set. Sáez-Aguado and Trandafir [14] improved the p-median model by considering a coverage constraint. A dynamic uncapacitated hub location problem was present in Contreras et al.'s paper [15]. Correia et al. [16] proposed four mixed-integer linear programming formulations in order to study the extension of classical capacitated single-allocation hub location problem.

For the wagon flow organization problem, Bodin et al. [17] developed a nonlinear, mixed-integer programming model for the railroad blocking problem. Martinelli and Teng [18] applied neural network to solve the railway operation problem. Some research described the railway blocking problem with network theory. Newton et al. [19] took the railroad blocking problem as a network design problem and developed a column generation and branch-and-bound algorithm to solve it. Similarly, Barnhart et al. [20] proposed a Lagrangian relaxation approach for optimizing railway blocking problem. Fukasawa et al. [21] considered both the loaded and empty cars in the network and proposed an integer multicommodity flow model for the problem. Woxenius [22] provided six principles of rail operation and applied them into intermodal rail freight transport network system. Jeong et al. [23] formulated a linear integer programming model in a hub-and-spoke network. Jha et al. [24] compared arc-based with path-based formulations of the block-to-train assignment problem and proved that the latter is smaller in scale. Keaton [25] presented a mixed-integer programming for railroad blocking problem.

In China, Wu [26] studied the organization scheme for through trains. Lin et al. [27] formulated a nonlinear 0-1 through train formation model considering the different cost parameters and block capacity constraint. Nonlinear 0-1 programming models were established in Cao et al.'s study [28, 29] to determine the freight train scheduling plan based on analyzing the logistics system costs.

Most of the research in literature focused either on the location of stations or the wagon flow organization, while the influence of the location on wagon flow organization should be considered. In this paper, a two-stage method is used to solve this problem.

3. The Two-Stage Programming

3.1. Model of Optimal Railway Freight Center Station Location Problem. As the location of railway freight center stations is similar to the hub location problem, customer specifies the ordinary railway freight station, while service point specifies the candidate railway freight center station.

3.1.1. Decision Variables. The objective of this model is to find the optimal location of service points and the assignment between customer and service point. The location decision and assignment are treated as decision variables. Those are

x_{ij} equals 1 if customer i is assigned to service point j. Otherwise, it equals 0.

y_j equals 1 if service point is located at candidate service point j. Otherwise, it equals 0.

3.1.2. Objective Function. Customers hope that the service points are located close to themselves, so as to send the goods to the station quickly and cheaply, while the planners want to maximize the railway coverage with limited center stations, so as to reduce the total investment. Both the transport cost from costumers to service points and construction costs of stations are considered by the following objective function:

$$\min Z = \mu_1 \sum_{i\in I} \sum_{j\in J} \lambda d_{ij} q_i' x_{ij} + \mu_2 \sum_{j\in J} C_j y_j, \tag{1}$$

where

λ is unit cost to transport the goods from customer to service point;

μ_1 and μ_2 are weight of transport cost and construction cost in objective function. The values are defined in advance. And $\mu_1 + \mu_2 = 1$, $\mu_1 \geq 0$, $\mu_2 \geq 0$;

d_{ij} is distance between customer i and candidate service point j;

q_i' is transport demand of customer i;

C_j is fixed cost to construct a service point at candidate service point j;

I is set of customers, $i \in I$;

J is set of candidate service points, $j \in J$.

3.1.3. Constraints. The coverage constraint of a service point is considered. The whole distance which is greater than the preestablished coverage distance at a service point should not exceed a previously chosen value. This constraint is related to the maximum covering location problem (MCLP), whereas the investment of service point may change the transport demand. The model also takes this situation into account.

(i) Each customer must be assigned to one service point

$$\sum_{j \in J} x_{ij} = 1 \quad \forall i \in I. \tag{2}$$

(ii) Candidate service point j cannot serve any customer, if j is not chosen as a service point

$$x_{ij} \leq y_j \quad \forall i \in I, \quad j \in J. \tag{3}$$

(iii) The total number of chosen service points should be constrained

$$\sum_{j \in J} y_j \leq p. \tag{4}$$

p is the maximum number of the stations.

(iv) Sum of the distance which is greater than coverage distance DC at a service point should not exceed δ. Both DC and δ are prespecified

$$\sum_{i \in I} l_{ij} x_{ij} \leq \delta \quad \forall j \in J. \tag{5}$$

l_{ij} is defined as follows:

$$l_{ij} = \begin{cases} d_{ij} & d_{ij} > \text{DC} \\ 0 & \text{otherwise.} \end{cases} \tag{6}$$

(v) The goods serviced by point j cannot exceed its capacity Cap_j.

$$\sum_{i \in I} q_i' x_{ij} \leq \text{Cap}_j \quad \forall j \in J. \tag{7}$$

q_i' is defined as follows:

$$q_i' = \begin{cases} \varepsilon q_i & \text{point } i \text{ is not a service point} \\ q_i & \text{otherwise} \end{cases} \qquad \forall i \in I, \tag{8}$$

where ε is a discount coefficient of demand at point i if i is not a service point, which describes the change of transport demand. q_i is the expected transport demand at point i.

