Rail Transit Development Experience of World-class Multi-airport System at Abroad

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Abstract. The advanced development experience of rail transit in foreign world-class multi-airport systems is studied and refined. Based on the fact that China's world-class multi-airport systems will consolidate the development pattern of rail transit as the backbone distribution mode, and based on the perspective of spatial structure and traffic mode of foreign world-class urban agglomerations, the Pacific coast multi-airport system of Japan, the northwest European multi-airport system and the London multi-airport system of Britain are selected as objects of reference for rail transit development experience. Systematically sorting out the current situation of rail transit development of the selected world-class multi-airport systems, from the point of view of development model, hub level, integrated hub, interconnection, true service and so on, this paper studies and summarizes the beneficial enlightenment which is helpful to the development of rail transit of world-class multi-airport systems in our country.

1. Introduction

The construction of world-class multi-airport systems has entered a period of acceleration in China. The China’s Civil Aviation Transport Airport Layout Plan clearly points out that a modern airport system with extensive coverage, reasonable distribution, perfect functions and intensive environmental protection will be built, and three world-class multi-airport systems in Jing Jin Ji area, Yangtze River Delta and Pearl River Delta will be formed by 2025[1]. The Action Program for Building a Civil Aviation Power in the New Era clearly points out that we will achieve the leap from a single air transport power to a civil aviation power in many fields, and build world-class multi-airport systems such as in Jing Jin Ji area, Yangtze River Delta, Pearl River Delta and Chengdu-Chongqing region from 2021 to 2035[2].

High-speed railway and inter-city railway are still in the period of construction and development in China. According to China’s the Medium-and Long-term Railway Network Planning, on the basis of "four vertical and four horizontal" high-speed railway, a high-speed railway network with "eight vertical and eight horizontal" high-speed railway as the skeleton, regional connection lines and inter-city railway supplement is constructed to realize the high-speed railway access to the provincial capital cities and the efficient and convenient connection between the district levels[3].

The construction of urban rail transit in China is still in a period of rapid development. By the end of 2019, the number of cities opened, the scale of line network and the scale of passenger flow in China’s mainland ranked first in the world, and the mileage scale of Shanghai and Beijing ranked among the top two in the world, and cities with mileage of more than 200 kilometers are mostly distributed along the Yangtze River and Pearl River Delta[4]; 229 urban rail transit lines under
construction in China’s mainland are concentrated in 46 cities such as Chengdu, Beijing, Guangzhou, Hangzhou, with a total mileage of 5680.84 km[5]. With the decentralization of administrative examination and approval, the construction of urban metropolitan areas and active fiscal policy is expected to promote the rapid development of urban rail transit construction in China.

Obviously, with the accelerated improvement of the rail transit network of urban agglomerations such as Jing Jin Ji area, Yangtze River Delta, Pearl River Delta and Chengdu-Chongqing region, as an indispensable part of China's world-class multi-airport system, the ground transportation collection and distribution system will consolidate and form a development pattern with rail transit as the backbone, which will effectively support the full play of the overall efficiency and the significant enhancement of the core competitiveness and international influence of the multi-airport system. In order to better promote the sustainable development of rail transit in China's world-class multi-airport systems, it is of great significance to learn from the valuable rail transit development experience of foreign relatively mature world-class multi-airport systems.

2. Reference object

World-class multi-airport system is accompanied by world-class urban agglomeration. According to the standard of urban agglomeration proposed by French geographer Jane Gottman, there are six world-class urban agglomerations in the world, namely, the Pacific coastal urban agglomeration of Japan with Tokyo as the center, the Yangtze River Delta urban agglomeration of China with Shanghai as the center, the urban agglomeration of northwestern Europe with Paris as the center, the London urban agglomeration of the United Kingdom with London as the center, the Atlantic coastal urban agglomeration of the northeastern United States with New York as the center, and the Great Lakes urban agglomeration of North America with Chicago as the center. The world-class urban agglomeration needs the matching world-class multi-airport system as the support for development. Through the interaction and linkage development between the two, they will continue to add new power and inject new momentum into the economic and social development.

