Research Article

Multiperiod Hierarchical Location Problem of Transit Hub in Urban Agglomeration Area

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With the rapid urbanization in developing countries, *urban agglomeration area* (UAA) forms. Also, transportation demand in UAA grows rapidly and presents hierarchical feature. Therefore, it is imperative to develop models for transit hubs to guide the development of UAA and better meet the time-varying and hierarchical transportation demand. In this paper, the multiperiod hierarchical location problem of *transit hub in urban agglomeration area* (THUAA) is studied. A hierarchical service network of THUAA with a multiflow, nested, and noncoherent structure is described. Then a multiperiod hierarchical mathematical programming model is proposed, aiming at minimizing the total demand weighted travel time. Moreover, an improved adaptive clonal selection algorithm is presented to solve the model. Both the model and algorithm are verified by the application to a real-life problem of Beijing-Tianjin-Hebei Region in China. The results of different scenarios in the case show that urban population migration has a great impact on the THUAA location scheme. Sustained and appropriate urban population migration helps to reduce travel time for urban residents.

1. Introduction

In the process of rapid urbanization in developing countries, regional spatial structure experiences tremendous changes, especially with the development of *urban agglomeration area* (UAA). On the one hand, because of the increasing close connection between cities in UAA, intercity passenger demand grows rapidly and presents hierarchical features from the aspects of travel distance and travel space. Also, more convenient transport service is required by passengers. On the other hand, the development of UAA is uncoordinated and meets challenges. More specifically, some megacities develop fast but face conflicts between their growing population and decreasing urban carrying capacity, while some small and medium-sized cities have low proportion of urban residents and their developments lag behind. Therefore, it is required to intensify the transportation network, promote the distribution of key industries and public resources, and shift away some of the megacities' functions and population, so as

to help small and medium-sized cities to develop industries and attract residents to UAA.

In addition, it is demonstrated that transit hubs have the potential to drive the development of their surrounding areas. Thus, it is necessary to study the hierarchical location problem of *transit hub in urban agglomeration area* (THUAA), which contributes to accommodating the hierarchical feature of *passenger demand in urban agglomeration area* (PDUAA) and coordinating the development of UAA. Moreover, the location problem of THUAA is a long-term planning. Transportation network and passenger demand in the process of rapid urbanization are constantly changing. The hubs are hard to rebuild due to its huge resource consumption and political impacts. Considering all these, it is imperative to make overall plan for *the multiperiod hierarchical location problem* (MHLP) of THUAA.

MHLP of THUAA studied in this paper is a strategic planning. The planning horizon is divided into several time periods. It decides which hierarchy a city or an administrative

district should be in each specific period. The goal is to maximize the accessibility of population to get transportation services in a UAA. Therefore, it does not involve the detailed location problem of stations.

The main contributions of this paper are (i) a hierarchical service network of THUAA with a multifold, nested and noncoherent structure; (ii) a mathematical programming model and a solution algorithm for MHLP of THUAA; and (iii) application to a real-life problem in China to meet changes in the process of rapid urbanization.

The remainder of this paper is organized as follows. Section 2 reviews the related hierarchical and multiperiod facility location problem literatures. Section 3 defines the hierarchical service network of THUAA. Section 4 presents the optimization model. Section 5 proposes a solution method to solve the model. In Section 6 the model is applied to a real-life case of Beijing-Tianjin-Hebei Region in China. Finally, main findings and future work directions are summarized in Section 7.

2. Literature Review

In the context of rapid urbanization, the system of THUAA is multilevel so as to provide hierarchical service for various passengers. However, the hierarchical feature of THUAA system has been neglected in most researches. Furthermore, the multiperiod nature of the hierarchical location problem of THUAA attracted few attention. According to the previous definitions, the location problem of THUAA can be viewed as a facility location problem. Therefore, the hierarchical and multiperiod facility location models can be applied to MHLP of THUAA, which are reviewed as follows.

There has been a rich body of literatures about *hierarchical facility location problem* (HFLP), as seen in the recent reviews [1, 2]. The HFLP models are now mainly employed in the following areas: health care system [3–5], education system [6], disaster management [7, 8], solid waste management [9], and telecommunications network [10, 11], and so forth. However, the HFLP models have not been applied in the location problem of THUAA. Exact solution methods, such as branch-and-bound [12], are utilized to solve HFLPs. With the increasing size and complexity of real-life HFLPs, nonexact solution methods have also been proposed (e.g., approximation algorithm [13, 14], tabu search [15]).

As a kind of dynamic facility location models (see the review [16]), multiperiod facility location model divides the planning horizon into several time periods, which helps to better deal with the time-varying parameters [17]. Till now, a large number of researches have been done on multiperiod facility location models [18–21]. However, there are few literatures involving multiperiod HFLP models. Hinojosa et al. [22] presented a mix integer programming model to address the location-allocation problem of the production plants and intermediate warehouses in different time periods. The model was solved by Lagrangian relaxation combined with a heuristic procedure. Wang et al. [23] addressed the location problem of regional distribution centers and stores in a distribution system across several time periods. A genetic

FIGURE 1: The hierarchical structure of PDUAA.

algorithm based heuristic was utilized to solve the problem. Antunes et al. [24] proposed a multiperiod hierarchical location model for urban hierarchy planning, aiming at minimizing the total demand weighted travel time for the residents to get service from different-level facilities during several time periods. Pehlivan et al. [3] studied the adjustment of hierarchical perinatal network, that is, when and where to locate different-level maternity facilities. The objective of the model is to minimize the total cost. Also, the service quality of each facility is ensured above a given level.

The preceding analyses show that multiperiod HFLP modeling needs more researches and the solution methods for solving large-size problems in realistic situations should be paid more attention. Therefore, the application of multiperiod HFLP models to MHLP of THUAA is innovative and has practical significance.

3. Problem Description

In the process of rapid urbanization, PDUAs form a hierarchical system (see Figure 1), and so are the THUAs (see Figure 2). In addition, different-level THUAs serve different-level PDUAs (see Figure 2).

The hierarchical structure of PDUAA is presented in Figure 1. According to the travel distance and the travel space, PDUAs are divided into 3 levels of demands, in which the intercity short-distance and middle-distance travel are called level-1 demand, the external middle-distance travel is called level-2 demand, and the external long-distance travel is called level-3 demand.