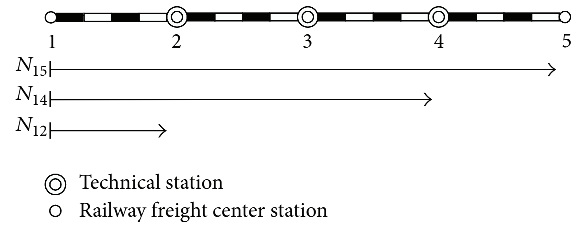

Figure 1: A simple rail network.

3.1.4. Mathematical Model. The location model of railway freight center stations can be stated as

(M-I)

$$\begin{aligned} \min \quad & Z = \mu_1 \sum_{i \in I} \sum_{j \in J} \lambda d_{ij} q_i' x_{ij} + \mu_2 \sum_{j \in J} C_j y_j \\ \text{s.t.} \quad & \sum_{j \in J} x_{ij} = 1 \quad \forall i \in I \\ & x_{ij} \leq y_j \quad \forall i \in I, \ j \in J \\ & \sum_{j \in J} y_j \leq p \\ & \sum_{i \in I} l_{ij} x_{ij} \leq \delta \quad \forall j \in J \\ & \sum_{i \in I} q_i' x_{ij} \leq \text{Cap}_j \quad \forall j \in J \\ & x_{ij}, y_j \in \{0, 1\} \quad \forall i \in I, \quad j \in J. \end{aligned} \tag{9}$$

3.2. Model of Wagon Flow Organization Problem. The outputs of M-I include the location of railway freight center stations and the transport demand of each station. Based on the average loaded weight of a wagon, the transport demand can be turned into wagon flows. Those are the input data of wagon flow organization.

3.2.1. An Example of Wagon Flow Organization Problem. The wagon flow organization problem can be illustrated by a simple network (see Figure 1), which has three technical stations, two freight center stations, and three shipments (N_{12}, N_{14}, and N_{15}).

There are 12 combinations for routing all the shipments on potential train services (see Figure 2). Arcs in the network specify the available train connections. The OD pair will be reclassified at the technical stations in the itinerary if it is not served by through train. If transport demand between two adjacent stations is positive, the train service must be provided. So shipment N_{12} has only one service strategy that is served by the train service $1 \rightarrow 2$.

Strategy 1 (see Figure 2(a)). The OD pairs N_{15}, N_{14}, and N_{12} are consolidated in train service $1 \rightarrow 2$ at the origin station 1.