Based on the perspective of geographical location, spatial structure, administrative pattern and traffic mode of world-class urban agglomerations, especially considering the relatively mature development of rail transit in Japan and Europe and the fact that rail transit in China is still in a period of accelerated construction, we choose to draw lessons from the advanced development experience of the Pacific coast multi-airport system of Japan, the northwest European multi-airport system and the London multi-airport system of Britain. Follow the objective law of the development of multi-airport system rail transit, and provide useful reference for guiding the development of world-class multi-airport system rail transit in Jing Jin Ji area, Yangtze River Delta, Pearl River Delta and Chengdu-Chongqing region.

Table 1. Basic attributes and traffic patterns of world-class urban agglomerations[6-7]

| World-class urban agglomeration | Population (ten thousand people) | Area (ten thousand square kilometers) | Traffic mode |
|-------------------------------|----------------------------------|---------------------------------------|--------------|
| The Pacific coastal urban agglomeration of Japan | 7000 | 3.5 | Rail transit is dominant and cars are supplementary |
| The urban agglomeration of northwestern Europe | 4600 | 14.5 | Rail transit and highway |
| The London urban agglomeration of the United Kingdom | 3650 | 4.5 | Rail transit and highway |
| The Atlantic coastal urban agglomeration of the northeastern United States | 6500 | 13.8 | Car and partial rail transit |
| The Great Lakes urban agglomeration of North America | 5000 | 24.5 | Car-based |
The Yangtze River Delta urban agglomeration of China

3. Development situation

3.1. The Pacific coast multi-airport system of Japan

The Pacific coast multi-airport system of Japan consists of nine transport airports, of which six airports, Tokyo Haneda, Tokyo Narita, Nagoya Central International, Osaka Kansai, Osaka International (Yidan) and Kobe, have directly introduced rail transit lines.

Table 2. Ground traffic collection and distribution system for each airport of the Pacific coast multi-airport system of Japan

| Serial number | Airport name                  | Passenger throughput (ten thousand person-times) | Cargo and mail throughput (ten thousand tons) | Rail transit line                                    |
|---------------|--------------------------------|--------------------------------------------------|-----------------------------------------------|-----------------------------------------------------|
| 1             | Tokyo Haneda                  | 8550                                             | 126                                           | Kyokohama Express Electric Railway                   |
|               |                                |                                                  |                                               | Tokyo Monorail Tram                                 |
|               |                                |                                                  |                                               | JR Narita East Japan Express Electric Railway        |
|               |                                |                                                  |                                               | Narita Air Port Line                                 |
|               |                                |                                                  |                                               | Electric Railway Cost Line                           |
| 2             | Tokyo Narita                  | 4435                                             | 226                                           |                                                    |
| 3             | Nagoya Central International  | 1235                                             | 19                                            | Nagoya Railway Airport Line                          |
|               | Osaka International (Yidan)   | 73                                               | 0                                             |                                                    |
| 4             | Osaka Kansai                  | 2941                                             | 81                                            | JR West Japan Kansai Airport Line                    |
|               |                                |                                                  |                                               | Tramway Airport Line                                 |
| 5             | Kobe                          | 319                                              | 0                                             | Harbour Artificial Island Line-Airport Line          |
| 6             | Nagoya Nanji Bai Bang         | 93                                               | 0                                             |                                                    |
| 7             |                                | 16                                               | 0                                             |                                                    |

3.2. The northwest European multi-airport system

The northwest European multi-airport system consists of 14 transport airports, of which seven airports, including de Gaulle, Schiphol, Olic, Brussels, Dusseldorf, Cologne Bonn and Lille, are directly connected to rail transit lines.

Table 3. Ground traffic collection and distribution system for each airport of the northwest European multi-airport system

| Serial number | Airport name                  | Passenger throughput (ten thousand person-times) | Cargo and mail throughput (ten thousand tons) | Rail transit line                                    |
|---------------|--------------------------------|--------------------------------------------------|-----------------------------------------------|-----------------------------------------------------|
| 1             | Tokyo Haneda                  | 8550                                             | 126                                           |                                                    |
|               |                                |                                                  |                                               |                                                    |
| 2             | Tokyo Narita                  | 4435                                             | 226                                           |                                                    |
| 3             | Nagoya Central International  | 1235                                             | 19                                            |                                                    |
|               | Osaka International (Yidan)   | 73                                               | 0                                             |                                                    |
| 4             | Osaka Kansai                  | 2941                                             | 81                                            |                                                    |
| 5             | Kobe                          | 319                                              | 0                                             |                                                    |
| 6             | Nagoya Nanji Bai Bang         | 93                                               | 0                                             |                                                    |
| 7             |                                | 16                                               | 0                                             |                                                    |
3.3. The London multi-airport system of Britain

The London multi-airport system of Britain is composed of 13 transport airports, of which Heathrow, Gatwick, Manchester, Stansted, Luton, Birmingham, London City and Southend have directly introduced or closely linked up rail transit lines.