Figure 2 presents the hierarchical structure of THUAA and the demands served by different-level hubs. THUAA

FIGURE 2: The hierarchical structure of THUAA and the demands served by different-level hubs.

system consists of 3 levels of hubs. Different-level hubs provide different-level services. More specifically, level-3 hub provides all services (i.e., it can serve all demands). Level-2 hub provides level-2 service and level-1 service (i.e., it can serve level-2 demand and level-1 demand). Level-1 hub provides level-1 service (i.e., it can only serve level-1 demand).

The essence of MHLPP of THUAA can be explained as follows: (i) in a given UAA, the transportation network and passenger demand are known, and the planning horizon is divided into several time periods; (ii) a hub can only serve the demands in its coverage area; and (iii) the target is to choose appropriate administrative districts or cities for different-level hubs in each period, thus satisfying different-level demands in UAA and minimizing the total demand weighted travel time. As shown in Figure 3, the yellow point, the red point, the blue point, and the gray point represent level-3 hub, level-2 hub, level-1 hub, and demand point, respectively. The coverage area of a hub is marked with a dashed line circle.

According to the previous descriptions, the hierarchical location problem of THUAA is a HFLP with a multiflow, nested, and noncoherent structure (see Figure 4). It is a multiflow system because any lower-level demand can be assigned to any higher-level hub. For instance, level-1 demand of C1 is assigned to a level-2 hub B2. Because higher-level hubs provide more services than lower-level hubs, it is nested. Since the structure is noncoherent, the demand points served by the same hub for their lower-level demands may be served by different hubs for their higher-level demands. For instance, level-1 demands of B0 and C0 are both assigned to B1, while level-3 demands of B0 and C0 are assigned to A3 and B3, respectively.

4. Modeling

4.1. Notation. In order to formulate the model, the following notations are defined.

Sets

H : the set of demand levels (or set of service levels or set of hub levels), $H = \{1, 2, 3\}$

I : the set of demand points

J : the set of candidate hubs

FIGURE 3: The concept about hierarchical location problem of THUAA.

FIGURE 4: The hierarchical service network of THUAA with a multi-flow, nested and noncoherent structure.

T : the set of periods, $T = \{1, 2, 3\}$. More specifically, periods 1, 2, and 3 represent the short-term period, the medium-term period, and the long-term period, respectively

Parameters

L_{ij} : the line distance between demand point i and candidate hub j

d_{ijt} : the shortest travel time between demand point i and candidate hub j in period t

q_{ist} : level- s demand of demand point i in period t

c_h : the minimum quantity of level- h demand served by a level- h hub

C_{jst} : the maximum capacity of level- s service provided by candidate hub j in period t

R_h : the coverage of level- h hub

Decision Variables

x_{ijst} : let x_{ijst} be one if level- s demand of demand point i is served by hub j in period t , zero otherwise.

y_{jht} : let y_{jht} be one if candidate hub j is opened as a level- h hub in period t , zero otherwise.

4.2. Assumptions

- (1) For a demand point, demands at each level are served by only one hub.
- (2) The coverage of hubs at each level and the planning periods are specific.
- (3) The transportation network and different-level demands of each demand point in each period are known.
- (4) The minimum quantity of the highest-level demand served by different-level hubs is a known constant.
- (5) The maximum capacities of different-level services provided by each candidate hub in each period are limited and known.

4.3. Mathematical Formulation. The multiperiod hierarchical location model of THUAA is formulated as follows:

$$\text{Minimize } \sum_{i \in I} \sum_{j \in J} \sum_{s \in H} \sum_{t \in T} d_{ijst} q_{ist} x_{ijst} \quad (1)$$

$$\text{Subject to: } \sum_{j \in J} x_{ijst} = 1 \quad \forall i \in I, s \in H, t \in T \quad (2)$$

$$\sum_{h \in H} y_{jht} \leq 1 \quad \forall j \in J, t \in T \quad (3)$$

$$x_{ijst} \leq \sum_{h \in H | h \geq s} y_{jht} \quad (4)$$

$$\forall i \in I, j \in J, s \in H, t \in T$$

$$\sum_{i \in I} q_{iht} x_{ijst} \geq c_h y_{jht} \quad (5)$$

$$\forall j \in J, h \in H, t \in T$$

$$\sum_{i \in I} q_{ist} x_{ijst} \leq \sum_{h \in H | h \geq s} C_{jst} y_{jht} \quad (6)$$

$$\forall j \in J, s \in H, t \in T$$

$$\sum_{h \in H | h \geq s} y_{jht} R_h \geq x_{ijst} L_{ij} \quad (7)$$

$$\forall i \in I, j \in J, s \in H, t \in T$$

$$y_{jh(t-1)} \leq \sum_{k \in H | k \geq h} y_{jkt} \quad (8)$$

$$\forall j \in J, h \in H, t \in \{2, 3\}$$

$$x_{ijst} \in \{0, 1\},$$

$$y_{jht} \in \{0, 1\} \quad (9)$$

$$\forall i \in I, j \in J, h \in H, s \in H, t \in T.$$

The objective function (1) minimizes the total demand weighted travel time in the planning horizon. Constraints (2) ensure that all demands in each period are satisfied. Constraints (3) represent that different-level hubs cannot be located at the same candidate hub in each period. Constraints (4) impose that demands at each level can only be served by a hub of equal or higher level in each period. Constraints (5) enforce that the highest-level demand served by a hub in each period exceeds the minimum quantity. Constraints (6) state that different-level demands served by a hub in each period do not exceed the maximum capacity. Constraints (7) limit that a hub can only serve the demand points in its coverage area. Constraints (8) guarantee that a hub cannot be downgraded once it is opened. Constraints (9) are the binary constraints for the variables.

5. Solution Method: Improved Adaptive Clonal Selection Algorithm (IACSA)

Adaptive clonal selection algorithm (ACSA) [25, 26] is widely used because of its fast convergence. Simulated annealing (SA) [27] is a parallel and global optimization algorithm, not depending on the initial population. Considering the feature of the encoding and decoding for the MHLPP model, improved adaptive clonal selection algorithm (IACSA) is put forward, in which the idea of SA is introduced into ACSA, thus ensuring global optimization and fast convergence.