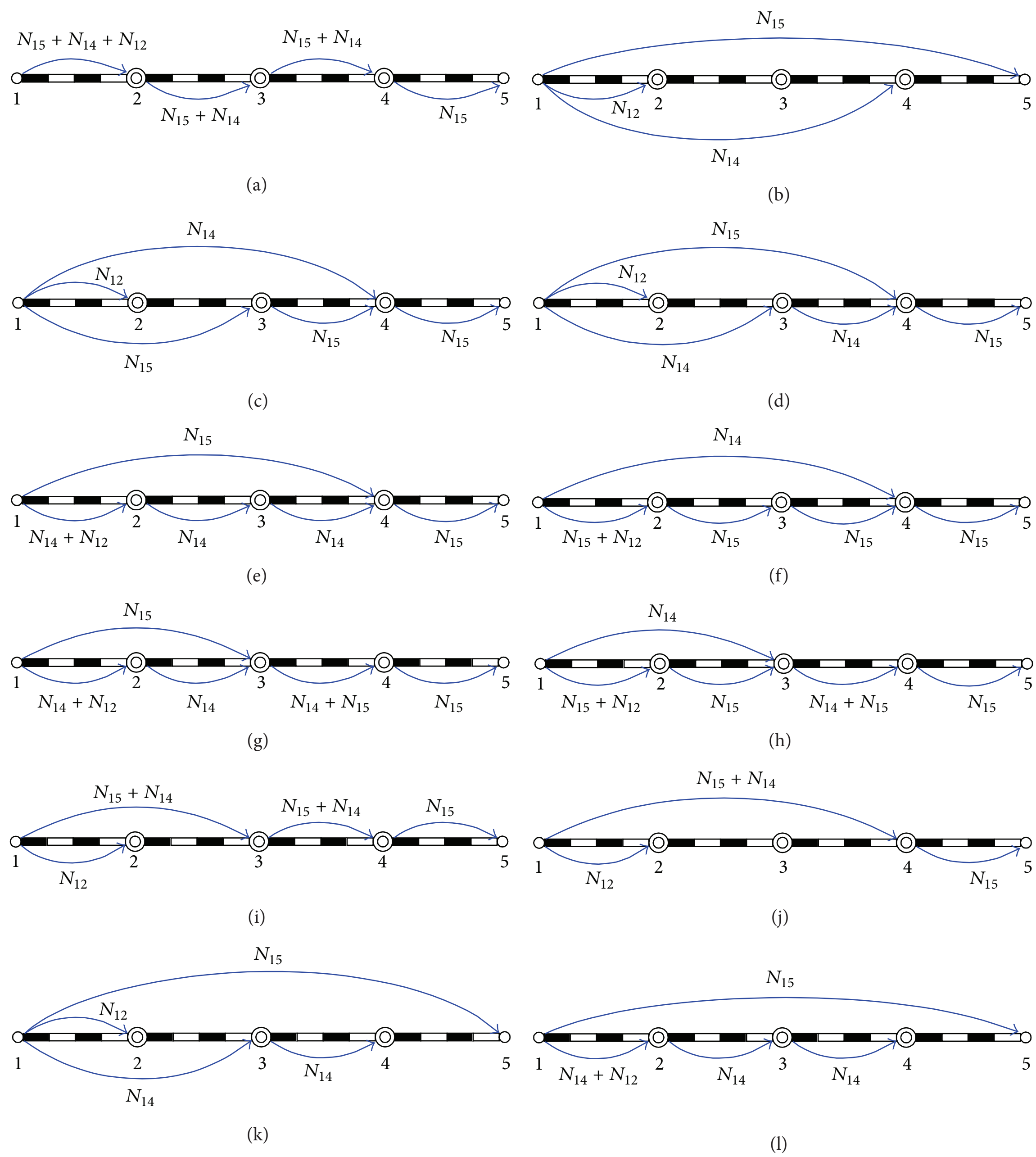

FIGURE 2: Twelve combinations for routing all the shipments on potential train services.

In this case, N_{15} is reclassified at technical stations 2, 3, and 4. N_{14} is reclassified at technical stations 2 and 3.

Strategy 2 (see Figure 2(b)). There are two through train services $1 \rightarrow 4$ and $1 \rightarrow 5$. In this case, both N_{15} and N_{14} are directly shipped to the destination.

Strategy 3 (see Figure 2(c)). There are two through train services $1 \rightarrow 3$ and $1 \rightarrow 4$. In this case, N_{14} is directly shipped to the destination. While N_{15} is directly shipped to technical station 3, and N_{15} still needs to be reclassified at technical stations 3 and 4.

Strategy 4 (see Figure 2(d)). Strategy 3 and Strategy 4 share the common train service set, but the train services are different. N_{15} is directly shipped to technical station 4 and reclassified there. N_{14} is directly shipped to technical station 3 and reclassified there.

Strategy 5 (see Figure 2(e)). There is one through train service $1 \rightarrow 4$. In this case, N_{15} is directly shipped to the technical station 4 and reclassified there. N_{14} and N_{12} are consolidated in train service $1 \rightarrow 2$. N_{14} is reclassified at technical stations 2 and 3.

Strategy 6 (see Figure 2(f)). Strategy 5 and Strategy 6 share the common train service set, but the train services are different. N_{14} is directly shipped to technical station 4 by train service $1 \rightarrow 4$. N_{15} and N_{12} are consolidated in train service $1 \rightarrow 2$. N_{15} is reclassified at technical stations 2, 3, and 4.

Strategy 7 (see Figure 2(g)). There is one through train service $1 \rightarrow 3$. In this case, N_{15} is directly shipped to the technical station 3 and reclassified at technical stations 3 and 4. N_{14} and N_{12} are consolidated in train service $1 \rightarrow 2$. N_{14} is reclassified at technical stations 2 and 3.

Strategy 8 (see Figure 2(h)). Strategy 7 and Strategy 8 share the common train service set, but the train services are different. N_{14} is directly shipped to technical station 3 by train service $1 \rightarrow 3$ and reclassified there. N_{15} and N_{12} are consolidated in train service $1 \rightarrow 2$. N_{15} is reclassified at technical stations 2, 3, and 4.

Strategy 9 (see Figure 2(i)). There is one through train service $1 \rightarrow 3$. In this case, N_{15} and N_{14} are directly consolidated together and shipped to the technical station 3 by train service $1 \rightarrow 3$. N_{14} is reclassified at technical station 3. N_{15} is reclassified at technical station 3 and 4.

Strategy 10 (see Figure 2(j)). There is one through train service $1 \rightarrow 4$. In this case, N_{15} and N_{14} are consolidated together and directly shipped to the technical station 4 by train service $1 \rightarrow 4$. N_{15} is reclassified there.

Strategy 11 (see Figure 2(k)). There are two through train services $1 \rightarrow 3$ and $1 \rightarrow 5$. In this case, N_{15} is directly shipped to destination by train service $1 \rightarrow 5$. N_{14} is directly shipped to the technical station 3 by train service $1 \rightarrow 3$ and reclassified there.

Strategy 12 (see Figure 2(l)). There is one through train service $1 \rightarrow 5$. In this case, N_{15} is directly shipped to destination by train service $1 \rightarrow 5$. N_{14} and N_{12} are consolidated in train service $1 \rightarrow 2$. N_{14} is reclassified at technical station 2 and 3.

3.2.2. Analysis of Wagon Flow Organization Problem. Among the twelve strategies above, there are two extreme ones, that is, Strategy 1 and Strategy 2.

(1) In Strategy 1, train connection services are only provided between adjacent stations. In this way, the number of through train services reaches minimum; that is, the total waiting time at the dispatching station reaches minimum. However, each shipment will be reclassified at each technical station on its itinerary. Thus the reclassification fee and time consumption will increase significantly. The increasing number of reclassified wagons may cause congestion and time delay at some technical stations.

(2) In Strategy 2, transport demands are all delivered to their destinations without reclassification, which will reduce the reclassification fee and time consumption. However, this strategy may be unworkable. Such strategy requires enough classification tracks to store outbound trains, and single OD pair must be large enough to dispatch a through train service. Waiting time at the dispatching station will increase if the OD pair is small.

The solution of wagon flow organization problem is a tradeoff between Strategy 1 and Strategy 2, aiming at minimizing the total shipping and handling cost for all shipments. The time consumption is used to weigh the cost.