Table 4. Ground traffic collection and distribution system for each airport of the London multi-airport system of Britain

| Serial number | Airport name       | Passenger throughput (ten thousand person-times) | Cargo and mail throughput (ten thousand tons) | Rail transit line                                      |
|---------------|--------------------|--------------------------------------------------|-----------------------------------------------|-------------------------------------------------------|
| 1             | Heathrow           | 8089                                             | 159                                           | Airport Railway Line                                   |
|               |                    |                                                  |                                               | Subway Piccadilly Line                                 |
| 2             | Gatwick            | 4609                                             | 12                                            | Airport Express (Gatwick Express)                      |
|               |                    |                                                  |                                               | British National Railway                               |
| 3             | Stansted           | 2800                                             | 24                                            | Airport Express (Stansted Express)                     |
|               |                    |                                                  |                                               | British National Railway                               |
| 4             | Luton              | 1677                                             | 3                                             | British National Railway                               |
| 5             | London City        | 482                                              | 0                                             | Light Rail DLR                                         |
| 6             | Beech              | 0.2                                              | 0                                             | -                                                      |
| 7             | Southend           | 148                                              | 0                                             | British National Railway                               |
| 8             | Birmingham         | 1246                                             | 3                                             | British National Railway                               |
|               |                    |                                                  |                                               | Airport Rapid Transit System                           |
| 9             | Liverpool          | 505                                              | 0                                             | -                                                      |
| 10            | Manchester         | 2829                                             | 12                                            | British National Railway                               |
| 11            | Lizzie Bradford    | 404                                              | 0                                             | -                                                      |
| 12            | Doncaster          | 122                                              | 1                                             | -                                                      |
4. Beneficial enlightenment

Taking a comprehensive view of the current development of the rail transit of the Pacific coast multi-airport system of Japan, the northwest European multi-airport system and the London multi-airport system of Britain, all guided by better supporting the development of the world-class multi-airport systems to a higher quality, they have realized the organic connection and deep integration with the rail transit system of the world-class urban agglomerations, and established a functional, efficient, smooth, convenient and fast integrated rail transit system of the multi-airport system, and are not a simple combination and spatial superposition of the collection and distribution system of individual airport and ground rail transit in the group.

4.1. The multi-mode rail transit network system of multi-airport system is constructed

Driven by the continuous growth of air passengers in world-class urban agglomerations, fully considering the differences in functional positioning and service characteristics of different rail transit modes[8], a multi-mode airport group rail transit network system with different types of rail transit undertaking different service functions is established. Among them, the high-speed railway mainly serves the medium-and long-distance passenger travel around the urban agglomeration or between the urban agglomeration, the inter-city railway mainly provides efficient and convenient transport services for the medium-and short-distance passengers between the neighboring cities in the urban agglomeration, the urban railway mainly serves the short-distance passengers between the urban areas and suburbs and connecting the satellite towns or urban circles around the city, and urban rail transit is more responsible for the travel service function of cross-group passengers within the city.

The Pacific coast multi-airport system of Japan has formed a multi-mode airport group rail transit network system, which is mainly composed of inter-city railway and city railway. Tokyo Narita, Osaka Kansai, Nagoya Central International and other airports are directly introduced into the inter-city railway. Tokyo Haneda, Osaka Kansai, Osaka International (Yidan), Kobe and other airports are directly connected to the Metropolitan Railway.

The northwest European multi-airport system has formed a multi-mode airport group rail transit network system composed of high-speed railway, intercity railway, urban rail transit and so on. Airports such as de Gaulle, Schiphol, Brussels and Cologne Bonn are directly connected to the high-speed railway, airports such as Schiphol and Cologne Bonn introduce intercity railway, airports such as de Gaulle and Cologne Bonn are directly connected to the urban railway, while Ollie, Dusseldorf and other airports introduced urban rail transit.

