A Study on Location of Logistics Hubs of Hub-and-Spoke Network in Beijing-Tianjin-Hebei Region

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Abstract: Through the analysis of the logistics operation scene in Beijing-Tianjin-Hebei region, a hub-and-spoke regional logistics network with four modes of transportation was constructed. Considering the network balance factor, the number of network hubs should be determined. Then, with full consideration of various factors including fixed cost, transshipment cost and integrated transportation advantages, the hub-and-spoke logistics network location model is established. We design the corresponding genetic algorithm to solve the location problem of Beijing-Tianjin-Hebei regional logistics network hub. Finally, the feasibility of the model is verified by the actual logistics operation data of Beijing-Tianjin-Hebei region, and the optimal layout of regional logistics hub is calculated. According to the analysis of the final logistics hub layout, we can find that 7 selected logistics hub in Beijing-Tianjin-Hebei region are distributed evenly. In terms of Beijing, the 3 selected logistics hubs in the city are located in the north, southwest and east west areas, which form a stable triangle covering Beijing-Tianjin-Hebei region. In terms of Tianjin, the 2 selected logistics hubs play an important role in connecting Tianjin with the surrounding cities around the region. In terms of Hebei, the 2 selected logistics hubs serve the southern region as well as cross-regional logistics operations.

1. Introduction
Regional logistics plays an important role in serving and supporting regional economic development. Beijing-Tianjin-Hebei region, as one of the three key economic circles in China, has gradually become one of the regions with the fastest economic growth and the greatest social influence in China. The development of the Beijing-Tianjin-Hebei region is not balanced, and the differences in logistics demand and road network density across the region are obvious. Therefore, constructing a Hub-and-Spoke logistics network in Beijing-Tianjin-Hebei region can greatly mobilize the transportation potential of the axle roads and make up for the shortage of the branch transportation capacity, and maximize the advantages of Hub-and-Spoke logistics network [1].

The research on Hub-and-Spoke regional logistics mainly focuses on model design and application. In terms of model design, O'Kelly first proposed the concept of Hub-and-Spoke network, and designed
the P-hub median model for facility location and network design [2]. Chieh-Yu construct a multi-hub transport network for the US air transport industry with a hub-and-spoke network [3]. Cheng-Chang Lin and Yu-Jen Lin built a hub-and-spoke freight network for global air express delivery companies, and verified the superiority of the hub-and-spoke network through the transportation data of various cargo carriers [4]. Isabel Correia and Stefan Nickel study the single-distribution hub-and-spoke network [5]. Campell first proposed a multi-distribution hub-and-spoke network, and establish a hybrid integer-programming model with the goal of minimum total transportation cost [6]. Weng Kerui et.al analyzed the form, advantages and disadvantages of Hub-and-Spoke logistics network, and pointed out that scale effect, number and location of hub, distribution of logistics demand nodes and transportation routes should be considered in the network design[7]. Zhu Xin et.al optimize the design of the hub-and-spoke logistics network in Guangxi by principal component analysis and reconstructed gravity model [8]. At present, there are some achievements in the application of hub and spoke network to regional logistics planning in China. Haifeng et al. [9] establish a regional logistics network based on the hub-and-spoke network, and conduct an empirical analysis of the model in Hubei Province. Tong shiqi et al. [10] Construct a three-level marine logistics network based on a hub-and-spoke network for the marine logistics system of an archipelago in southern China. However, there are few studies on the construction of Beijing-Tianjin-Hebei regional logistics network. In order to improve the efficiency of Beijing-Tianjin-Hebei regional logistics, Li Mingfang et al [11] construct a hub and spoke regional logistics network with principal component analysis and urban gravity model, combining with the characteristics of Beijing-Tianjin-Hebei regional logistics system.