5.1. The Procedure of IACSA. In immunology, clone means asexual propagation. A clone refers to one or more offspring derived from a single ancestor, whose genetic composition is identical to that of the ancestor. In IACSA, (i) an antibody represents a solution; (ii) affinity measures the fitness of an antibody; and (iii) antibody population is a group of solutions. As is shown in Figure 5, the steps of IACSA are as follows.

Step 1 (initialization). M feasible antibodies are generated randomly, composing the initial antibody population P .

Step 2 (evaluation). The affinities of the antibodies in P are calculated according to the affinity function and then are sorted in descending order.

Step 3 (clonal proliferation). Each antibody in P is cloned and then an antibody population C is formed.

Step 3.1. The antibody in P is cloned by neighborhood search. The clonal factor of an antibody (i.e., the number of clones created for an antibody) is proportional to its affinity. Namely, an antibody with a higher affinity will have a higher clonal factor.

FIGURE 5: The procedure of IACSA.

Step 3.2. $\Delta c = C(m') - C(m)$ is defined to compare the affinity of a clone $C(m')$ with that of its ancestor $C(m)$. Specifically, the idea of SA is introduced to use probability proportion to accept the worse clones, thus expanding the search space and preventing premature. According to the Metropolis acceptance criteria (i.e., an acceptance theory based on probability): if $\Delta c \leq 0$, the ancestor is replaced by the clone; otherwise, the clone is accepted with probability $\exp(-\Delta c/C(m))$.

Step 3.3. Steps 3.1 and 3.2 are repeated M times to form an antibody population C .

Step 4 (hypermutation). A new antibody population C^* is generated by the hypermutation operation.

Step 5 (clonal selection). Select the antibodies whose affinities rank in the top b from C^* to replace the antibodies whose affinities rank in the bottom b in P .

Step 6 (termination test). If termination criterion is met, stop and output the antibody with the highest affinity in P ; otherwise, go to Step 3.

5.2. The Detail of IACSA. The detailed design of IACSA is as follows.

(1) *Encoding and Decoding.* Integer encoding is used. Each antibody is composed of 9 fragments. Each fragment of an antibody represents the serial numbers of hubs which serve different-level demands of each demand point in each period. For example, in Figure 6, level-1 and level-2 demands of demand point 1 are both served by hub 1 in period 1, while level-3 demand of demand point 1 is served by hub 2 in period 1.

Moreover, each antibody is divided into 3 parts by period. The hub level in each period can be judged by each part of the antibody. Firstly, a hub which serves level-3 demand is judged as a level-3 hub. Secondly, a hub serves level-2 demand but no

FIGURE 6: Encoding of solution.

FIGURE 7: The population and urban residents proportion of cities in Beijing-Tianjin-Hebei Region in 2014.

FIGURE 8: The population of each administrative district in Beijing in 2014.

level-3 demand is judged as a level-2 hub. Finally, a hub serves only level-1 demand is judged as a level-1 hub. For instance, Figure 6 shows that (i) in period 1, hubs 2 and 4 are both level-3 hubs, while hubs 0 and 1 are both level-2 hubs and hub 3 is a level-1 hub; (ii) in period 2, hubs 0, 2, and 4 are all level-3 hubs, while hub 1 and hub 3 are level-2 hub and level-1 hub, respectively; and (iii) in period 3, hubs 0, 2, and 4 are all level-3 hubs, while hubs 1 and 3 are both level-2 hubs.

(2) *Initialization.* Because different-level demands are served by different-level hubs, each gene of the antibody is generated according to the corresponding candidate hub set. More specifically, level-3 demand can be served by level-3 candidate hubs. Level-2 demand can be served by level-2 and level-3 candidate hubs. Level-1 demand can be served by all candidate hubs. Firstly, a candidate hub is selected randomly from the corresponding candidate hub set for each gene in period 1. Then the antibody fragments of period 1 are copied to periods 2 and 3, respectively. Thus, an initial antibody is formed.

(3) *Affinity Function.* According to the above encoding and initialization method, constraints (2), (3), (4), and (9) are all satisfied. Constraints (8) are judged whether it is satisfied when a new antibody is generated. Therefore, constraints

(5), (6), and (7) are dealt with the penalty function method, adding to the objective function. Q is a large constant. δ_1 , δ_2 , and δ_3 are penalty factors. The affinity function F is shown in

$$\begin{aligned}
 F = Q & \left\{ \sum_{i \in I} \sum_{j \in J} \sum_{s \in H} \sum_{t \in T} d_{ijt} q_{ist} x_{ijst} \right. \\
 & + \delta_1 \sum_{j \in J} \sum_{h \in H} \sum_{t \in T} \max \left\{ 0, c_h y_{jht} - \sum_{i \in I} q_{iht} x_{ijht} \right\} \\
 & + \delta_2 \sum_{j \in J} \sum_{s \in H} \sum_{t \in T} \max \left\{ 0, \sum_{i \in I} q_{ist} x_{ijst} - \sum_{h \in H | h \geq s} C_{jst} y_{jht} \right\} \\
 & \left. + \delta_3 \sum_{i \in I} \sum_{j \in J} \sum_{s \in H} \sum_{t \in T} \max \left\{ 0, x_{ijst} L_{ij} - \sum_{h \in H | h \geq s} y_{jht} R_h \right\} \right\}^{-1}.
 \end{aligned} \quad (10)$$

(4) *Clonal Factor.* The clonal factor of the antibody whose affinity ranks number r is defined as $a_r = A(1 - r/N)$. Moreover, it is limited that $a_r \geq a_0$. A and a_0 are the maximum and minimum clonal factors, respectively. N is the maximum number of iterations.

FIGURE 9: The population of each administrative district in Tianjin in 2014.

(5) *Mutation Rate*. The mutation rate is defined as $\varepsilon = \varepsilon_{\max}(1 - n/N)$. Moreover, it is limited that $\varepsilon > \varepsilon_{\min}$. $\varepsilon_{\max}$ and $\varepsilon_{\min}$ are the maximum and minimum mutation rates, respectively. n is the number of current iterations. N is the maximum number of iterations.

(6) *Mutation Operation*. A gene in each fragment of an antibody is selected randomly. A random number λ between 0 and 1 is generated. The current gene is replaced if $\lambda < \varepsilon$; otherwise it remains itself.