The London multi-airport system of Britain has formed a multi-mode airport group rail transit network system composed of intercity railway and urban rail transit, in which airports such as Stansted and Birmingham are directly connected to or closely connected with the intercity railway, while Heathrow, Gatwick, Stansted, the City of London and other airports have introduced urban rail transit.

4.2. The multi-level multi-airport system rail transit hub system has been created

Measures are taken for the classification of passengers in the hinterland with different levels or functions of airports and different scope and intensity of services, the formation of a high-level airport to introduce a relatively large number of (external) rail transit modes and lines of the multi-level structure of the multi-airport group rail transit hub system[9] is formed. The typical characteristics are that the high-level airport external rail transit (high-speed railway, intercity railway) and internal rail transit (urban railway, urban rail transit) are relatively developed, while the low-level airport is mainly internal rail transit. Rail transit lines are mostly directly connected with major urban railways, highways, urban rail transit and other hubs.

The Pacific coast multi-airport system of Japan has formed a hierarchical rail transit hub system with Tokyo airport as the core, Osaka airport and Nagoya airport as the backbone, and other airports as important components. Among them, Tokyo airport is connected to two rail transit modes, inter-city
railway and urban railway, and five rail transit lines, providing rapid collection and distribution services for air passengers inside and outside the Tokyo metropolitan area; Osaka airport is connected to two rail transit modes, inter-city railway and urban railway, and three rail transit lines, which make it convenient for the airport to collect and distribute air passengers inside and outside the Osaka metropolitan area; Nagoya airport is connected to a rail transit mode of intercity railway and a rail transit line, which quickly radiate air passengers in the Nagoya metropolitan area; Kobe airport accesses a rail transit mode of urban railway and a rail transit line, which are mainly responsible for the traffic distribution function of the airport to the local market; Other airports have not yet been connected to the rail transit.

The northwest European multi-airport system has formed a hierarchical rail transit hub system with Paris and Cologne airports as the core, Schiphol, Brussels airport and Dusseldorf airport as the backbone, and other airports as the important composition. Among them, Paris airport has access to three rail transit modes: high-speed railway, urban railway and urban rail transit, while Cologne Bonn airport has access to three rail transit modes: high-speed railway, intercity railway and urban railway to fast service for air passengers in the city where the airport is located and its surrounding areas; Both Schiphol airport and Brussels airport have access to two rail transit modes, high-speed railway and intercity railway, to provide fast collection and distribution services for air passengers departing from the surrounding areas of the airports; Dusseldorf airport has access to two rail transit modes of intercity railway and urban railway, which are convenient for the airport to collect and distribute air passengers in and around the city; Lille airport is connected to urban rail transit as a rail transit mode, which is mainly responsible for the traffic distribution function of the airport to the local market; Other airports have not yet been connected to rail transit.

The London multi-airport system of Britain has formed a hierarchical rail transit hub system with London airport as the core, Manchester airport and Birmingham airport as the backbone, and other airports as important components. Among them, London airport has access to two rail transit modes, inter-city railway and urban rail transit, to quickly serve air passengers inside and outside the London metropolitan area; Manchester, Birmingham and Southend airports are all connected to a rail transit mode of inter-city railway, which is mainly responsible for the service function of passengers in the surrounding area to quickly arrive and leave the airport; Other airports have not yet been connected to rail transit.

4.3. The airport integrated transportation hub system with seamless connection has been constructed

Guided by the high-quality transfer experience of maximizing the seamless connection between civil aviation flights and rail transit trains, it has basically realized the close integration of the transport airport terminals and rail transit airport stations that have introduced rail transit lines into the multi-airport system, and established a hub group or cluster composed of airport integrated transportation hubs with efficient air-rail transit for air passengers.