In this paper, we first identify the occurrence and demand points of logistics in Beijing, Tianjin and Hebei Province, and analyze various logistics transportation modes in the region. Based on the research experience of domestic and foreign scholars in hub-and-spoke network, we formulate standards for the selection of logistics hub nodes, and design a non-strict hub-and-spoke logistics network location model with node cost and its solving algorithm. Finally, we investigate the relevant data and use the algorithm to form the regional hub-and-spoke logistics network.

2. Problem statement and Model

2.1 Problem and assumption
At present, the problem of location of network hub nodes is mainly limited to that all OD flows must transfer through at least one of pivot points in the hub and spoke network. This restriction greatly increases freight traffic volume through the hub. However, the vehicle is forced to detour when the cargo with the linear distance close and the pass-through capacity, the transportation distance required is farther compared with the straight-through distance between the OD pairs, thus the total cost of the entire network system increases. To ensure that the economies of scale of the hub and spoke network are maximized without excessive waste of resources, the transportation mode of network in this paper includes three transportation modes: straight through mode, through a transit hub and two hubs mode (see in Figure 1).
2.2 Notation

\( N \): set of OD points.

\( H \): set of alternative hubs.

\( p \): quantity of hubs.

\( W \): total transportation cost of the network.

\( f_j \): freight traffic volume between node \( i \) and node \( j \).

\( X_{ij} \): the proportion of total cargo flow that are transport in straight through mode between node \( i \) and node \( j \); When all of freights are transported by this mode, \( X_{ij} = 1 \).

\( X_{ij}^1 \): the proportion of total cargo flow that are transported through one hub between node \( i \) and node \( j \); When all of freights are transported by this mode, \( X_{ij}^1 = 1 \).

\( X_{ij}^{km} \): the proportion of total cargo flow that are transported through two hubs between node \( i \) and node \( j \); When all of freights are transported by this mode, \( X_{ij}^{km} = 1 \). \( k = m \) denotes the single hub mode.

\( X_{ij}^{km}(t) \): the proportion of total cargo flow that are transported through two hubs between node \( i \) and node \( j \); When all of freights are transported by this mode, \( X_{ij}^{km}(t) = 1 \). \( k \neq m \).

\( \partial \): discount coefficient of transportation cost between hubs, \( 0 \leq \partial \leq 1 \).

\( C_{ij} \): unit transport cost of straight through mode between node \( i \) and node \( j \).

\( C_{ij}^l \): unit volume transportation cost through hub \( l \) between node \( i \) and node \( j \), \( C_{ij}^l = C_{ij} + \partial_l C_{ij} \).

\( C_{ij}^{km}(r) \): unit road volume transportation cost through hub \( k \) and hub \( m \) between node \( i \) and node \( j \), \( C_{ij}^{km}(r) = C_{ik} + \partial_l C_{km}(r) + \partial_m C_{ij} \).

\( C_{ij}^{lm}(t) \): unit railway volume transportation cost through hub \( k \) and hub \( m \) between node \( i \) and node \( j \), \( C_{ij}^{lm}(t) = C_{ik} + \partial_l C_{lm}(t) + \partial_m C_{ij} \).

\( Y_k \): Whether the hub is selected at the point \( k \). If so, \( Y_k = 1 \); If not, \( Y_k = 0 \).

\( G_p(f_k) \): transportation and storage cost of goods through hub. \( G_p \) is a function relation related to node cost and OD flow.

\( S_k(r) \): whether use road transport in hub \( k \).

\( S_k(t) \): whether use railway transport in hub \( k \).

\( M_k(r) \): fixed transport connection cost in hub \( k \) in road transport.

\( M_k(t) \): fixed transport connection cost in hub \( k \) in railway transport.

