Study on the Optimization of Air-rail Intermodal Network Layout in The Beijing-Tianjin-Hebei Region under the Background of Xiong’an New Area

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Abstract—The construction and integration of infrastructure is the hardware foundation for the air-rail intermodal system. The overall structural characteristics and traffic radiation range of The Beijing-Tianjin-Hebei Regional railway network were analyzed with complex network theory. The railway structures including four major airports of The Beijing-Tianjin-Hebei Region were analyzed. The corresponding optimization ideas are put forward based on the current railway network and existing planning.

1. INTRODUCTION
To lead the construction of world-class urban agglomeration in the Beijing-Tianjin-Hebei Urban Agglomeration, the regional traffic structure of The Beijing-Tianjin-Hebei Region needs to be upgraded and transformed into an international, modern, intelligent and multimodal transportation structure. In particular, relying on the developed high-speed railway and intercity railway network in the region, the rapid and efficient traffic links main cities in the region and four major airports (the Capital International Airport, Beijing Daxing Airport, Tianjin Binhai Airport, Shijiazhuang Zhengding Airport) which can be realized in The Beijing-Tianjin-Hebei Region. On April 1, 2017, the establishment of Xiong’an new area has an important impact on the development of The Beijing-Tianjin-Hebei Region comprehensive transportation system: Firstly, Xiong’an new area would construct as the future comprehensive transportation hub and main transportation node of The Beijing-Tianjin-Hebei Region and connect the core cities of the region. Secondly, as an "international first-class innovative city", Xiong’an new area not only relies on the national network of high-speed rail and aviation but also has the demand to go to the world through the international aviation network. Under the background of the establishment of Xiong’an new area, this paper starts from the analysis of traffic structure, then explores the efficient and appropriate optimization ideas of the national railway and urban rail network system and the four major airport comprehensive transportation hubs, finally improves the traffic organization mode of the air-rail combined transportation, which aims to realize the efficient connection between air transportation and railway transportation in The Beijing-Tianjin-Hebei Region.

2. OPTIMIZATION ANALYSIS OF RAILWAY NETWORK STRUCTURE IN THE BEIJING-TIANJIN-HEBEI REGION BASED ON AIRPORT GROUP
The regional railway transportation network with four major airports in The Beijing-Tianjin-Hebei Region is an important foundation of air-rail intermodal. This paper uses the complex network theory and its analysis tool Pajek software for quantitative analysis. The constructions of the complex network
in this paper are as follows: (1) Definition of the network. Generally, the network can be defined in three Spaces: P, R, L \[1\]. Because this paper requires studying the connection between The Beijing-Tianjin-Hebei Regional railway transportation lines, which chooses to construct a transfer network in P space. In P space, nodes are defined as stations. If at least one train stops at two stations, an edge is connected between the two stations. \[2\] (2) Nodes of the network. This paper does not focus on the relationship between the cities rather focuses on the accessibility of the main railway stations and studies from the perspective of air-rail intermodal. Therefore, the four major airport rail stations and the main railway stations in the region (terminal stations and transfer stations connecting multiple lines) are taken as nodes in the network construction. (3) The edge of the network. Since the paper is from the perspective of urban agglomeration, it does not consider urban rail transit, but only considers the intercity and high-speed rail transportation. (4) The abstraction of the network. In general, the railway is considered to be bidirectional, which leads the network abstracted into an undirected network without considering the direction of the line. Moreover, the paper only study the topological properties of the network. The connection between nodes only indicates that there is a railway connection between the railway stations (the topological distance is 1) And the network is abstracted into a non-weighted network without considering the frequency and quantity of railway departure, that is, the problem of connection weight in the network is not considered.

According to the above description, the specific analysis process of using Pajek software \[3\] is as follows:

2.1. Abstracted and Sorted out the Current Planning Railway Network of The Beijing-Tianjin-Hebei Regional

The undirected graph is drawn by using the visualization tool Netdraw, as shown in Figure 1. The node color is used to distinguish regions (red -- Beijing, green -- Tianjin, blue -- Hebei). And the node shape is used to distinguish the properties of railway stations (triangle -- airport, circular -- non-airport), the positions of each node in the figure are independent of the actual position.

![Figure 1. Structure of The Beijing-Tianjin-Hebei Regional railway network](image)

2.2. Analysis of Network Characteristics

• Degree and degree distribution: The degree of a node refers to the number of edges connecting the node, and the degree distribution P (k) of a node defines the probability that an arbitrarily selected node has exactly K edges \[4\]. The degree of nodes in this paper reflects the direct accessibility of the railway station in the regional railway transportation network \[5\]. The degree distribution of the above network nodes can be found in Fig. 2. The larger degree of nodes in the figure is 9, which indicates that these points are connected with 9 stations, corresponding to Langfang in the figure. From the comparison of the nodes of the four major airports, the degrees of Beijing Daxing Airport and Shijiazhuang Airport are 8 and 6, indicates that the direct accessibility of the two airports is better. The Capital Airport and Tianjin Airport are slightly weaker with degrees of 3 and 4. The station with the
highest probability proportion is the station with degree 4, which indicates that most stations can form a direct connection with four stations.