The Pacific coast multi-airport system of Japan has formed a hub group composed of six airport integrated transportation hubs with efficient and convenient air-rail transfer. Among them, Tokyo Haneda airport has two domestic terminals T1 and T2, an international terminal and five rail transit stations, Kyokohama Express Electric Railway Haneda Airport Line has a domestic station on the negative third floor between the two domestic terminals and an international station on the negative second floor of the international terminal, Tokyo Monorail Tram has two stations T1 and T2 on the negative second floor near the two domestic terminals and an international station on the third floor of the international terminal. Tokyo Narita airport has three terminals T1, T2 and T3, as well as three rail transit stations at Narita Airport Terminal T2 near T2, Narita Airport Station near T1, and East Narita Station in the middle, Narita Airport Terminal T2 Station and Narita Airport Station are all composed of JR East Japan and Electric Railway, East Narita Station only stops on Electric Railway Cost Line, the negative floor of Narita Airport Terminal T2 of Narita Airport leads to Terminal T2 and T3, and there is an underground passageway directly connected to East Narita Station. The Central International airport has a cross-shaped terminal (the south is the domestic terminal and the north is
the international terminal) and a central international airport station on the Nagoya Railway Airport Line next to the terminal. Osaka Kansai airport has two terminals T1 and T2, as well as a Kansai Airport Station shared by JR West Japan Kansai Airport Line and Tramway Airport Line on the second floor of Terminal T1. The terminal area of Osaka International (Yidan) airport is composed of two terminals: the south terminal and the north terminal and the central area, with a walking distance of no more than 300 meters to the Osaka Monorail Tram Airport Station which can reach the south terminal and the north terminal. Kobe airport has a terminal and a Kobe Airport Station on the Harbor artificial Island Line-Airport Line where passengers can transfer quickly.

The northwest European multi-airport system has formed a hub group composed of seven airport integrated transportation hubs with efficient and convenient air-rail transfer. Among them, Charles de Gaulle airport has three terminals: T1, T2 (main terminal), T3 and two rail transit stations, The French Trunk High-speed Railway sets up T2 Terminal Station at the junction of Terminal E and F in the middle of Terminal T2 at the same station with the Suburban Express Railway line, and the Suburban Express Railway line has T1 Terminal Station next to Terminal T3. Dutch Railway Schiphol Railway Station is located below the departure hall of Schiphol airport, Brussels Airport Railway Station is located on the ground floor of Brussels airport Terminal, passengers can quickly reach the urban area and other domestic and international destinations by train. Ollie airport has two terminals, the West Terminal and the South Terminal, and the Airport Rail Transit Line (Orlyval) has stations in both terminals. Dusseldorf airport has three terminals A, B and C, the Air Track Airport Line (monorail) has Terminal A/B Station between terminal A and B, terminal C has Terminal C Station, and the Intercity Light Rail Line S11 has a station in the north of the terminal. Cologne Bonn Airport has two terminals, T1 and T2, ICE (High Speed Rail), RE (Regional Express) and S-Bahn (Metropolitan Railway), all of them pass through the airport railway station below the terminal. Lille airport has a two-story passenger terminal, and the Airport Express (la navette) has an airport station opposite the terminal.

The London multi-airport system of Britain has formed a hub group of eight airport integrated transport hubs with efficient and convenient air-rail transfer. Among them, Heathrow airport has a total of four terminals 2, 3, 4 and 5 (terminal 1 has been closed), the Airport Railway Line has one stop at terminal 2 and 3 and another at terminal 5, the Subway Piccadilly Line has stations in all four terminals. Gatwick airport has two north and south terminals, and British National Railway and Airport Express(Gatwick Express) have stations inside the airport. Manchester airport has three terminals T1, T2 and T3, while the British National Railway connects three terminals through the air promenade. On the ground floor of Stansted airport terminal is the Airport Railway Station and Airport Express (Stansted Express) Station. Luton airport has a terminal and Luton Airport Railway Station is located very close to the airport. Birmingham airport has two terminals T1 and T2, its Rapid Transit System has set up a station at terminal T1, which is directly connected to the Birmingham International Railway Station 600 meters away. There is a London City Airport Station on the Light Rail DLR line next to London City airport. There is a railway station at Southend airport.

4.4. The integrated rail transit network pattern of the multi-airport system has been formed

The airport integrated transportation hub connected to the rail transit line, as an integrated transportation hub composed of civil aviation and rail transit, is the key node to integrate into the urban agglomeration rail transit network system. Relying on the interconnected rail transit network constructed by the rail transit integrated hub in the urban agglomeration, the integrated multi-airport group rail transit network pattern is formed, which strongly supports the construction of the world-class multi-airport system, and effectively meets the functional requirements of efficient access between core airports, emergency services and so on.