3.2.3. Decision Variables. From the example above, it can be concluded that there are three train services for a wagon flow: the first one is shipped to the destination by nonstop shipping scheme at the origin station, the second one is served by nonthrough shipment, and the third one is shipped to a technical station in the itinerary by nonstop shipping scheme consolidated with other OD pairs. These variables are

$$x_{st} = \begin{cases} 1 & N_{st} \text{ is shipped by nonstop scheme} \\ 0 & \text{otherwise} \end{cases}$$

$$x_{st}^{k} = \begin{cases} 1 & N_{st} \text{ is shipped to first technical} \\ & \text{station } k \text{ in the itinerary and} \\ & \text{reclassified there} \\ 0 & \text{otherwise} \end{cases} \qquad \forall k \in V(s) \tag{10}$$

$$y_{st}^{k} = \begin{cases} 1 & N_{st} \text{ is shipped to tcehnical station } k \\ & \text{and reclassified there} \\ 0 & \text{otherwise} \end{cases} \qquad \forall k \in P(s),$$

where

N_{st} is number of wagon flow from origin s to destination t;

s is origin station;

t is destination station;

$V(s)$ is set of technical stations next to the origin station s, $k \in V(s)$;

$P(s)$ is set of technical stations in the itinerary of wagon flow N_{st}; exclude the technical station next to the origin station, $P(s) \cap V(s) = \emptyset$, $k \in P(s)$.

3.2.4. Objective Function. The optimal goal is to obtain the wagon flow organization plan with minimum time consumption, which means the level of service. The travel time is not considered for it is identical. In order to simplify the problem, the following assumptions are proposed: (1) the supply of empty wagons is not considered, (2) the storage capacity of the origin and destination station are not considered, (3) the shipping routes for all the service are given, and (4) the train formation plans (TFP) of the technical stations in the itinerary are known. This information can be obtained previously.

Time consumption of three train services for N_{st} is as follows.

(i) For the nonstop service, the service time equals the loading and unloading times As there is no intermediate service such as reclassification

$$F_1 = N_{st} w_{st} x_{st}, \tag{11}$$

where

w_{st} is loading and unloading time at the origin and destination for a wagon served by nonstop shipping scheme.

(ii) Nonthrough shipment cost, which includes the reclassified time in the itinerary and loading and unloading time

$$F_2 = \sum_{k \in V(s)} N_{st} \overline{\overline{w}}_{st} x_{st}^k + \sum_{k \in V(s)} \sum_{g \in G(k,t)} N_{st} t_g x_{st}^k, \tag{12}$$

where

$\overline{\overline{w}}_{st}$ is loading and unloading time at the origin and destination for a wagon shipped by non-through shipment;

t_g is reclassified time at technical station g;

$G(k,t)$ is set of technical stations in the itinerary after N_{st} has been reclassified at technical station k, and $g \in G(k,t)$.

(iii) The wagon flow is shipped to a technical station in the itinerary by nonstop shipping scheme. This item includes the reclassified time consumption in the itinerary and time consumption for loading and unloading

$$F_3 = \sum_{k \in P(s)} N_{st} \overline{w}_{st} y_{st}^k + \sum_{k \in P(s)} \sum_{g \in G(k,t)} N_{st} t_g y_{st}^k, \tag{13}$$

where

$\overline{w}_{st}$ is loading and unloading time at the origin and destination for a wagon shipped to a technical station in the itinerary by nonstop shipping scheme.

Then, the total time consumption for N_{st} can be formulated as

$$F_{st} = F_1 + F_2 + F_3. \tag{14}$$

The objective function of wagon flow organization can be stated as

$$\min \sum_{s \in S} \sum_{t \in Q(s)} F_{st}, \tag{15}$$

where S is set of origin stations and $s \in S$. $Q(s)$ is set of destinations of the wagon flows that originate from s. And $Q(s) = \{t : N_{st} \neq 0\}$. $t \in Q(s)$.

3.2.5. Constraints. The wagon flow organization problem has two constrains.

(1) Loading and Unloading Capacity Constraint for Nonstop Train. The loading and unloading capacity must reach the minimum size of loading or unloading a whole nonstop train. If there are several wagon flows consolidated together to be shipped to a technical station in the itinerary by nonstop shipping scheme, the sum of their loading or unloading capacity must reach the average marshaling number of wagons in a nonstop shipping scheme

$$\overline{m}_{st} I\left(\sum_{t \in Q(s)} y_{st}^k\right) - \sum_{t \in Q(s)} m_{st} y_{st}^k \leq 0 \quad \forall s \in S,\ k \in P(s), \tag{16}$$

where

m_{st} is the smaller one between maximum loading capacity of station s and maximum unloading capacity of station t at certain period;

$\overline{m}_{st}$ is the average marshaling number of wagons in nonstop shipping scheme;

$I(x)$ is a step function, $I(x) = \begin{cases} 1 & \text{if } x > 0 \\ 0 & \text{otherwise} \end{cases}$.

(2) Each Wagon Flow Is Served by One and Only One Train Service.

$$I_{st} x_{st} + \sum_{k \in V(s)} x_{st}^k + \sum_{k \in P(s)} y_{st}^k = 1 \quad \forall s \in S, \quad t \in Q(s), \tag{17}$$

where $I_{st} = \begin{cases} 1 & \text{if } m_{st} \geq \overline{m}_{st} \\ 0 & \text{otherwise} \end{cases}$ $\forall s \in S$, $t \in Q(s)$, which ensures that only the wagon flow that reaches the average marshaling number of wagon in nonstop shipping scheme can be shipped by it.