\( T_k \): fixed construction cost of hub.
2.3 Basic model

The total cost of regional logistics network hub location model is shown in equation (4-1).

\[
\begin{align*}
\min W &= \sum_{i,j}^{N} N X_{ij} C_{ij} + \sum_{i,j}^{N} N X_{ij} f_{ij} C_{ij}
+ \left[ \sum_{i,j}^{N} N P_{ij} \sum_{k}^{p} X_{ij}^{km} (r) f_{ij} C_{ij}^{km} (r) + \sum_{k}^{p} M_{k} (t) \right] : S_{k} (r) \\
&+ \left[ \sum_{i,j}^{N} N P_{ij} \sum_{k}^{p} X_{ij}^{km} (t) f_{ij} C_{ij}^{km} (t) + \sum_{k}^{p} M_{k} (t) \right] : S_{k} (t) \\
&+ \sum_{i,j}^{N} N P_{ij} \sum_{k}^{p} G_{k} (f_{ij}) + \sum_{p}^{T} T_{p} \\
\text{s.t.} \quad \sum_{k}^{N} Y_{k} = P \\
X_{ij} + \sum_{k}^{p} X_{ij}^{km} (r) + \sum_{m}^{M} X_{ij}^{km} (t) = 1 \quad \forall i, j \in N; k, \in H \\
C_{ij} = C_{ij} + \hat{\varepsilon} C_{ij} \\
C_{ij}^{km} (r) = C_{ij} + \hat{\varepsilon} C_{ij}^{km} (r) + \hat{\varepsilon} C_{ij}^{m} \\
C_{ij}^{km} (t) = C_{ij} + \hat{\varepsilon} C_{ij}^{km} (t) + \hat{\varepsilon} C_{ij}^{m} \\
X_{ij} \leq Y_{k} \quad \forall i, j \in N; l \in H \\
X_{ij}^{km} \leq Y_{l} \quad \forall i, j \in N; k, m \in H \\
X_{ij}^{km} \leq Y_{m} \quad \forall i, j \in N; k, m \in H \\
Y_{k} = \begin{cases} 
0 & \text{Not elected to the hub} \\
1 & \text{elected to the hub} 
\end{cases} \quad \forall i, j \in N \\
S_{k} (r) = \begin{cases} 
0 & \forall i, j \in N \\
1 & \forall i, j \in N 
\end{cases} \quad \forall i, j \in N \\
S_{k} (t) = \begin{cases} 
0 & \forall i, j \in N \\
1 & \forall i, j \in N 
\end{cases} \quad \forall i, j \in N \\
X_{ij} \in \{0,1\} \quad \forall i, j \in N \\
X_{ij} \in \{0,1\} \quad \forall i, j \in N; l \in H \\
X_{ij}^{km} \in \{0,1\} \quad \forall i, j \in N; k, m \in H \\
X_{ij}^{km} \in \{0,1\} \quad \forall i, j \in N; k, m \in H \\
0 \leq \hat{\varepsilon} \leq 1
\end{align*}
\]

As shown in equation (2-1), the first four sections are transportation costs and denote the different transport mode. The fifth and last section denote transfer cost and fixed cost respectively.

Restraint expressions (2-2) of constraints ensures the quantity of selected hubs of logistics network. Restraint expressions (2-2) - (2-6) denote the per unit transport cost corresponding to different transport modes. Restraint expressions (2-7) - (2-8) - (2-9) reflect the transport line are determined with the determination of the hubs. Relations (2-10) - (2-11) represent that the decision variable can only be 0 or 1. Relations (2-12) - (2-16) represent that only one mode of transportation can be selected between OD. The last formula is the range of scale effect coefficient.

3. Model solve

3.1 Hub quantity

The optimal locations and the number of hubs in the hub-and-spoke network model cannot be balanced. Factors such as the actual condition, the construction cost and transport mode should be also taken into
account, so it is difficult to obtain accurate results with the mathematical model. The optimal number of hubs is set artificially according to the specific situation of the research problem. Referring to previous research, it is defined in most literatures as shown in formula (3-1):

\[ p = \sqrt{N} \]  

(3-1)

Taking the square root of the total number of nodes in the network as the optimal number of hubs. In this paper, Beijing is divided into 16 OD points, similar as 11 OD points in Tianjing and Hebei. The network contains 38 demand points, and the number of hub is set as 6 or 7. The calculations of network in section 4 are based on this proposition.

