Citation: CUI Yanbo, LIANG XiaoJie, SUI Ling. Evaluation on the Convenience of air–rail Multimodal Transportation [J]. Urban Transport of China, 2019 (04): 73–79, 104.

Evaluation on the Convenience of air–rail Multimodal Transportation

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Abstract: Based on the connotation and practical significance of air–rail multimodal transportation (ARMT), this paper reviews the development of ARMT in major cities' airports in China. In terms of facilities and operational services, the paper compares the convenience of transfer between air transportation and railway in different airports. With the subjective and objective comprehensive weighting method and the entropy weight method, the paper develops a subjective and objective comprehensive evaluation method for evaluating the convenience of ARMT. The development level of each indicator and the areas to be improved are systematically sorted out. In order to give full use to the efficiency of rail transit collecting and dispatching and to achieve the application of ARMT at a higher level and a wider scope, the paper provides planning suggestions: 1) actively build high-speed railway and intercity stations around the hub airports; 2) rationally plan all types of rail transit facilities; 3) optimize the strategy of train formation; 4) promote the integration of air transportation and railway sectors and create cooperative products and services. **DOI:** 10.13813/j.cn11-5141/u.2019.0411-en

Keywords: transportation planning; air–rail multimodal transportation; subjective and objective comprehensive weighting method; entropy weight method

1 Background and theory

1.1 Background and significance of air–rail multimodal transportation

Air–rail multimodal transportation (ARMT) started in Western European countries and has been developing for decades. Among the five busiest airports in Europe, except London Heathrow International Airport which is located outside of continental Europe, the other four airports have all built high-speed rail (hereinafter referred to as HSR) lines. The HSR lines diverted some domestic passengers and promoted the increase in international passengers. They eventually brought more passengers to civil aviation, which led to the expansion of airports [1].

In recent years, the construction of transportation infrastructure has been on the rise in China. The passenger and freight throughput volumes of HSR and civil aviation have maintained double-digit growth, leading to the world's largest HSR network and the second largest aviation network [2]. The coverage of rail and urban rail transit has gradually expanded, and the details are shown in Figure 1.

Since 2012, the number of civil aviation and HSR facilities and passenger volumes have been growing rapidly in China, with the growth rate of HSR passenger volume being even greater. Due to the increasing density of the HSR network and the shortage of airspace resources, passengers who originally travel by air for medium- and short-distance trips gradually shift to HSR [3]. After the Wuhan–Guangzhou section of the Beijing–Guangzhou HSR was opened, many flights in the airways of the central and southern region, such as Wuhan–Guangzhou, Wuhan–Changsha, and Changsha–Guangzhou airways, were reduced or even stopped [4]. Dialectically, the benign market competition between HSR and civil aviation has pushed civil aviation to shift its valuable transportation capacity from short-distance airways with less profitability to medium- and long-distance airways for more profit, and the efficient and dense transportation network of HSR has also provided more medium- and long-distance passengers to aviation quickly and on time.

Meanwhile, the urban rail transit construction has ushered in prosperity. The number of cities that have opened urban rail transit increased year by year, and the total mileage grew swiftly. By 2017, there were 18 cities that invested more than CNY 10 billion to urban rail transit. From 2011 to 2017, the annual growth rates of vehicles, passengers, and mileages open for operation and under construction all exceeded 15%.

The network operation of HSR has also brought more passengers to civil aviation. HSR and civil aviation have the advantages for trips between 300 km and 800 km and over 800 km, respectively [5–7]. In the context of the dual growth of