3.2.6. Constraint Linearization. Constraint (16) can be linearized by introducing a variable y_{sk}

$$y_{sk} = I\left(\sum_{t \in Q(s)} y_{st}^k\right) = \begin{cases} 1 & \sum_{t \in Q(s)} y_{st}^k > 0 \\ 0 & \text{otherwise} \end{cases} \quad \forall s \in S, \quad k \in P(s). \tag{18}$$

Then constraint (16) can be formulated as follows:

$$\overline{m}_{st} y_{sk} - \sum_{t \in Q(s)} m_{st} y_{st}^k \leq 0 \quad \forall s \in S,\ k \in P(s). \tag{19}$$

Constraint (20) is also introduced to ensure that y_{sk} equals 1 if and only if $y_{st}^k = 1$

$$M y_{sk} \geq \sum_{t \in Q(s)} y_{st}^k \quad \forall s \in S,\ k \in P(s), \tag{20}$$

where M is a large positive constant.

3.2.7. Mathematical Model. The wagon flow organization model can be stated as

(M-II)

$$\min \sum_{s\in S}\sum_{t\in Q(s)} F_{st}$$

$$\begin{aligned}
\text{s.t.}\quad & I_{st}x_{st} + \sum_{k\in V(s)} x_{st}^k + \sum_{k\in P(s)} y_{st}^k = 1 \qquad \forall s\in S,\ t\in Q(s) \\
& \overline{m}_{st}y_{sk} - \sum_{t\in Q(s)} m_{st}y_{st}^k \le 0 \qquad \forall s\in S,\ k\in P(s) \\
& My_{sk} \ge \sum_{t\in Q(s)} y_{st}^k \qquad \forall s\in S,\ k\in P(s) \\
& x_{st}, x_{st}^k \in \{0,1\} \qquad \forall s\in S,\quad t\in Q(s), \quad k\in V(s) \\
& y_{sk}, y_{st}^k \in \{0,1\} \qquad \forall s\in S,\quad t\in Q(s), \quad k\in P(s).
\end{aligned} \tag{21}$$

4. Solution Algorithm

Tabu search (TS) [30, 31] uses the tabu list to record the information of local optimal solutions, which can help to enlarge the search space and avoid the locally optimal solutions. The adaptive clonal selection algorithm (ACSA) [32–34] is shown to be an evolutionary strategy capable of high convergence rate and diversified. In this section, TS and ACSA are combined into a new heuristics method, called T-ACSA, to solve the proposed models.

4.1. The Detail Techniques of T-ACSA

4.1.1. Affinity Measure. Affinity measure of the algorithm is the objective of the model; the smaller the better. In order to extend the space of solution, the algorithm accepts solutions which fail to satisfy the constraints. However, penalty coefficient will be added to the affinity measure.

4.1.2. The Design of Antibody. The antibody of model M-I is designed as follows.

The length of antibody is equal to the amount of customers in I. The codes in antibody are in J, and the amount of codes is p. To better understand the antibody, a simple example consisting of seven customers and four service points is proposed. p equals three (see Figure 3). Service point 2 is not included in the antibody, which means that it is not chosen as a service point.

The antibody of model M-II is designed as follows.

According to the optimal result of model M-I, the antibody of each service point can be designed. A piece of antibody is proposed (see Figure 4).

The number of y_{st}^k in each piece is decided by the amount of technical stations in $P(s)$ in the itinerary $s \rightarrow t$, which can be obtained when the route is set. The sum value of each piece is 1. The pieces are separated between each other. And their amount equals the number of wagon flows.

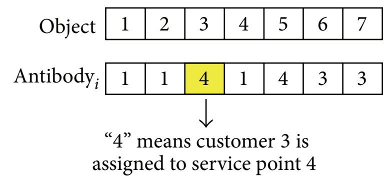

Figure 3: The design of antibody for M-I.

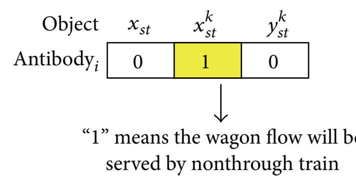

Figure 4: One piece of antibody for M-II.

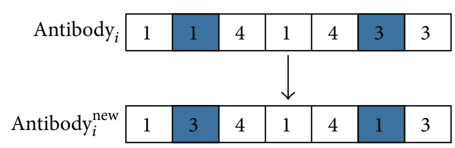

Figure 5: Neighborhood search operation of model M-I.

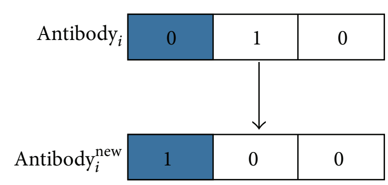

Figure 6: Neighborhood search operation of model M-II.

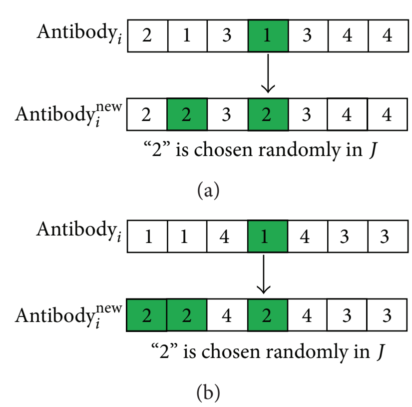

Figure 7: The mutation operation of model M-I.