3.2 Genetic algorithm design

3.2.1 Chromosome encoding.
In this paper, an integer coding method is selected, the length of chromosome is the number of hubs in the network. The alternative nodes are directly marked with integer values ranging from 1 to 19. The resulting chromosomes (the initial solution) should be a 1×7 matrix in which each gene does not repeat.

As genetic algorithms search for multiple individuals in a population simultaneously, the size of population will directly affect the operational efficiency of genetic algorithms and the degree of optimization of results. In this paper, the population size is 200.

3.2.2 The fitness function
The initial population of chromosomes generates the spatial Layout of multimodal transport network. The next step is to calculate the optimal transport mode between different OD according. In this paper, four transport modes are involved in the transport process, so a 4*N transport combination storage matrix is generated to store the optimal transport mode different OD of the network during the decoding process. The determination of OD transport mode is firstly to calculate the optimal route of the four transportation modes in combination with the spatial layout of network, and then to determine the optimal transportation mode by comparison.

The ultimate goal of the model solution is to minimize the transportation cost of the logistics network. According to the transport combination storage matrix, the target function value of each chromosome is calculated with the basic model in equation (2-1).

3.2.3 Genetic algorithm operation
This paper uses roulette wheel selection which determines the probability \( P_i \) that the next generation is retained based on the proportion of each individual's fitness.

\[ P_i = \frac{f_i}{\sum f_i} \]  

(3-2)

Where \( f_i \) denote value of individual chromosome fitness, m represent the population size.

As the chromosome gene represents hub number, the crossover process needs to satisfy the restrictions (i.e., isometric crossover, no overlapping). PMX(Partially Matched Exchange) is the crossover operator. Different from the traditional crossing method, PMX operation firstly adds the whole part of the previous chromosome that needs to be crossed into the latter chromosome, and then tests the genes in the latter chromosome one by one to delete the duplicated gene. The operation process is shown in Figure 2.
The previous generation chromosome A (56|8437|10) deleting the duplicated gene (85|37106|4)
intermediate chromosome A’ (8437|85371064) preposing the crossover gene (37106|56843710)
The next generation chromosome A1 (84375106) generating the new chromosome B (85|37106|4)

Figure 2. Schematic of PMX Crossover Operation
The mechanism of mutation is to locate the mutation of area at a certain point in the chromosome and change the gene to generate new chromosome codes.

4. Case study on logistics hubs location in Beijing-Tianjin-Hebei region

4.1 Parameter settings
The basic data related to nodes include: (1) the number of OD points, alternative logistics hub points and their corresponding location information in our case. (2) The setting of fixed parameters

(1) Basic data of OD and alternative logistics hub
In this paper, 16 origin and 16 destination points in Beijing and 11 origin and destination points in Tianjin are considered in accordance with districts region, Hebei province is divided into 11 origin and 11 destination points according to the city region. 19 alternative hub points are set up. The coordinate information of OD points, the distance matrix between OD-alternative points and the distance matrix between each alternative point are respectively shown in appendix A, appendix B and appendix C.

(2) Network cost parameters
The scale effect factors in this paper are discussed in terms of the type of the nodes that connect at both ends of the road: The size effect coefficient between straight-through transportation roads is 1, the size effect coefficient of sub-axis roads is 0.8, and the size effect coefficient of axis roads is 0.7. When highway transportation is adopted between the hubs, it is set at 7.8 yuan/ton; when railway transportation is adopted between the hubs, it is set at 5.8 yuan/ton. In addition, it is assumed that each alternative hub provides a fixed link fee of 800,000 yuan for highway transportation, while each alternative hub provides a fixed link fee of 1,000,000 yuan for railway transportation.