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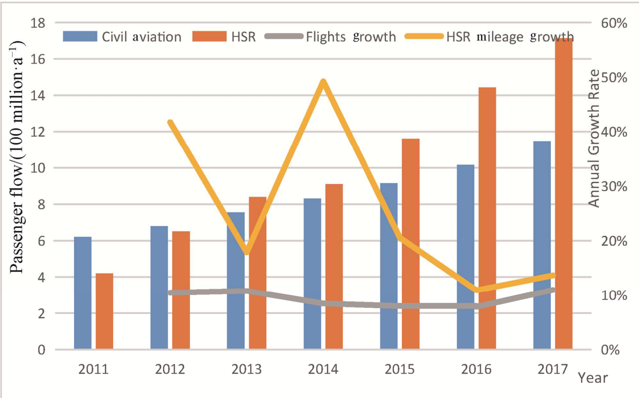
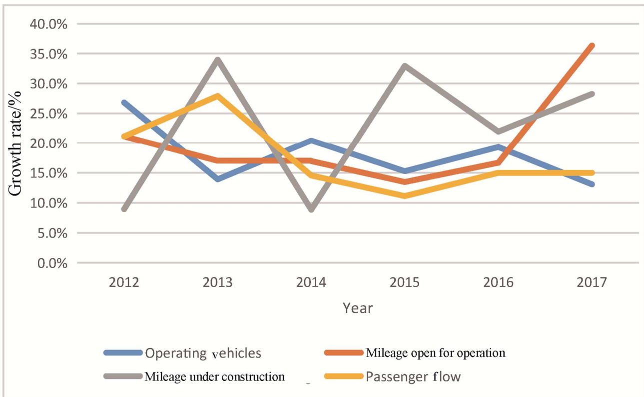
HSR and civil aviation since 2012, the average distance of railway has gradually shortened and that of civil aviation has gradually increased. The advantages of division of labor and coordination between the two have become increasingly prominent. With the completion of new airports in Beijing, Chengdu and other international aviation hub cities and new terminals in Chongqing, Wuhan, Zhengzhou and other China's aviation hub cities, the implementation of ARMT based on infrastructure can fully meet the growing travel demand and integrate the internal and external transportation capacities, which has great practical significance in the optimization of resource allocation.



a Civil aviation and HSR network construction and traffic growth trend



b Urban rail transit construction and traffic growth trend

Figure 1 Development statistics of civil aviation, high speed rail, and urban rail transit in China

Source: *Statistical Communique of Transport Industry* over the years

ARMT is conducive to giving full play to the advantages of airport hubs (wide coverage) and railways (large-range, large-capacity, and fast and on time). ARMT can eventually complement each other's advantages, avoid disorderly competition, and improve the convenience of air travel. Moreover, it can reduce transfer time, lower the interference of transferring passengers to urban traffic, and turn an airport into a large integrated transportation hub connecting cities.

As aviation hubs, the three first-tier cities, Beijing, Shanghai and Guangzhou, are facing increasingly busy international airways as well as limited urban land and airspace resources. The demand for regional airlines cannot be met, which further promotes HSR, as a substitute for regional airlines, to form a hub radial ARMT network with mainline airlines [8].

1.2 Theories and comparative analysis

ARMT refers to a joint mode of transportation between aviation and railways, involving civil aviation airports, airlines, railway systems, etc. There are two major types of ARMT: ARMT based on infrastructure and ARMT based on transportation services. The ARMT based on infrastructure is also called the dual-modal direct-access mode. It connects railway facilities and airport terminals to realize the centralized layout of multiple fast, punctual and large-capacity public transportation facilities so that the aviation and railway complement each other in the form of "trunk and branch". Narita International Airport and Haneda International Airport in Tokyo are known as this type. The ARMT based on transportation services focuses on the integration of services, such as ticketing, baggage check-in, and remote check-in, and the integration of multiple transportation enterprises and departments. "Zero-elevation regional aviation", represented by Frankfurt, Germany, links the railway train number with the flight number through code sharing, and makes it possible for passengers to book train tickets through Lufthansa's booking network. Moreover, it matches train schedules with flight times and allows passengers to check in, get through security and check in luggage at the railway station without the need to get through security again at the airport. ARMT expands the influence area and the agglomeration effect of the airport, improves the travel convenience and the overall economic benefits, and makes the multi-level development of the internal transportation within the urban agglomeration clearer.

The railways in ARMT generally include the following types: HSR (national HSR and intercity HSR), ordinary railways, and urban rail transit (airport express railway line, subway, and light rail), among which two types exist in China's current ARMT: HSR and urban rail transit (hereinafter referred to as URT).

The first large-scale civil airport with Ground Transportation Center (GTC) in China is Shanghai Hongqiao International Airport (hereinafter referred to as "Hongqiao Airport"). Hongqiao Railway Station, which is directly connected with Hongqiao Airport, is a special station in the national HSR network. Since then, Haikou, Changchun, Wuhan, Zhengzhou, Changsha, Sanya and other cities have successively connected HSR stations with other intercity railway stations through airport intercity lines. Some of them even built both intercity and URT lines, while Chengdu and Shijiazhuang directly built the airport railway station as the national HSR station. Zhengding International Airport (hereinafter referred to as SJW) in Shijiazhuang introduced one-stop ticketing service (on the CTRIP website) for air–rail tickets and free accommodation for overnight transfers. More than 40% of SJW's ARMT passengers are from Beijing, so

JSW undertakes the passenger overflow from Beijing Capital International Airport (hereinafter referred to as “Capital Airport”).