4.1.3. Neighborhood Search Operation. The neighborhood search operation of model M-I is as follows: choose two positions in the antibody randomly and exchange the values. The neighborhood search operation of the antibody in Figure 3 is shown in Figure 5.

TABLE 1: The investment for each candidate station.

Candidate point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
C_j	150	300	170	160	210	170	200	230	180	210	150	60	110	250	180	50

Unit: ten thousand CNY.

TABLE 2: The parameters of model M-I and T-ACSA.

	Parameters of model M-I								
	μ_1	μ_2	DC	p	δ	Cap_j	λ	ε	
Value	0.3	0.7	182 (km)	8	200 (km)	1752000 (t)	0.67 (CNY/t)	0.8	
	Parameters of T-ACSA								
	$w_{\max}$	$w_{\min}$	L	D	α	N	H	R	U
Value	8	2	100	18	0.6~0.8	20~30	4~6	10~15	8

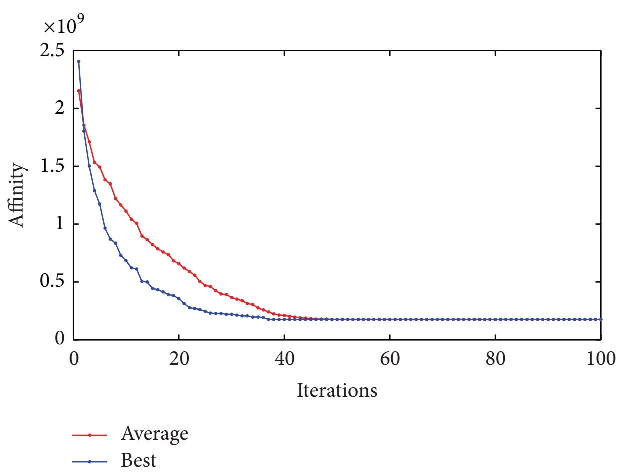

FIGURE 8: The iterative process of T-ACSA for M-I.

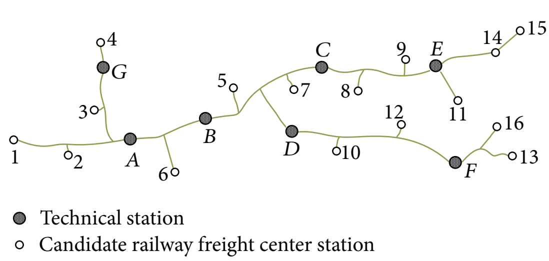

FIGURE 9: The railway network and the location of candidate freight center stations.

The neighborhood search operation of model M-II is as follows: choose a piece in antibody randomly. Find a code whose value is 0 and assign it to 1. Change the other codes into 0. The other pieces of antibody remain the same. The neighborhood search operation of the antibody in Figure 4 is shown in Figure 6.

4.1.4. Mutation Operation. Mutation operation of model M-I is shown in Figure 7: the maximum number of codes is

TABLE 3: The reclassified time consumption at a technical station.

Technical station	t_A	t_B	t_C	t_D	t_E	t_F	t_G
t_g	4	6	4.5	5	4	5	4.5

Unit: car hour.

TABLE 4: The wagon flows between railway freight center stations.

Origin	Destination					Sum of wagon flows
	3	5	6	13	14	
3	—	24	8	42	21	95
5	14	—	20	41	22	97
6	23	7	—	14	40	84
13	19	28	15	—	25	87
14	28	7	6	34	—	75

four. If the amount of the chosen candidate points reaches the maximum, choose a code e in the antibody randomly. Change both e and the codes whose value is the same as e (see Figure 7(a)). Else choose a code e and change its value randomly (see Figure 7(b)).

The mutation operation of model M-II is the same as the neighborhood search operation.

4.1.5. TS Operation. The tabu strategy is first in first out. The length of tabu list is H; the search times are R. The number of the candidate solutions is U. TS operation procedure is as follows.

Step 1. Choose an antibody and set it as the current solution. Initialize the tabu list and the best solution.

Step 2. Use the neighborhood search operation to update the current solution and generate U candidate solutions. Then sort them by the affinity measure values. Choose the best solution.

Step 3. Judge whether the best solution is tabued. If it is tabued, go to Step 2. Else judge whether the length of tabu list reaches H. If not, add the best solution into the tabu list and tabu it. Else remove the tabu information of the first solution

Table 5: The parameters of model M-II and T-ACSA.

	Parameters of model M-II								
	w_{st}	$\overline{w}_{st}$	$\overline{\overline{w}}_{st}$	$\overline{m}_{st}$	m_{st}				
Value	20 (car hour)	15 (car hour)	12 (car hour)	40	40				
	Parameters of T-ACSA								
	$w'_{\max}$	$w'_{\min}$	L'	D'	α'	N'	H'	R'	U'
Value	6	2	50	10	0.6~0.8	16~20	4	5~15	6

Table 6: The optimal result of wagon flow organization.