(7) *Selection Pool Size and Remainder Replacement Size*. Selection pool size and remainder replacement size are both defined as b . More specifically, $b = B(1 - n/N)$. Moreover, it is limited that $b > b_0$. B and b_0 are the maximum and minimum sizes, respectively. n is the current iteration. N is the maximum number of iterations.

(8) *Termination Criteria*. The algorithm terminates when the number of iterations reaches the predefined maximum number.

FIGURE 10: The spatial development pattern of Beijing-Tianjin-Hebei Region.

6. Case Study

This section applies the model to a real-life problem of Beijing-Tianjin-Hebei Region in China. Beijing-Tianjin-Hebei Region is an important UAA in China. However, the development of Beijing-Tianjin-Hebei Region is not coordinated enough. In Figure 7, the population and urban residents proportion of cities in Beijing-Tianjin-Hebei Region in 2014 are presented, which show that the population and urban residents proportion of Beijing and Tianjin are much higher than those of other cities.

Figure 8 presents the population of each administrative district in Beijing in 2014. It can be seen that the population in the central area is much higher than that of suburban districts. More specifically, Beijing is facing great pressure of population, which needs functional dispersal and decentralization population in the future. Figure 9 presents the population of each administrative district in Tianjin in 2014. The center of Tianjin has high population density, while the population of Binhai and other suburban areas in Tianjin are small.

In the future, Beijing-Tianjin-Hebei Region will be developed in the light of the spatial pattern presented in Figure 10. Moreover, intercity rail will be constructed according to the planning described in Figure 11.

6.1. *Data*. The administrative districts in Beijing (see Figure 8), the administrative districts in Tianjin (see Figure 9), and the other 11 cities in Beijing-Tianjin-Hebei Region (see Figure 7) are considered as both demand points and candidate hubs. Periods 1~3 represent the short-term period (year

FIGURE 11: Intercity rail planning of Beijing-Tianjin-Hebei Region (years 2014~2030).

TABLE 1: The results comparison between IACSA and CPLEX.

The number of areas in UAA	Objective function value			Computational time (s)	
	Z_{CPLEX}	Z_{IACSA}	Gap (%)	CPLEX	IACSA
38	83523	83635	0.1	952.6	12.3
300	3652384	3681603	0.6	42485.7	1845.1

2015~2020), the medium-term period (year 2020~2025), and the long-term period (year 2025~2030), respectively. The data source and the value of the parameters are shown as follows:

L_{ij} : it is measured in arcGIS; see Table 2 in Appendix.

R_h : R_1 is defined as 70 km. R_2 is defined as 150 km. R_3 is defined as 300 km.

c_h : it is estimated according to the passenger transport volume of Beijing-Tianjin-Hebei Region from China's Urban Statistical Yearbooks in the recent years. c_1

is defined as 7000 thousand persons annually. c_2 is defined as 3000 thousand persons annually. c_3 is defined as 2500 thousand persons annually.

d_{ijt} : considering the intercity rail planning presented in Figure 11, it is calculated by arcGIS. For example, the travel time between areas in period 1 is presented in Table 3 in Appendix.

q_{ist} : considering the population migration in the future and the increase of urban residents, it is reckoned by the population and trip frequency. For

TABLE 2: Distances between areas in Beijing-Tianjin-Hebei Region (km).