Among other airports with high passenger throughput, Capital Airport, Shanghai Pudong International Airport, and Guangzhou Baiyun International Airport (hereinafter referred to as “Baiyun Airport”), etc. have built or are building airport express lines. However, most of the lines have too many stops with the maximum speed of 80–100 km·h^{-1}. Large-capacity URT has been generally valued in the infrastructure construction of China’s hub airports.

Different from Hongqiao Airport, other airports have to rely on connection lines or HSR hubs to transfer for their ARMT since the train stations in or near the airport districts have limited number of trains and limited handling capacity. The number of transfers and train frequencies have great impact son the convenience of ARMT. Compared with URT, HSR or intercity railways are more effective in short- and medium-distance railway ground transportation to connect with long-distance aviation of international or regional hub airports. Therefore they are more effective in expanding the influence of these airports.

2 Construction of ARMT convenience indicator system

2.1 Selection of evaluation indicators

This paper studies the cities that run HSR or intercity railways to airports (Shanghai Hongqiao Station is not included since it is a special station in the national HSR network) and compares their ARMT based on infrastructure. Indicators such as rail transit type, rail capacity, airport throughput, and train interval are adopted to analyze the development status and the horizontal gap. Eight major international airports which are also regional hubs are selected, including Chengdu Shuangliu International Airport (hereinafter referred to as “CTU”), Zhengzhou Xinzheng International Airport (hereinafter referred to as “CGO”), Changsha Huanghua International Airport (hereinafter referred to as “CSX”), Wuhan Tianhe International Airport (hereinafter referred to as “WUH”), Haikou Meilan International Airport (hereinafter referred to as “HAK”), Sanya Fenghuang International Airport (hereinafter referred to as “SYX”), Changchun Longjia International Airport (hereinafter referred to as the “CGQ”), and SJW.

With the reference to the classification of the ARMT mode, the convenience of ARMT is evaluated according to infrastructure conditions and operational service capabilities in the design of the indicator system. The structure of the indicator system is shown in Table 1. In Table 1, a_{11} is the platform size of the transfer station; a_{12} is the distance between the airport and the nearest HSR hub; $a_{13}=\begin{cases}1, & \text{HSR}\\ 2, & \text{Intercity rail transit}\\ 3, & \text{Secon}\end{cases}$ a_{14} is the number of stations that can be accessed within three hours from the airport. For operational service capacity,

$$a_{21}=r_t\times n_r\times 2+r_e\times n_r\ , \quad (1)$$

$$a_{22}=r_e\times n_c\ , \quad (2)$$

$$a_{23}=L/\left(r_t+r_e\right)\ , \quad (3)$$

where r_t is the daily number of trains passing through the airport/(trains·d); r_e is the daily number of trains starting or ending at the airport/(trains·d); n_r is the average passenger capacity of a railway train/(persons·train); n_c is the average passenger capacity of an URT train/(persons·train); L is the length of train operation hours/h in a day; a_{24} is the ratio of the passenger capacity of the current transfer station to the daily average airport throughput. When the daily passenger-carrying capacities of railways and URT (a_{21} and a_{22}) are estimated, the rated passenger capacity of the actual train model is multiplied by the number of train cars. Since the existing rail transit stations are all located at the end of the line, the calculation of daily passenger-carrying capacity of URT only includes trains starting or ending at the airport.