Origin	Destination				
	3	5	6	13	14
3	—	$y^B_{3,5} = 1$	$x^A_{3,6} = 1$	$x_{3,13} = 1$	$y^B_{3,14} = 1$
5	$x^B_{5,3} = 1$	—	$x^B_{5,6} = 1$	$x_{5,13} = 1$	$x^C_{5,14} = 1$
6	$x^A_{6,3} = 1$	$x^B_{6,5} = 1$	—	$x^B_{6,13} = 1$	$x_{6,14} = 1$
13	$y^B_{13,3} = 1$	$y^D_{13,5} = 1$	$y^B_{13,6} = 1$	—	$y^D_{13,14} = 1$
14	$y^B_{14,3} = 1$	$x^E_{14,5} = 1$	$y^B_{14,6} = 1$	$x^E_{14,13} = 1$	—

in the tabu list and add the best solution into the tabu list. Go to Step 4.

Step 4. Judge whether the current best solution is the best one in the history. If not, go to Step 5. Else set it as the best one in the history. Go to Step 5.

Step 5. Judge whether the search times reach R. If not, go to Step 2. Else update the antibody with the best solution in the history.

4.2. The Process of T-ACSA. Based on the aforementioned detailed analysis, T-ACSA approach is designed as follows.

Step 1. Initialize the population of antibody. Generate N antibodies and constitute the species group P.

Step 2. Count the affinities and sort the antibodies according to their affinities in an ascending order.

Step 3. Clone each antibody in P then get a new species group C. The number of clone is $n_i = [w_{\max}(1-((i-1)/N))]$ and $n_i \geq w_{\min}$, where i is the order of the antibody after sorting. $w_{\max}$ is the maximum clone number and $w_{\min}$ is the minimum clone number.

Step 4. Apply the TS operation to update each antibody in C and get the new species group C'.

Step 5. Use mutation operation to update each antibody in C'. And get the new species group C''. The probability of mutation is inversely proportional to the evolution generation $\varphi_l = [\alpha(1-(l/L))]$. Where α is the coefficient, l is the current generation and L is the maximum generation.

Step 6. Choose the first d_l antibodies in C'' and replace the worst d_l antibodies in P by them; $d_l = [(\overline{f} - f_{\min})(D/\overline{f})]$. Where D is the coefficient, $\overline{f}$ is the average value of affinities in C'' and $f_{\min}$ is the minimum value of affinities in C''.

Step 7. If current status does not meet the terminal condition (the maximum searching times), go to Step 2. Otherwise, go to Step 8.

Step 8. Output the best solution, that is, the optimal location of service points or the wagon flow organization.

5. Numerical Experiments

The models and algorithm are tested by a railway network with 48 railway freight stations. Station 1 to station 16 is candidate freight center stations. The parameters of this physical network are provided in Tables 7 and 8, which include the distance information and the transport demand of each customer. Table 1 shows the investment to locate a center station at the candidate sites. Parameters of M-I model and T-ACSA are shown in Table 2.

We test the algorithm ten times by different combination of parameters. The best affinity value of objective function is 176776352.8 CNY. And the final location plan is 3, 5, 6, 13, and 14. The assignments for the forty-eight freight stations are 3, 3, 3, 3, 5, 6, 5, 5, 14, 6, 13, 13, 13, 14, 14, 13, 3, 3, 3, 3, 3, 5, 5, 5, 6, 5, 6, 5, 6, 6, 6, 5, 5, 5, 6, 13, 6, 14, 14, 6, 13, 14, 13, 13, 13, 14, 14, and 13. The iterative process of the algorithm is shown in Figure 8.

For the second step, we can plan wagon flow organization with outputs of model M-I, such as the location of freight center stations, the transport volume between each center station. Assuming the average loaded weight of a rail wagon is 50 t, and the stations operate for 365 days per year. Then the total transport demand can converted into daily transport volume. The average volumes of railway freight center station 3, 5, 6, 13, and 14 are 95, 97, 84, 87, and 75, respectively. The railway network and the location of railway freight center stations are shown in Figure 9. The reclassified time

Table 7: The distance between customer and service point.