4.2 Calculation results of logistics hub location
The site selection results of the hub and the corresponding total network costs and overall transport schemes are shown in Table 1.

| Calculation results | Quantity | Total cost (yuan) | Selected Number of hubs | by single hub (highway) | by dual hub (highway) | by dual hub (railway) |
|---------------------|----------|-------------------|------------------------|------------------------|----------------------|----------------------|
|                     | 6        | 7.883e+8          | 9, 5, 4, 16, 2, 19     | 106                    | 174                  | 0                    |
|                     | 7        | 7.721e+8          | 9, 12, 1, 16, 4, 2, 19 | 143                    | 218                  | 0                    |

In this situation, the total cost of regional logistics network is RMB 7.721e+8, and the number of single and double hub transport routes in the network is 143 and 218, respectively. Additionally, the whole area network does not contain the railway transport in the transportation scheme regardless of the quantity of hubs, it is due to the Beijing-Tianjin-Hebei region is in a small scope, which lead the railway transport cannot fully exert its advantage over the long haul transportation, moreover, link fee in hubs for the railway transportation is relatively high, hence the railway transportation is not adopt in the
transportation of any OD point. Select the serial number 1, 2, 4, 9, 12, 16 and 19 in the set of alternative hubs as the hub node in the network and these selected nodes respectively located in Tongzhou district, Changping district and Fengtai district of Beijing, Wuqing district, Baodi district of Tianjin and Baoding city, Hengshui city of Hebei province.

4.3 Analysis of logistics hub location
Because this network allows direct transportation between non-hub nodes, there are 1407 lines of transportation between 38 OD points. According to Table 1, a total of 143 routes were selected to be transported via single hub and 218 were selected to be transported via a dual hub. So the focus of this part is to discuss the application characteristics and radiation areas of transfer modes via single hub and double hub.

4.3.1 Analysis on transport results via single hub

(1) Transport scheme via hub 1, 2, 4.

The hub 1 is located in Changping district, Beijing, the northernmost of all alternative logistics hubs. A total of 22 routes were transferred to the demand point via this hub. As can be seen from figure 3(a), hub 1 primarily serves two major logistics channels in the Beijing-Tianjin-Hebei region, which radiates from north to south which includes Chengde of Hebei, Huairou, Yanqing, Changping of Beijing and Baoding of Hebei.

Hub 2 is located in Fengtai district of Beijing, and a total of 19 routes are selected to be transported to the destination via this node. As shown in figure 3(a), hub 2 is located in the southern part of Beijing, and it is mainly responsible for the collection and distribution of goods from Baoding, Langfang, Cangzhou and other places of Hebei province to the main urban area of Beijing. The selection of hub 2 can gather and distribute the goods from Hebei in advance, reducing the number of freight vehicles directly into Beijing and ease the transit pressure of Beijing.

Hub 4 is located in Tongzhou district of Beijing. A total of 35 routes are selected to be transported via the hub 4 to the destination point. This result fully reflected the status of hub 4 in the Beijing-Tianjin-Hebei regional logistics network. As shown in figure 3(a), Hub 4 mainly connects the eastern part of the region and the main urban area of Beijing, forming a crosswise logistics channel in the middle of the region. Similar to hub 2, hub 4 can also relieve the transit pressure in the main urban area of Beijing. In addition, hub 4 also connects the northeast suburbs of Beijing and forming the regional central longitudinal logistics channel.

(2) Transport scheme via hub 9, 12, 16, 19.

Hub 9 is located in Wuqing district of Tianjin. According to figure 3(b), we can infer that hub 9 plays two important roles in regional logistics operations: first, hub 9 is a vital node connecting Tianjin urban area with the southeastern area of Beijing; second is that the hub 9 is the node which connects Chengde,
Jizhou district, Miyun district, Pinggu district in the north area of network with southern Jinghai, Cangzhou, Hengshui etc., forming the eastern vertical logistics channel. There are 30 lines selected to be transported via hub 12. The goods in Tianjin urban areas, Xiqing district, Dongli district, and Jinghai district have been concentrated and combined to the Chengde, Tangshan and Qinhuangdao via this central node.