Table 1 Convenience indicator system of ARMT

Primary indicator	Secondary indicators	Tertiary indicators
Convenience of ARMT a	Infrastructure condition a_1	Platform size of the transfer station a_{11}
		Distance to the nearest HSR hub a_{12}
		Rail transit type a_{13}
		Number of accessible stations a_{14}
	Operational service capacity a_2	Daily passenger-carrying capacity of railway a_{21}
		Daily passenger-carrying capacity of URT a_{22}
		Average departure interval a_{23}
		Ratio of railway capacity to airport throughput a_{24}

2.2 Weighting and evaluation methods

The subjective and objective comprehensive weighting method is adopted to comprehensively evaluate the convenience of ARMT. Subjective methods include the Analytic Hierarchy Process (AHP), the Delphi method, and the comparison sort method, among which AHP is the most widely used method. The objective methods include the standard deviation method, the regression method, and the entropy weight method. Subjective methods focus on expert experience, while objective methods pay more attention to the values of indicators. Due to the lack of authoritative evaluation on various indicators of ARMT, the subjective and objective comprehensive weighting method is conducive to comprehensively considering both subjective experience and objective data, so the evaluation result is more comprehensive and reliable.

When objective methods are adopted, data processing should be conducted first to convert benefit data, cost data and 0–1 integer variables into normalized indicators in the range of [0, 1]. The formula to calculate normalized cost and benefit indicators with the upper and lower limits are as follows:

$$s_i = \frac{z_i - \min i}{\max i - \min i}\ , \tag{4}$$

$$s_i = \frac{\max i - z_i}{\max i - \min i}\ , \tag{5}$$

where z_i is the value of the indicator; max$i$ is the maximum value of the indicator (i.e., the upper limit); min$i$ is the minimum value (i.e., the lower limit); s_i is the value of the normalized indicator. In this indicator system, a_{11}, a_{13}, a_{14}, a_{21}, a_{22}, and a_{24} are benefit indicators, and the rest are cost indicators. According to the collection/distribution capacity and passenger capacity, different types of rail transit are assigned with different a_{13} values: 0.4 for the HSR, 0.4 for the intercity railway, and 0.2 for the URT. The numbers are then added to calculate a score.

The entropy weight method is used to determine the entropy value as follows:

$$E_j = -(\ln m)^{-1}\sum_{i=1}^{m} p_{ij}\ln p_{ij},\quad i=1,2,\cdots,m;\ j=1,2,\cdots,n, \tag{6}$$

where m is the number of evaluation indicators; n is the number of objects to be evaluated, and $p_{ij} = \frac{b_{ij}}{\sum_{i=1}^{m} b_{ij}}$; b_{ij} is the normalized value of the j^{th} object of the i^{th} indicator s_i. To define the value of $\ln p_{ij}$, we assume that when $p_{ij} = 0$, there is $\lim_{p_{ij}\to 0}\ln p_{ij} = 0$.

Entropy values are used to calculate the entropy weight as follows:

$$W_j = \frac{1 - E_j}{n - \sum_{j=1}^{n} E_j},\ j = 1,2,\cdots,n\ . \tag{7}$$

2.3 Least squares optimization model

The preference of subjective experience as well as the authenticity and differentiation of decision making should be considered. Then a weighted least square optimization model is established to determine the indicator weight by introducing the deviation function with the target to minimize the difference between the comprehensive weight and the subjective/objective weight [9].

$$\min \sum_{k=1}^{2}\sum_{i=1}^{8}\sum_{j=1}^{8}\alpha_k\left[(w_j - w_{kj})b_{ij}\right]^2\ , \tag{8}$$

$$\text{s.t.}\ \sum_{j=1}^{m} w_j = 1,\ w_j > 0\,(j\in M)\ , \tag{9}$$

where w_j ($j \in M$) is the comprehensive weight; w_{kj} is the weight for indicator j in weighting method k; a_k is the weighting coefficient for weighting method k; b_{ij} is the normalized evaluation matrix of indicator i and object j, and $\sum_{k=1}^{q} a_k = 1$; q is the number of weighting methods. The Lagrangian function can be formed as follows:

$$L(w,\lambda) = \sum_{k=1}^{2}\sum_{i=1}^{8}\sum_{j=1}^{8}\alpha_k\left[(w_j - w_{kj})b_{ij}\right]^2 + 2\lambda\left(\sum_{j=1}^{m} w_j - 1\right). \tag{10}$$

After taking partial derivatives on both sides of Equation (10), we can obtain the optimal solution of the model according to the necessary conditions for the existence of extreme values.