Area	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
1	0	6	10	18	19	20	36	24	36	40	29	29	58	74	76	81	138	140	122	168	114	93	92	164	162	145	101	58	300	160	293	178	451	402	193	226	216	272
2	6	0	18	13	15	18	32	26	43	42	23	25	61	81	80	82	140	142	125	170	117	95	94	166	164	147	108	61	294	154	295	181	445	396	194	230	223	266
3	10	18	0	29	31	24	49	19	30	44	38	43	53	68	72	84	133	135	117	163	109	88	87	159	157	140	95	58	312	172	288	173	462	414	196	222	211	281
4	18	13	29	0	11	18	23	37	60	54	21	24	74	93	92	94	132	140	123	156	122	101	99	171	170	146	120	64	285	145	300	186	436	387	206	242	221	264
5	19	15	31	11	0	16	24	38	61	50	30	15	75	94	94	90	140	148	132	164	128	107	105	178	176	154	122	72	286	146	307	192	437	388	202	244	230	273
6	20	18	24	18	16	0	37	45	48	37	37	23	62	86	81	78	159	161	143	189	136	114	113	185	183	166	113	79	299	159	314	199	450	401	190	231	237	280
7	36	32	49	23	24	37	0	60	78	71	24	36	92	111	110	111	160	157	145	190	137	115	119	186	184	167	138	81	265	125	320	206	416	367	223	260	225	265
8	24	26	19	37	38	45	60	0	26	61	44	51	50	61	87	101	126	127	110	155	102	80	72	151	150	132	88	57	323	183	274	159	474	425	213	237	203	287
9	36	43	30	60	61	48	78	26	0	47	68	68	24	41	42	87	153	155	138	183	130	108	100	179	177	160	88	84	338	198	302	187	488	440	199	192	231	315
10	40	42	44	54	50	37	71	61	47	0	62	44	55	98	73	43	175	177	159	200	151	130	128	201	199	181	125	98	326	186	330	215	477	428	155	223	253	305
11	29	23	38	21	30	37	24	44	68	62	0	43	83	101	101	103	121	129	121	145	113	92	97	163	161	144	129	53	281	141	298	183	431	383	215	251	202	244
12	29	25	43	24	15	23	36	51	68	44	43	0	84	102	102	83	154	161	145	178	144	122	121	193	191	167	130	86	288	148	322	208	439	390	195	252	242	284
13	58	61	53	74	75	62	92	50	24	55	83	84	0	59	21	94	183	184	167	212	159	138	120	208	207	189	97	108	353	213	322	207	504	455	206	180	261	325
14	74	81	68	93	94	86	111	61	41	98	101	102	59	0	50	138	139	146	170	163	144	140	70	165	137	192	34	116	374	234	263	149	524	476	250	160	263	347
15	76	80	72	92	94	81	110	87	42	73	101	102	21	50	0	113	202	204	186	232	179	157	109	228	226	209	88	127	373	233	310	196	524	475	225	153	280	344
16	81	82	84	94	90	78	111	101	87	43	103	83	94	138	113	0	218	220	203	248	195	173	172	244	242	225	168	141	366	226	373	259	517	468	135	267	296	348
17	138	140	133	132	140	159	160	126	153	175	121	154	183	139	202	218	0	11	22	25	16	38	77	42	68	40	116	83	321	181	266	122	457	423	320	298	114	251
18	140	142	135	140	148	161	157	127	155	177	129	161	184	146	204	220	11	0	37	18	31	53	85	36	71	51	123	91	333	193	266	122	467	435	333	298	124	262
19	122	125	117	123	132	143	145	110	138	159	121	145	167	170	186	203	22	37	0	48	20	44	106	72	83	35	144	64	293	153	281	137	443	395	312	313	114	241
20	168	170	163	156	164	189	190	155	183	200	145	178	212	163	232	248	25	18	48	0	45	65	99	30	80	59	138	110	338	198	261	126	463	421	350	302	119	257
21	114	117	109	122	128	136	137	102	130	151	113	144	159	144	179	195	16	31	20	45	0	22	81	57	82	46	119	66	304	164	277	133	455	406	304	308	128	253
22	93	95	88	101	107	114	115	80	108	130	92	122	138	140	157	173	38	53	44	65	22	0	54	80	89	68	126	35	315	175	284	140	466	417	283	307	139	263
23	92	94	87	99	105	113	119	72	100	128	97	121	120	70	109	172	77	85	106	99	81	54	0	103	84	128	47	70	375	235	210	96	526	477	281	238	199	324
24	164	166	159	171	178	185	186	151	179	201	163	193	208	165	228	244	42	36	72	30	57	80	103	0	41	83	134	116	362	222	233	108	482	440	354	284	138	276
25	162	164	157	170	176	183	184	150	177	199	161	191	207	137	226	242	68	71	83	80	82	89	84	41	0	130	103	113	378	238	199	55	528	480	351	231	182	319
26	145	147	140	146	154	166	167	132	160	181	144	167	189	192	209	225	40	51	35	59	46	68	128	83	130	0	168	87	297	157	326	182	425	383	336	359	81	219
27	101	108	95	120	122	113	138	88	88	125	129	130	97	34	88	168	116	123	144	138	119	126	47	134	103	168	0	151	415	275	230	116	566	517	277	147	239	363
28	58	61	58	64	72	79	81	57	84	98	53	86	108	116	127	141	83	91	64	110	66	35	70	116	113	87	151	0	253	132	250	129	379	335	212	194	137	218
29	300	294	312	285	286	299	265	323	338	326	281	288	353	374	373	366	321	333	293	338	304	315	375	362	378	297	415	253	0	130	484	367	160	109	309	440	212	110
30	160	154	172	145	146	159	125	183	198	186	141	148	213	234	233	226	181	193	153	198	164	175	235	222	238	157	275	132	130	0	367	250	265	220	224	315	136	130
31	293	295	288	300	307	314	320	274	302	330	298	322	322	263	310	373	266	266	281	261	277	284	210	233	199	326	230	250	484	367	0	130	574	543	409	183	294	412
32	178	181	173	186	192	199	206	159	187	215	183	208	207	149	196	259	122	122	137	126	133	140	96	108	55	182	116	129	367	250	130	0	470	433	311	152	188	306
33	451	445	462	436	437	450	416	474	488	477	431	439	504	524	524	517	457	467	443	463	455	466	526	482	528	425	566	379	160	265	574	470	0	53	468	576	286	165
34	402	396	414	387	388	401	367	425	440	428	383	390	455	476	475	468	423	435	395	421	406	417	477	440	480	383	517	335	109	220	543	433	53	0	418	527	252	130
35	193	194	196	206	202	190	223	213	199	155	215	195	206	250	225	135	320	333	312	350	304	283	281	354	351	336	277	212	309									

TABLE 3: Travel time between areas in Beijing-Tianjin-Hebei Region in 2020 (h).