The hub 16 is located in the middle of the Beijing-Tianjin-Hebei region connecting the regional logistics transport: it connects Daxing district, Fangshan district, Mentougou district, Zhangjiakou city with southern Hebei province; it also connects western Hebei province with eastern Tianjin.

As the southernmost alternative logistics hub, hub 19 is located in Hengshui city, Hebei province and connect the central areas with southern areas of the Beijing-Tianjin-Hebei region. The goods in the south of the region are transported to the middle of the region via the No.19 hub, forming the vertical logistics channel in the south of the region.

4.3.2 Analysis on transport results via dual hubs

A total of 218 lines of all transport lines are selected and transported to their respective destination via two different pivot points. By analyzing the location distribution of each hub, it can be found that there are four kinds of dual hub connection modes in the network according to the relative position of two hubs in the region, which is vertical connection of dual hub (two hubs are distributed relative to north and south), the horizontal connection of dual hubs (two hubs are distributed relative to east and west), the positive oblique connection of dual hubs (two hubs are distributed relative to northeast and southwest), and the reverse oblique connection of dual hubs (two hubs are distributed relative to northwest and southeast), respectively.

Considering that the feature of Beijing-Tianjin-Hebei region which the depth of north-south direction is long and the range of east-west direction is relatively short. Therefore, the mode of the connection between north and south has become the main mode of the transportation of the two hubs. In figure 4, there are four vertical connection modes with dual hubs (1-2, 1-16, 1-19 and 2-19), five positive oblique connection modes (2-16, 4-16, 4-19, 9-19, 16-19), three reverse oblique connection modes (1-4, 2-9, 2-12), and only the route 9-16 is selected as the horizontal connection between the two hubs.

As can be seen from figure 4, the selected dual hub transport mode is dominated by the nodes within the south-central region. This is because that six cities including Baoding, Cangzhou, Shijiazhuang, Hengshui, Xingtai and Handan in Hebei province are located in the central and southern part of Beijing-Tianjin-Hebei, which covers a large area and is far from the northern region. In addition, the volume of logistics in the central and southern regions are large, but compared with the Beijing and Tianjin, the network density here is relatively low, and the transportation difficulty is relatively large, hence the mode with dual hub are adopted to carry out transportation business in this situation is vital.

Figure 4. Schematic Diagram of Double-Hub Connection

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5. Conclusion
Under the background of regional integration of Beijing-Tianjin-Hebei, in this paper, we take the regional logistics operation scene of Beijing-Tianjin-Hebei as the research object, and construct the regional logistics network hub location model with the lowest total network cost as the objective function. We solve the problem and find that the seven alternative hubs, No. 1, No. 2, No. 4, No. 9, No. 12, No. 16, No. 19, are the optimal layout schemes for the Beijing-Tianjin-Hebei regional logistics network hub. On this basis, we observe the radiation scope and position of each hub in the regional logistics network through the analysis of the optimal layout scheme of the hub; and get layout of logistics channels formed by single hub and double hub connection modes in regional logistics networks and their roles through the analysis of OD's choice of transport routes in the network.

Appendix

### Appendix A

| Partly matrix of OD-distance | Dongcheng | Xicheng | Haidian | Changping | Fengtai | Fengtai | Shijingshui |
|-----------------------------|-----------|---------|---------|-----------|---------|---------|-----------|
| Dongcheng                  | 0.00      | 6.07    | 20.37   | 8.89      | 16.30   | 20.90   | 107.87    | 86.46    |
| Xicheng                    | 4.87      | 0.00    | 117.59  | 32.47     | 11.01   | 10.39   | 130.39    | 95.23    |
| Haidian                    | 20.17     | 23.59   | 0.00    | 25.28     | 21.31   | 11.03   | 127.52    | 108.00   |
| Changping                  | 8.89      | 53.47   | 25.09   | 0.00      | 15.25   | 20.89   | 165.03    | 77.95    |
| Fengtai                    | 8.89      | 53.47   | 25.09   | 0.00      | 15.25   | 20.89   | 165.03    | 77.95    |
| Fengtai                    | 8.89      | 53.47   | 25.09   | 0.00      | 15.25   | 20.89   | 165.03    | 77.95    |
| Shijingshui                | 107.87    | 130.39  | 95.23   | 127.52    | 108.00  | 77.95   | 0.00      | 24.44    |