Figure 2. Degree distribution of nodes

- Average shortest path length and diameter: The distance between every two points in the network refers to the number of edges contained in the shortest path connecting the two points. The average path length of the network can be obtained by averaging the distances of all pairs of nodes. In this paper, the average path length reflects the approximate number of transfers between any station. Shorter the average path length is less the number of transfers to the destination [5]. According to the calculation, the average would be shortest path length of the network in Figure 1 is 2.6351, which shows that the average passenger departs from a railway station in the rail network and arrives at the destination by 2.6351 trains. The diameter of the network is 5, which indicates that the farthest topological distance between the two nodes is 5, also is the distance from Shijiazhuang to Zhangjiakou.

- Betweenness: The betweenness of a node reflects the role and influence of the corresponding node in the whole network [6]. The betweenness of each point in the network shows in Figure 3. It can be seen from the figure that the betweenness of 93% of the nodes is less than 0.15. For the transfer system, it is a more reasonable network structure that the betweenness is relatively uniform without considering the flow. Inside the region, Shijiazhuang, Baoding East, Gu’an West, Xiong’an, Cangzhou, Langfang, Huailai, Huanghua, Beijing City Vice center and Tianjin West are the main stations for other node pairs to travel through. Therefore, it is an important goal for The Beijing-Tianjin-Hebei Regional railway integration to realize efficient connectivity with these important nodes. Compared with other two airports, Beijing Daxing airport and Shijiazhuang airport have more influence on the whole regional railway transportation network than the other two airports. There are more railway lines directly connect and undertake certain rail transit transfer functions. However, the direct connection level between Beijing Daxing airport and Tianjin airport and the regional railway transportation network have a lower level of direct connection, which remains to be strengthened.

Figure 3. Distribution of betweenness of nodes in the network
2.3. Analysis of Network Optimization Scheme

Based on the above analysis, under the condition of current planning, it can be further optimized to realize the integration of a railway transportation network. It is suggested that the existing line planning should be used to build the intercity connecting line between Tianjin West railway station and Northern New Area Station, so that trains arriving at Tianjin West railway station (such as Baoding, Shijiazhuang direction) can directly contact with the airport through the Northern New Area Station, greatly reduce travel time, and expand the hinterland of Tianjin airport. Besides, Tianjin Airport connects Binhai West station with the Beijing Binhai intercity railway. And then with the Bohai Rim railway and the second Beijing-Shanghai line. It can expand the cities in Hebei (to the south of Cangzhou) and Shandong. Under this optimization idea, Pajek software is used again to calculate the eigenvalues of a complex network and compare it with the current planning (see Table 1). It can be seen that the average degree and clustering coefficient of the optimized network are higher than those of the original planning network, indicating that the optimization scheme increases the connection of nodes in the network and the connection between stations. The average route length is reduced by 2.87%, which indicates that the number of times passengers need to transfer to the destination is reduced and travel convenience is improved. The maximum betweenness of nodes is reduced by 7.25%, which indicates that the scheme can play a certain role in relieving and diverting the railway passenger flow through Langfang.

| Network characteristics | Status quo of the planning network | Optimization of the network | Rate (%) |
|------------------------|-----------------------------------|----------------------------|---------|
|                        | Characteristic value              | Rate (%)                   |
| Average degree         | 4.6875                            | 5.1875                      | 10.67   |
| Average shortest path length | 2.6351                           | 2.5595                      | -2.87   |
| Clustering Coefficient | 0.4566                            | 0.4620                      | 1.18    |
| Maximum Node betweenness | 0.2360                           | 0.2189                      | -7.25   |

By comparing the node betweenness of the four major airport rail stations in The Beijing-Tianjin-Hebei Region before and after optimization, as shown in Figure 4, it can be seen that through the optimization, the influence of Tianjin Airport Rail Station within The Beijing-Tianjin-Hebei Region has been significantly enhanced and it is more closely connected with other stations. Besides, as the optimization scheme is proposed based on the current planning, the passenger flow of the line can be induced and the overall passenger flow benefit of the line can be improved by improving the direct access between the Baoding-Shijiazhuang area and Tianjin airport. Moreover, the optimized line belongs to the urban line, with low engineering cost and flexible operation organization, which can better meet the actual passenger flow demand and realize the main passenger flow demand service. Therefore, it is feasible and economical.

Figure 4. Comparison of the betweenness of four airports before and after optimization
3. OPTIMIZATION ANALYSIS OF INTEGRATED TRANSPORTATION HUB OF FOUR AIRPORTS IN THE BEIJING-TIANJIN-HEBEI REGION

Under the current planning conditions, a convenient interconnection railway traffic connection structure can be formed between the four airports.