Area	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
1	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.2	0.3	0.3	0.2	0.2	0.5	0.6	0.6	0.7	1.2	1.2	1.0	1.4	1.0	0.8	0.8	1.4	1.4	1.2	0.8	0.2	1.2	0.6	4.2	1.5	1.8	1.6	0.8	1.9	0.9	3.9	
2	0.1	0.0	0.1	0.1	0.1	0.2	0.3	0.2	0.4	0.3	0.2	0.2	0.5	0.7	0.7	0.7	1.2	1.2	1.0	1.4	1.0	0.8	0.8	1.4	1.4	1.2	0.9	0.2	1.2	0.6	4.2	1.5	1.8	1.6	0.8	1.9	0.9	3.8	
3	0.1	0.1	0.0	0.2	0.3	0.2	0.4	0.2	0.2	0.4	0.3	0.4	0.4	0.6	0.6	0.7	1.1	1.1	1.0	1.4	0.9	0.7	0.7	1.3	1.3	1.2	0.8	0.2	1.2	0.7	4.1	1.4	1.8	1.7	0.8	1.8	0.8	4.0	
4	0.1	0.1	0.2	0.0	0.1	0.2	0.2	0.3	0.5	0.4	0.2	0.2	0.6	0.8	0.8	0.8	1.1	1.2	1.0	1.3	1.0	0.8	0.8	1.4	1.4	1.2	1.0	0.3	1.1	0.6	4.3	1.5	1.7	1.5	0.8	2.0	0.9	3.8	
5	0.2	0.1	0.3	0.1	0.0	0.1	0.2	0.3	0.5	0.4	0.2	0.1	0.6	0.8	0.8	0.8	1.2	1.2	1.1	1.4	1.1	0.9	0.9	1.5	1.5	1.3	1.0	0.3	1.1	0.6	4.4	1.6	1.7	1.6	0.8	2.0	0.9	3.9	
6	0.2	0.2	0.2	0.2	0.1	0.0	0.3	0.4	0.4	0.3	0.3	0.2	0.5	0.7	0.7	0.6	1.3	1.3	1.2	1.6	1.1	1.0	0.9	1.5	1.5	1.4	0.9	0.3	1.2	0.6	4.5	1.7	1.8	1.6	0.8	1.9	0.9	4.0	
7	0.3	0.3	0.4	0.2	0.2	0.3	0.0	0.5	0.6	0.6	0.2	0.3	0.8	0.9	0.9	0.9	1.3	1.3	1.2	1.6	1.1	1.0	1.0	1.6	1.5	1.4	1.2	0.3	1.1	0.5	4.6	1.7	1.7	1.5	0.9	2.2	0.9	3.8	
8	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.0	0.2	0.5	0.4	0.4	0.4	0.5	0.7	0.8	1.0	1.1	0.9	1.3	0.9	0.7	0.6	1.3	1.2	1.2	1.1	0.7	0.2	1.3	0.7	3.9	1.3	1.9	1.7	0.9	2.0	0.8	4.1
9	0.3	0.4	0.2	0.5	0.4	0.5	0.4	0.6	0.2	0.4	0.6	0.6	0.2	0.3	0.4	0.7	1.3	1.3	1.1	1.5	1.1	0.9	0.8	1.5	1.5	1.3	0.7	0.3	1.4	0.8	4.3	1.6	2.0	1.8	0.8	1.6	0.9	4.5	
10	0.3	0.3	0.4	0.4	0.4	0.3	0.6	0.5	0.4	0.0	0.5	0.4	0.5	0.8	0.6	0.4	1.5	1.5	1.3	1.7	1.3	1.1	1.1	1.7	1.7	1.5	1.0	0.4	1.3	0.7	4.7	1.8	1.9	1.7	0.6	1.9	1.0	4.4	
11	0.2	0.2	0.3	0.2	0.2	0.3	0.2	0.4	0.6	0.5	0.0	0.4	0.7	0.8	0.8	0.9	1.0	1.1	1.0	1.2	0.9	0.8	0.8	1.4	1.3	1.2	1.1	0.2	1.1	0.6	4.3	1.5	1.7	1.5	0.9	2.1	0.8	3.5	
12	0.2	0.2	0.4	0.2	0.1	0.2	0.3	0.4	0.6	0.4	0.4	0.0	0.7	0.9	0.8	0.7	1.3	1.3	1.2	1.5	1.2	1.0	1.0	1.6	1.6	1.4	1.1	0.3	1.2	0.6	4.6	1.7	1.8	1.6	0.8	2.1	1.0	4.1	
13	0.5	0.5	0.4	0.6	0.6	0.5	0.8	0.4	0.2	0.5	0.7	0.7	0.0	0.5	0.2	0.8	1.5	1.5	1.4	1.8	1.3	1.1	1.0	1.7	1.7	1.6	0.8	0.4	1.4	0.9	4.6	1.7	2.0	1.8	0.8	1.5	1.0	4.6	
14	0.6	0.7	0.6	0.8	0.8	0.7	0.9	0.5	0.3	0.8	0.8	0.9	0.5	0.0	0.4	1.2	1.2	1.2	1.4	1.4	1.2	1.2	0.6	1.4	1.1	1.6	0.3	0.5	1.5	0.9	3.8	1.2	2.1	1.9	1.0	1.3	1.1	5.0	
15	0.6	0.7	0.6	0.8	0.8	0.7	0.9	0.7	0.4	0.6	0.8	0.8	0.2	0.4	0.0	0.9	1.7	1.7	1.6	1.9	1.5	1.3	0.9	1.9	1.9	1.7	0.7	0.5	1.5	0.9	4.4	1.6	2.1	1.9	0.9	1.3	1.1	4.9	
16	0.7	0.7	0.7	0.8	0.8	0.6	0.9	0.8	0.7	0.4	0.9	0.7	0.8	1.2	0.9	0.0	1.8	1.8	1.7	2.1	1.6	1.4	1.4	2.0	2.0	1.9	1.4	0.6	1.5	0.9	5.3	2.2	2.1	1.9	0.5	2.2	1.2	5.0	
17	1.2	1.2	1.1	1.1	1.2	1.3	1.3	1.0	1.3	1.5	1.0	1.3	1.5	1.2	1.7	1.8	0.0	0.1	0.2	0.2	0.1	0.3	0.6	0.4	0.6	0.3	1.0	0.3	2.7	0.7	3.8	0.5	3.8	2.1	1.3	4.3	0.5	3.6	
18	1.2	1.2	1.1	1.2	1.2	1.3	1.3	1.1	1.3	1.5	1.1	1.3	1.5	1.2	1.7	1.8	0.1	0.0	0.3	0.1	0.3	0.4	0.7	0.3	0.6	0.4	1.0	0.4	2.8	0.8	3.8	0.5	3.9	2.2	1.3	4.3	0.5	3.7	
19	1.0	1.0	1.0	1.0	1.1	1.2	1.2	0.9	1.1	1.3	1.0	1.2	1.4	1.4	1.6	1.7	0.2	0.3	0.0	0.4	0.2	0.4	0.9	0.6	0.7	0.3	1.2	0.3	2.4	0.6	4.0	0.5	3.7	2.0	1.2	4.5	0.5	3.4	