$$w_j = \sum_{k=1}^{q}\alpha_k u_{kj},\ j\in M\ , \tag{11}$$

$$h(u_i, u_j) = \sum_{l=1}^{m} u_{il}\lg\frac{u_{il}}{u_{jl}}\ , \tag{12}$$

where u_{kj} is the weight of object j in the k^{th} weighting method, calculated based on the score of each indicator. According to the conclusion of the optimization theory, when there is a global optimal solution $d^* = (d_1^*, d_2^*,\ \ , d_m^*)$, it should satisfy the following condition:

$$d_i^* = \frac{\prod_{j=1}^{q}(u_{ji})^{\frac{1}{q}}}{\sum_{i=1}^{m}\prod_{j=1}^{q}(u_{ji})^{\frac{1}{q}}},\ i = 1,2,\cdots,m\ . \tag{13}$$

Equation (13) is used to calculate the fitness $h(u_i, d^*)(i = 1, 2,\cdots, q)$ of the i^{th} weighting result and the aggregation weight as well as the credibility of each weighting result. The greater fitness of the k^{th} weighting result and the aggregation weight vector indicates its more obvious effect in the combination weight. Its credibility weight is

$$\alpha_i = \frac{h(u_i, d^*)}{\sum_{i=1}^{q} h(u_i, d^*)},\ i = 1,2,\cdots,q\ . \tag{14}$$

3 Evaluating the convenience of ARMT

3.1 Data collection and indicator calculation

As the original data of the daily passenger-carrying capacity of railways and URT are not published, a_{21} defined in Section 2.1 is estimated and the corresponding s_5 and b_{5j} are calculated by referring to relevant data. During the estimation, the daily passenger-carrying capacities are calculated according to the rated capacity of the actual train model and the number of train cars. In terms of the number of stations that can be accessed within three hours, although SJW and CTU are located on the mainline of China's national railway network and are accessible through many trains, people in Taiyuan or Kunming, which are far, generally do not choose these stations for ARMT. Therefore, this study only select the stations within 800 km (a distance range over which railways have advantages) of the airports as ARMT accessible stations. Data are collected to compare the airports with ARMT and to analyze the adaptiveness of existing railway facilities to the development of these airports. The results are shown in Table 2.

Apart from CGQ and SJW, the airports with ARMT in this study are all hub airports ranked in top 20 in terms of passenger throughput.

A questionnaire survey was conducted to understand the impact of each indicator on the passenger travel experience. The evaluation matrixes and consistency test indicators are obtained. The subjective weight calculated by the AHP method is $w_1 = [0.07, 0.16, 0.34, 0.03, 0.09, 0.04, 0.02, 0.25]$.

After the indicator scores in Table 2 are normalized, the entropy values and corresponding entropy weights of each indicator are calculated, and the entropy weight method is adopted to determine the objective weights as $w_2 = [0.07, 0.10, 0.02, 0.10, 0.12, 0.34, 0.07, 0.18]$.

The difference of the two weighting methods is mainly reflected in rail transit type a_{13}, number of accessible stations a_{14}, and daily passenger-carrying capacity of URT a_{22}, which have small variances for the objective method. By contrast, with the subjective method, a_{22} and a_{14} have larger variances among different airports and the weights in the entropy method are relatively higher.

Matlab is used to solve for the optimal solution, calculate the subjective and objective weighting coefficients α_1 and α_2 according to Equation (12) and (14), and calculate the comprehensive weights, which is $w = [0.07, 0.13, 0.20, 0.06, 0.10, 0.18, 0.04, 0.22]$. The final scores of each airport are shown in Table 3.

3.2 Analysis of comprehensive weighting results

The range of the comprehensive weights is [0, 1], which is expanded to the range of [0, 100]. After this expansion, the ARMT convenience scores of all airports in this study are distributed in (30, 70), which shows that the ARMT systems in these regional hub airports all have their own advantages with no one showing absolute advantages. CTU, WUH, and CGO are superior in infrastructure. They provide direct access to the airport using the dual railways of "Intercity + Metro" with frequent trains and large capacities, which are ranked as the top three airports with convenient ARMT. Among the airports with higher passenger throughput, CSX uses the low-cost low-to-medium-speed maglev train, which can fully meet the current passenger demand. However, CSX will face pressure to run more maglev trains on this single rail line when the passenger demand grows in the future, and it is difficult to provide convenient service of in-station-transfer in ticketing, security checks, and other aspects. As a result, the convenience for passengers outside Changsha is poor, which affects the score of CSX. CGQ is an airport with smaller passenger throughput, but its score is higher than the average due to more trains starting or ending at this station and abundant intermodal transportation capacities.