Among them, the Capital Airport and Beijing Daxing Airport have directly connected through the intercity railway connecting line. The Capital Airport and Tianjin Airport can be connected through the intercity railway connecting line + the Beijing Binhai intercity. The Capital Airport and Tianjin Airport are mainly connected through the Tianjin-Daxing Airport connecting line + Tianjin metro. Shijiazhuang Airport and Beijing Daxing airport or Tianjin airport are connected directly with Xiong’an as an important hub. It can be connected through Shijiazhuang-Xiong’an intercity railway + Beijing-Xiong’an intercity railway + Tianjin-Xiong’an intercity railway + Tianjin metro. Besides, the connection between Shijiazhuang airport and Beijing Daxing airport can also be realized through Beijing-Guangzhou high-speed railway + Gu’an-Baoding intercity railway + Langfang-Zhuozhou intercity railway.

3.1. The Capital Airport

For the Capital Airport, the only rail transit line introduced at this stage is the airport express line, with four stations including Dongzhimen, Sanyuanqiao, terminal T2, Terminal T3. There is the Beijing-Shenyang high-speed railway on the west side. The planned intercity railway connecting line starts from the Capital Airport area and ends at Beijing Daxing Airport. The comprehensive transportation hub of the capital airport should rely on the intercity railway connecting line to realize the rapid contact with Beijing Daxing Airport to meet the needs of air passengers transferring between the two venues. To the north, it should strengthen the connection with the Beijing-Shenyang high-speed railway, which can extend the intercity railway connection line to T1 and T2, and connect with Shunyi West station.

3.2. Tianjin Binhai Airport

For Tianjin Binhai Airport, the ground transportation center is connected with the M2 metro line, which is the direct connecting line between the Tianjin railway station and Tianjin Airport. It is planned to introduce the Beijing-Tianjin intercity airport branch line, Beijing-Binhai intercity railway and Metro Line C2 (connecting Tianjin airport with Dagang area), which will strengthen the connection between Tianjin airport and the Beijing area. For passengers in the direction of Chengde, the planned Tianjin-Chengcang intercity line needs to bypass the central urban area. It would increase the travel time. It is suggested to plan and construct the intercity connecting line between Tianjin West railway station and Northern New Area station. So that trains arriving at Tianjin West railway station can directly contact with the airport through the Northern New Area station, and greatly reducing travel time.
3.3. Shijiazhuang Zhengding Airport
For Shijiazhuang Zhengding Airport, the Beijing-Guangzhou high-speed railway has been introduced, which is passing through the east side of the airport. And a high-speed railway Zhengding Airport station is set up 3 km southeast of the airport. There are free shuttle buses between two transport. Shijiazhuang Metro Line 1 is planned to be introduced into the airport, but it still needs a long time to implement. It is planned that the Shijiazhuang-Xiong'an intercity railway can reach Zhengding Airport directly through Xiong’an station, Xiong’an West station, and Baoding East station. Since passengers still need to rely on ferry cars for transfer between two transport, which reduces the experience.

Shijiazhuang Metro Line 1 should be connected to GTC through Zhengding Airport Station of high-speed railway. In this way, the subway can form a ferry function between GTC and airport stations, which can improve the service level of air-rail intermodal transport.

3.4. Beijing Daxing Airport
For Beijing Daxing Airport, the rail lines planned to be introduced include the Beijing-Xiong’an intercity railway, Langfang-Zhuozhou intercity railway, Xiong’an-Daxing airport express line, the Capital Airport-Daxing Airport connecting line, and the branch line of Beijing-Xiong’an intercity railway to the new airport. In the long term, the R4 line will be planned between the two airports to realize the connection between Beijing’s Eastern Business District, railway transportation hub, and the new airport. It will cover the south and east area of the central city, and connect five comprehensive transportation hubs in series.

According to the above planning, Beijing Daxing Airport has initially formed a radial rail transit network with the airport as the core. In particular, through close contact with the two railway hubs in the Xiong’an New Area, Beijing Daxing Airport will bring stable growth of passenger flow. On this basis, Beijing Daxing Airport should also expand the radiation range of ground traffic to the west. It will actively attract air passengers from areas outside the Beijing-Tianjin-Hebei Region, such as Shanxi, to the new airport.

4. Conclusion
The construction and integration of infrastructure is the hardware foundation of the air-rail intermodal system. The hardware foundation of the air-rail transport system in The Beijing-Tianjin-Hebei Region includes two aspects: The construction of the regional railway transportation network with the four airports as the core, and the construction of the comprehensive transportation hub. In the context of the establishment of the Xiong’an New Area, the optimization path of air-rail intermodal transport network layout in The Beijing-Tianjin-Hebei Region is discussed, which is conducive to realize the optimal allocation of transportation resources and improve the comprehensive benefits.

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