20	1.4	1.4	1.4	1.3	1.4	1.6	1.6	1.3	1.5	1.7	1.2	1.5	1.8	1.4	1.9	2.1	0.2	0.1	0.4	0.0	0.4	0.5	0.8	0.3	0.7	0.5	1.1	0.4	2.8	0.8	3.7	0.5	3.9	2.1	1.4	4.3	0.5	3.7	
21	1.0	1.0	0.9	1.0	1.1	1.1	1.1	0.9	1.1	1.3	0.9	1.2	1.3	1.2	1.5	1.6	0.1	0.3	0.2	0.4	0.0	0.2	0.7	0.5	0.7	0.4	1.0	0.3	2.5	0.7	4.0	0.5	3.8	2.0	1.2	4.4	0.5	3.6	
22	0.8	0.8	0.7	0.8	0.9	1.0	1.0	0.7	0.9	1.1	0.8	1.0	1.1	1.2	1.3	1.4	0.3	0.4	0.4	0.5	0.2	0.0	0.4	0.7	0.7	0.6	1.0	0.1	2.6	0.7	4.1	0.6	3.9	2.1	1.1	4.4	0.6	3.8	
23	0.8	0.8	0.7	0.8	0.9	1.0	1.0	0.6	0.8	1.1	0.8	1.0	1.0	0.6	0.9	1.4	0.6	0.7	0.9	0.8	0.7	0.4	0.0	0.9	0.7	1.1	0.4	0.3	3.1	0.9	3.0	0.4	4.4	2.4	1.1	3.4	0.8	4.6	
24	1.4	1.4	1.3	1.4	1.5	1.5	1.6	1.3	1.5	1.7	1.4	1.6	1.7	1.4	1.9	2.0	0.4	0.3	0.6	0.3	0.5	0.7	0.9	0.0	0.3	0.7	1.1	0.5	3.0	0.9	3.3	0.4	4.0	2.2	1.4	4.1	0.6	3.9	
25	1.4	1.4	1.3	1.4	1.5	1.5	1.5	1.2	1.5	1.7	1.3	1.6	1.7	1.1	1.9	2.0	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.3	0.0	1.1	0.9	0.5	3.1	1.0	2.8	0.2	4.4	2.4	1.4	3.3	0.7	4.6	
26	1.2	1.2	1.2	1.3	1.4	1.4	1.1	1.3	1.5	1.2	1.4	1.6	1.6	1.7	1.9	0.3	0.4	0.3	0.5	0.4	0.6	1.1	0.7	1.1	0.0	1.4	0.3	2.5	0.6	4.7	0.7	3.5	1.9	1.3	5.1	0.3	3.1		
27	0.8	0.9	0.8	1.0	1.0	0.9	1.2	0.7	0.7	1.0	1.1	1.1	0.8	0.3	0.7	1.4	1.0	1.0	1.2	1.1	1.0	1.0	0.4	1.1	0.9	1.4	0.0	0.6	3.5	1.1	3.3	0.5	4.7	2.6	1.1	2.1	1.0	5.2	
28	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.2	0.3	0.4	0.2	0.3	0.4	0.5	0.5	0.6	0.3	0.4	0.3	0.4	0.3	0.1	0.3	0.5	0.5	0.3	0.6	0.0	2.1	0.5	3.6	1.1	1.5	4.8	3.0	2.8	2.0	3.1	
29	1.2	1.2	1.2	1.1	1.1	1.2	1.1	1.3	1.4	1.3	1.1	1.2	1.4	1.5	1.5	1.5	2.7	2.8	2.4	2.8	2.5	2.6	3.1	3.0	3.1	2.5	3.5	2.1	0.0	0.5	4.0	1.5	0.6	0.4	1.2	1.8	3.0	0.4	
30	0.6	0.6	0.7	0.6	0.6	0.6	0.5	0.7	0.8	0.7	0.6	0.6	0.9	0.9	0.9	0.9	0.7	0.8	0.6	0.8	0.7	0.7	0.9	0.9	1.0	0.6	1.1	0.5	0.5	0.0	1.8	1.0	1.1	0.9	0.9	1.3	1.9	1.9	
31	4.2	4.2	4.1	4.3	4.4	4.5	4.6	3.9	4.3	4.7	4.3	4.6	4.6	3.8	4.4	5.3	3.8	3.8	4.0	3.7	4.0	4.1	3.0	3.3	2.8	4.7	3.3	3.6	4.0	1.8	0.0	0.5	8.2	7.8	5.8	2.6	1.2	5.9	
32	1.5	1.5	1.4	1.5	1.6	1.7	1.7	1.3	1.6	1.8	1.5	1.7	1.7	1.2	1.6	2.2	0.5	0.5	0.5	0.5	0.5	0.6	0.4	0.4	0.2	0.7	0.5	1.1	1.5	1.0	0.5	0.0	3.9	3.6	2.6	2.2	2.7	4.4	
33	1.8	1.8	1.8	1.7	1.7	1.8	1.7	1.9	2.0	1.9	1.7	1.8	2.0	2.1	2.1	2.1	3.8	3.9	3.7	3.9	3.8	3.9	4.4	4.4	4.4	4.4	3.5	4.7	1.5	0.6	1.1	8.2	3.9	0.0	0.2	1.9	2.3	4.1	0.7
34	1.6	1.6	1.7	1.5	1.6	1.6	1.5	1.7	1.8	1.7	1.5	1.6	1.8	1.9	1.9	1.9	2.1	2.2	2.0	2.1	2.0	2.1	2.4	2.2	2.4	1.9	2.6	4.8	0.4	0.9	7.8	3.6	0.2	0.0	2.1	2.6	3.6	1.9	
35	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.6	0.9	0.8	0.8	1.0	0.9	0.5	1.3	1.3	1.2	1.4	1.2	1.1	1.1	1.4	1.4	1.3	1.1	3.0	1.2	0.9	5.8	2.6	1.9	2.1	0.0	2.3	2.7	4.9	
36	1.9	1.9	1.8	2.0	1.9	2.2	2.0	1.6	1.9	2.1	2.1	1.5	1.3	1.3	1.3	2.2	4.3	4.3	4.5	4.3	4.4	4.4	3.4	4.1	3.3	5.1	2.1	2.8	1.8	1.3	2.6	2.2	2.3	2.6	2.3	0.0	4.5	5.9	
37	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.8	0.9	1.0	0.8	1.0	1.0	1.1	1.1	1.2	0.5	0.5	0.5	0.5	0.5	0.6	0.8	0.6	0.7	0.3	1.0	2.0	3.0	1.9	1.2	2.7	4.1	3.6	2.7	4.5	0.0	1.7	
38	3.9	3.8	4.0	3.8	3.9	4.0	3.8	4.1	4.5	4.4	3.5	4.1	4.6	5.0	4.9	5.0	3.6	3.7	3.4	3.7	3.6	3.8	4.6	3.9	4.6	3.1	5.2	3.1	0.4	1.9	5.9	4.4	2.4