The Pacific coast multi-airport system of Japan relies on the hub group composed of six airport integrated transportation hubs that introduce rail transit, as well as JR lines, private railways and trams within the core cities all over Japan, it has realized the direct or indirect interconnection of rail transit
between major airports. For example, Haneda airport and Narita airport can be connected through the Kyokohama Express Electric Railway Airport Line and suburban railway.

The northwest European multi-airport system is a hub group composed of seven integrated airport transport hubs that introduce rail transit. France, Germany, the Netherlands, Belgium and other countries organically connected high-speed railway, inter-city railway (French high-speed railway is the main integrated transport corridor connecting the big cities in northwest Europe), as well as the urban railway and airport rail transit of the city where the airport is located. It ensures the direct or indirect interconnection of rail transit between important airports, for example, the connection between Charles de Gaulle airport and Ollie airport can rely on the Suburban Express Railway (RER-B) and Ollie Airport Rail Transit (Orlyval) line.

The London multi-airport system of Britain relies on a hub group of eight airport integrated transport hubs that introduce rail transit, as well as rail lines such as the British National Railway, Airport Rail Transit and the Rapid Transit System, which ensures the direct or indirect interconnection of rail transit between core airports. For example, Heathrow airport and Gatwick airport can establish close ties through National Railways, Heathrow airport and London City airport can be interconnected through the Subway Piccadilly Line, the Light Rail DLR and the London Underground Network.

4.5. The accurate rail transit service system for the multi-airport system has been established

Fully in line with the temporal and spatial distribution characteristics of air passenger flow in the multi-airport system, led by maximizing the differential distribution needs of passengers for different travel purposes or different types of passengers in terms of time, fare, comfort, convenience, etc., a more intimate and diverse high-quality airport group rail transit service system is built, which effectively improves the cluster transportation quality and passenger travel experience of world-class multi-airport system.

The operating time of rail transit in the multi-airport system tends to be maximized. The operation time of rail transit in the main airports with the introduction of rail transit in the world-class airport group is relatively long, which can basically meet the transport service needs of morning and evening passengers entering and leaving the port by rail transit. For example, the Tokyo Monorail Tram connected to Tokyo Haneda airport in the Pacific coast multi-airport system of Japan operates for about 19 hours, with an average of 4 minutes during the day, while the Suburban Express Railway (RER-B) introduced by Charles de Gaulle airport in the northwest European multi-airport system runs for more than 19 hours, with an average of 5-10 minutes. The operating time of the rail transit at Heathrow airport in the London multi-airport system of Britain is 18-19 hours, with an average of 15 minutes, while the operating time of the Rapid Transit System at Birmingham airport is close to 21 hours, with an average of 2 minutes.

The rail transport services of the multi-airport system are more diversified. The core airport rail transit that introduces into the world-class multi-airport system provides not only fast train services with high speed, few stops and high fares, but also slow train services with slow speed, many stops and low ticket prices, maximizing to meet the differential distribution needs of air passengers with different characteristics in terms of cost, time, speed and so on. For example, in the Pacific coast multi-airport system of Japan, the Kyokohama Express Electric Railway connected to Tokyo Haneda airport has five kinds of train services including ordinary, airport express, special emergency, and Tokyo Monorail Tram has three kinds of airport express, section fast and ordinary train services; The Suburban Express Railway (RER-B) introduced by Charles de Gaulle airport in the northwest European multi-airport system provides two kinds of train services: fast train and local train; The Airport Railway Line connected to Heathrow airport in the London multi-airport system of Britain also provides both fast and slow train services.

5. Conclusion

Taking a comprehensive view of the current development of rail transit in the Pacific coast multi-airport system of Japan, the northwest European multi-airport system and the London multi-airport
system of Britain, a multi-mode airport group rail transit network system is constructed, a multi-level airport group rail transit hub system is built, a seamless airport integrated transport hub group is constructed, an integrated airport group rail transit network pattern is formed, and an accurate rail transit service system of airport group is established, which can provide useful reference for guiding the development of world-class multi-airport system rail transit in Jing Jin Ji area, Yangtze River Delta, Pearl River Delta and Chengdu-Chongqing region.

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