Customer	The candidate service point															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	119	133	196	278	292	348	403	536	415	561	521	602	704	762	741
2	119	0	60	156	159	182	229	284	417	329	443	422	489	585	643	630
3	133	60	0	96	170	218	237	290	421	378	457	461	513	588	646	657
4	196	156	96	0	223	292	277	324	445	461	494	531	564	605	662	708
5	278	159	170	223	0	89	70	125	258	260	288	311	345	426	484	489
6	292	182	218	292	89	0	113	153	273	174	278	243	310	435	492	449
7	348	229	237	277	70	113	0	55	188	257	221	277	287	356	414	431
8	403	284	290	324	125	153	55	0	133	267	170	261	245	301	359	388
9	536	417	421	445	258	273	188	133	0	331	77	269	179	168	226	300
10	415	329	378	461	260	174	257	267	331	0	293	128	263	457	506	370
11	561	443	457	494	288	278	221	170	77	293	0	209	102	165	219	228
12	521	422	461	531	311	243	277	261	269	128	209	0	147	358	401	242
13	602	489	513	564	345	310	287	245	179	263	102	147	0	216	255	144
14	704	585	588	605	426	435	356	301	168	457	165	358	216	0	58	254
15	762	643	646	662	484	492	414	359	226	506	219	401	255	58	0	262
16	741	630	657	708	489	449	431	388	300	370	228	242	144	254	262	0
17	54	173	183	233	332	344	402	457	590	458	614	569	654	758	816	792
18	71	48	77	163	207	225	277	332	465	361	491	461	534	633	691	675
19	252	222	162	66	273	349	319	360	472	521	528	584	605	626	680	748
20	219	184	124	28	243	316	294	338	456	486	507	553	581	613	669	724
21	172	124	64	32	202	266	260	310	435	433	480	507	546	598	655	690
22	158	104	44	52	190	250	252	302	430	415	472	492	535	594	651	679
23	172	53	80	165	106	138	176	231	364	299	391	381	440	532	590	582
24	240	121	135	197	38	97	108	163	296	270	325	334	378	464	522	522
25	279	161	180	240	24	65	74	127	259	237	282	291	334	427	485	477
26	306	187	196	244	28	93	42	97	230	257	261	296	321	398	456	465
27	327	209	225	277	56	78	36	82	212	228	235	261	290	379	437	434
28	352	234	229	252	86	156	50	74	195	307	242	324	320	359	417	462
29	284	170	199	267	59	30	92	138	265	203	278	264	319	430	488	461
30	311	211	255	335	139	50	156	187	293	126	285	211	300	448	504	434
31	337	223	252	317	97	48	87	114	226	172	230	214	266	387	444	407
32	405	287	285	307	131	180	68	40	139	306	191	300	275	304	361	415
33	413	298	286	292	154	218	105	90	161	354	224	350	316	314	370	452
34	451	332	337	367	173	195	103	48	85	285	128	256	214	253	311	353
35	354	249	287	360	147	69	141	159	252	117	239	173	252	403	458	387
36	506	387	392	417	228	245	158	103	30	313	89	261	188	198	256	317
37	388	296	341	421	216	131	212	225	298	45	268	136	253	433	484	372
38	584	465	469	490	306	319	236	181	48	363	79	287	174	120	178	278
39	556	437	444	470	279	287	209	154	27	331	56	259	157	149	207	274
40	452	360	405	483	273	192	257	258	304	46	259	82	220	419	467	324
41	487	391	432	507	290	215	264	256	284	88	231	40	182	387	432	282
42	649	530	533	552	371	382	301	246	113	412	119	322	189	55	113	258
43	572	457	478	524	309	282	247	203	135	260	60	159	45	200	246	184
44	546	437	468	527	305	255	256	226	202	190	135	78	73	280	323	196
45	650	536	558	605	389	358	328	283	196	311	122	191	50	191	221	106
46	707	588	598	624	430	427	361	307	179	425	148	316	170	62	85	192
47	711	594	607	639	438	426	370	318	197	408	151	294	147	102	117	152
48	698	584	604	647	434	407	371	324	223	359	156	237	100	176	194	82

Unit: km.

Table 8: The transport demand of each customer.

Customer	1	2	3	4	5	6	7	8	9	10
Demand	219000	109500	197100	262800	219000	153300	131400	262800	438000	175200
Customer	11	12	13	14	15	16	17	18	19	20
Demand	306600	219000	109500	131400	175200	262800	438000	175200	219000	175200
Customer	21	22	23	24	25	26	27	28	29	30
Demand	328500	219000	219000	175200	131400	153300	394200	109500	219000	109500
Customer	31	32	33	34	35	36	37	38	39	40
Demand	175200	262800	262800	153300	109500	240900	284700	438000	197100	131400
Customer	41	42	43	44	45	46	47	48	—	—
Demand	175200	350400	219000	131400	175200	175200	21900	131400	—	—

Unit: ton per a year.

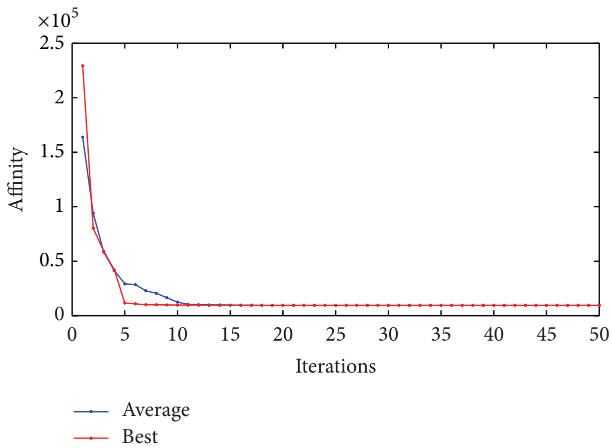

Figure 10: The iterative process of T-ACSA for M-II.

at technical stations is listed in Table 3. The wagon flows between railway freight center stations are shown in Table 4. And the parameters of model M-II and T-ACSA are shown in Table 5.

We test the algorithm five times by different combination of parameters. The final result of wagon flow organization is shown in Table 6. The iterative process of the algorithm is shown in Figure 10.

To verify the algorithm, we solved the models M-I and M-II by ILOG Cplex at the same time. The final results of the present algorithms and Cplex are the same. The run time of models M-I and M-II is less than 2 s and 1 s.

6. Conclusion

A two-stage programming is proposed to describe and solve the location of railway freight center stations and wagon flow organization problem. The first stage determines the optimal location with the objective to minimize the total cost of service and investment. The second stage optimizes the wagon flow organization among different stations. Different from the research in literature, the first model considered the coverage distance constraint and the change of transport demand. The second model analyzed the cost of different schemes. A heuristic algorithm that combines TS with ACSA is designed. The numerical example of a network with 48 stations demonstrates that the method is workable.

While the microoperations in wagon flow organization, like wagon flow route decision and the supply of empty wagons, have not been considered in the scheduling process, these aspects can be considered in the future research.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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