### Appendix B

| Partly matrix of OD-alternative points distance | Dongcheng | Xicheng | Haidian | Changping | Fengtai | Fengtai | Shijingshui |
|-----------------------------------------------|-----------|---------|---------|-----------|---------|---------|-----------|
| Dongcheng                                  | 64.22     | 64.05   | 25.31   | 44.17     | 46.24   | 35.33   | 150.26    | 100.05   |
| Xicheng                                    | 26.72     | 23.28   | 26.66   | 35.62     | 30.50   | 14.75   | 156.97    | 152.13   |
| Haidian                                    | 18.52     | 18.21   | 35.02   | 23.70     | 17.26   | 29.33   | 94.27     | 91.23    |
| Changping                                  | 5.46      | 5.46    | 45.16   | 20.79     | 37.35   | 45.42   | 85.67     | 56.45    |
| Fengtai                                    | 4.85      | 4.85    | 43.53   | 38.73     | 58.81   | 54.72   | 134.81    | 75.41    |
| Fengtai                                    | 5.46      | 5.46    | 45.16   | 20.79     | 37.35   | 45.42   | 85.67     | 56.45    |
| Shijingshui                                | 21.04     | 20.36   | 21.94   | 22.85     | 35.93   | 39.80   | 126.82    | 98.99    |
| Beijing                                    | 21.04     | 20.36   | 21.94   | 22.85     | 35.93   | 39.80   | 126.82    | 98.99    |

### Appendix C

| Partly matrix of alternative points distance | Dongcheng | Xicheng | Haidian | Changping | Fengtai | Fengtai | Shijingshui |
|---------------------------------------------|-----------|---------|---------|-----------|---------|---------|-----------|
| 1:00                                        | 46.49     | 57.67   | 105.42  | 98.62     | 137.24  | 244.62  | 220.12    |
| 2:00                                        | 6.07      | 46.49   | 57.67   | 105.42    | 98.62   | 137.24  | 244.62    | 220.12    |
| 3:00                                        | 20.37     | 46.49   | 57.67   | 105.42    | 98.62   | 137.24  | 244.62    | 220.12    |
| 4:00                                        | 8.89      | 46.49   | 57.67   | 105.42    | 98.62   | 137.24  | 244.62    | 220.12    |

### Appendix D

| Partly matrix of OD flow                  | Dongcheng | Xicheng | Haidian | Changping | Fengtai | Fengtai | Shijingshui |
|-------------------------------------------|-----------|---------|---------|-----------|---------|---------|-----------|
| Dongcheng                                 | 0.00      | 14.86   | 11.72   | 20.90     | 107.87  | 86.46   | 1.00      |
| Xicheng                                  | 103.10    | 0.00    | 14.86   | 11.72     | 20.90   | 107.87  | 86.46     |
| Haidian                                  | 50.44     | 25.28   | 0.00    | 11.72     | 20.90   | 107.87  | 86.46     |
| Changping                                | 8.89      | 45.16   | 25.28   | 0.00      | 11.72   | 20.90   | 107.87    |
| Fengtai                                  | 5.46      | 45.16   | 25.28   | 0.00      | 11.72   | 20.90   | 107.87    |
| Fengtai                                  | 5.46      | 45.16   | 25.28   | 0.00      | 11.72   | 20.90   | 107.87    |
| Shijingshui                               | 24.44     | 220.12  | 220.12  | 220.12    | 0.00    | 11.72   | 20.90     |

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