FIGURE 12: The iterative process of IACSA.

example, demands at each level in period 1 are presented in Table 4 in Appendix.

C_{jst} : it is estimated according to the intercity rail planning presented in Figure 11 and the passenger transport volume of Beijing-Tianjin-Hebei Region from China's Urban Statistical Yearbooks (2015). For example, capacities at each level in period 1 are presented in Table 4 in Appendix.

6.2. Computational Results. The IACSA is coded in C#, running on a laptop with 2.50 GHz Intel Core I5-2450M processor and 4 GB of RAM under the system Microsoft Windows 7. Also, the optimization software CPLEX version 12.2 is utilized to solve the problem. The parameters of the IACSA are defined as follows: $M = 30$, $A = 10$, $a_0 = 5$, $\varepsilon_{\max} = 0.9$, $\varepsilon_{\min} = 0.1$, $B = 15$, $b_0 = 5$, $N = 100$, $Q = 10^6$, $\delta_1 = 10^6$, $\delta_2 = 10^6$, and $\delta_3 = 10^6$.

The problem is run 10 times by IACSA. The iterative process of IACSA is presented in Figure 12.

The objective function value and computational time of IACSA are compared with the results from CPLEX, as shown in Table 1. Z_{CPLEX} is the optimal objective function value of the model, and Z_{IACSA} is the objective function value of IACSA. Gap is defined as follows:

$$\text{Gap} = \frac{Z_{\text{IACSA}} - Z_{\text{CPLEX}}}{Z_{\text{CPLEX}}} \times 100\%. \quad (11)$$

According to Table 1, Gap between IACSA and CPLEX is less than 1% for the case. Also, the average computational time of IACSA is shorter than that of CPLEX. For large-size problem, random numbers are generated (see Table 1). In large-size problem, the computational time of CPLEX is more than 10 h. However, IACSA can get the near optimum in half

TABLE 4: Different-level demands and maximum capacities of areas in Beijing-Tianjin-Hebei Region in 2020 (ten thousand persons annually).

Area	q_{i11}	q_{i21}	q_{i31}	C_{j11}	C_{j21}	C_{j31}
1	40301	2529	1651	61131	5227	5119
2	57598	3615	2360	87369	6142	5119
3	172395	9306	7065	261502	9648	8462
4	101128	6347	4144	153398	6534	13285
5	28755	1805	1178	43617	0	0
6	159168	7631	6523	241438	8574	0
7	32837	2061	1346	49809	6403	0
8	40057	2514	1642	60762	6860	5119
9	25249	1585	1035	38299	6599	9645
10	71147	4465	2916	107920	6272	0
11	50313	3158	2062	76318	6991	6399
12	12141	810	498	18417	0	0
13	11543	725	473	17510	0	0
14	10670	670	437	16185	3920	0
15	12187	765	499	18487	4247	0
16	7312	459	300	11092	0	0
17	90939	5430	3415	101352	5440	5701
18	12920	686	485	14399	2176	2851
19	14584	871	548	16254	3264	0
20	12774	763	480	14236	0	0
21	14568	870	547	16236	2984	0
22	20439	1085	767	22779	3228	0
23	16224	861	609	18082	3264	0
24	52152	2768	1958	58124	3445	5131
25	8552	454	321	9531	0	0
26	13815	733	519	15397	0	0
27	16345	868	614	18216	0	0
28	20616	3259	1481	23344	8299	0
29	53405	8443	3837	60471	19151	14505
30	40085	6337	2880	45388	12129	2872
31	13925	2201	1000	15767	2160	0
32	37114	5868	2666	42024	13086	8703
33	44258	6997	3180	50113	11810	2843
34	29118	4603	2092	32970	0	0
35	20911	3306	1502	23678	3541	0
36	14930	2360	1073	16905	3126	0
37	31108	4918	2235	35224	5832	0
38	17556	2775	1261	19878	2869	0

an hour. Gap between IACSA and CPLEX is still less than 1%. Therefore, it can be concluded that IACSA is producing reasonable results in large-size problems.

Figure 13 presents the location of THUAA in Beijing-Tianjin-Hebei Region. In the short-term period, the location planning of THUAA is consistent with the spatial development pattern, the transportation network, and the population distribution. In the medium-term and long-term periods, along with the development of intercity rail, the increase of urban population and the urban population migration from

FIGURE 13: The location of THUAA in Beijing-Tianjin-Hebei Region.

FIGURE 14: The demand weighted travel time in different scenarios.

city center to suburban, more and more level-2 and level-3 hubs are opened.

In addition, 3 scenarios are designed to investigate the impact of urban population migration on the location of THUAA. Scenario 0, the basic scenario with the parameters defined in the previous sections, includes 3 periods of urban population migration. In scenario 1, urban population migration happens in periods 1 and 2. In scenario 2, urban population migration happens only in period 1. Figure 14 shows that the more the urban population migration (from scenario 2 to scenario 0) is, the less the total demand weighted travel time is. In Figure 15, we can find that, in all scenarios as time goes, the number of level-1 hub reduces, while the number of level-2 hub increases and the number of level-3 hub remains the same or increases. Moreover, in each period, with more and more urban population migration (from scenario 2 to scenario 0), the number of level-1 hub remains the same or becomes lower, while both the numbers of level-2 hub and level-3 hub remain the same or become higher. In all, urban population migration helps to reduce travel time for urban residents, which needs a sustained and appropriate implementation.

7. Conclusion and Further Research

In this paper, the changes of passenger demand and the development of transportation network in the process of rapid urbanization are considered and MHLF of THUAA is studied. According to the hierarchical feature of PDUAA and the hierarchical nature of THUAA, a hierarchical service network of THUAA with a multiframe, nested and noncoherent structure is described. To better meet the time-varying demand in the process of rapid urbanization, the multiperiod nature of the hierarchical location problem of THUAA is taken into account. Thus, a mathematical programming model and a solution algorithm for multiperiod location

FIGURE 15: The number of hubs at each level in different scenarios.

of THUAA hierarchical system are proposed. The proposed model and algorithm are verified by the application to a real-life problem of Beijing-Tianjin-Hebei Region in China. The results of different scenarios in the case show that urban population migration has a great impact on the hub location scheme. Also, sustained and appropriate urban population migration helps to reduce travel time for urban residents.

Due to the uncertainty of the parameters (e.g., demands at each level, the coverages of different-level hubs, and the maximum capacity of each candidate hub), MHLF of THUAA under uncertainty needs further research in the future.

Appendix

In Tables 2, 3, and 4, the administrative districts in Beijing (i.e., Dongcheng, Xicheng, Chaoyang, Fengtai, Shijingshan, Haidian, Fangshan, Tongzhou, Shunyi, Changping, Daxing, Mentougou, Huairou, Pinggu, Miyun, and Yanqing) are numbered as 1~16, respectively. The administrative districts in Tianjin (i.e., city center, Dongli, Xiqing, Jinnan, Beichen, Wuqing, Baodi, Binhai, Ninghe, Jinghai, and Jixian) are numbered as 17~27, respectively. The 11 cities in Hebei Province (i.e., Langfang, Shijiazhuang, Baoding, Qinhuangdao, Tangshan, Handan, Xingtai, Zhangjiakou, Chengde, Cangzhou, and Hengshui) are numbered as 28~38, respectively.

Competing Interests

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

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