Comparing the scores of each indicator leads to the following conclusions:

1) In terms of the ARMT daily passenger-carrying capacity, CGO, CSX, and CGQ have larger capacities, which are on average more than 50% of the airport throughput. The main reason is that they use intercity or maglev express lines to run the trains between the HSR hubs in city centers and the airports more frequently. Furthermore, the airports are located at the end of the rail lines, thus ensuring that the rail lines are dedicated to serving the passengers arriving at or departing from airports more effectively. In contrast, the railway stations for SJW, WUH, SYX, and HAK are located on the main lines of the national HSR network, with fewer trains passing through and limited passenger-carrying capacities due to limited number of seats assigned to the airport stations in each train.

Table 2 Comparison of airport evaluation indicators

Airport	2017 Passenger throughput rank	a_{11}	The nearest HSR hub (railway station)	a_{12} / min	a_{13}	a_{14}	a_{21}/(10^4 persons·d^{-1})	a_{22}/(10^4 persons·d^{-1})	a_{23} / min	Daily passenger throughput/(10^4 persons·d^{-1})	a_{24}
CTU	4	2/6	Chengdu South	10	2+3	20	2.25	33.7	39	13.64	16.5%
CGO	13	2/4	Zhengzhou East	17	2+3	9	4.75	22.3	30	6.66	71.4%
CSX	14	1/2	Changsha South	19.5	3	2	0	7.26	18	6.51	111.5%
WUH	16	2/4	Hankou	12	2+3	28	1.80	2.61	39	6.34	28.4%
HAK	17	2/4	Haikou East	8	2	13	2.60	0	19	6.19	42.0%
SYX	20	2/4	Sanya	10	2	21	0.70	0	58	5.31	13.2%
CGQ	30	2/4	Changchun	15	2	10	3.44	0	20	3.19	107.7%
SJW	33	2/4	Shijiazhuang	14	1	22	1.25	0	28	2.62	47.6%

Data source: the railway 12306 website (https://www.12306.cn), the App "HSR Manager", the railway station facility inventory of various railway bureaus, and operation statistical bulletin of various airports.

Table 3 Airports evaluation score

Airport	CTU	CGO	CSX	WUH	HAK	SYX	CGQ	SJW	Average
Score	67	66	50	61	46	31	54	41	52

2) In terms of the connection to URT, the three regional hub airports, CTU, CGO, and WUH, all use the operation mode of dual railways “Intercity + Metro”, and the airport stations are all located at the end of the metro lines. The passenger-carrying capacity of URT can meet the existing demand of airport passenger throughput. However, from the perspective of urban transportation, unlike the maglev trains in Changsha, metros have more stops along the line, and a considerable part of their capacities is to serve the urban traffic. Therefore, the metro capacity actually used to serve the airport is limited, and for business travelers, the experience of the cheap, crowded, and slow metro is slightly worse than that of the airport express line.

3) In terms of the platform size, all existing airport stations in this study are second- or third-class stations with low levels and small scales. Except CTU and CJW which are located on the main line of the national HSR network, the number of stations that can be accessed without transfers from these airport stations is limited. The main function of these airport stations is to serve the passengers who enter or exit the airports through transfers, and their waiting room is limited.

4) In terms of intervals, the train departure intervals at CGO, CSX, and HAK are all within 15 min during operation, which can fully meet passenger needs and reduce passenger waiting time. However, some flights are too early or too late, and they have not been covered by the current train operation.

5) Compared with URT, the intercity HSR in ARMT covers a larger area and population. However, the existing airport express lines are generally more than 10 min away from the intercity HSR hubs. Compared with Hongqiao Airport, the airports in this study are not mature yet in the convenience of ARMT in the urban area.

6) The daily train services of CTU, CGO, WUH, and CSX last for 14.5 h, 17.5 h, 13 h, and 15.5 h, respectively. The operation is mainly concentrated in the peak passenger flow periods. However, the peak to enter or exit CTO is between 5:30 and 23:00 in summer, and the existing train service hours are too short to fully meet the passengers’ travel needs.

4 Suggestions for the development of ARMT

4.1 Actively build high-speed rail and intercity rail stations around hub airports

Among the top 10 busiest airports in China, only SHA and CTU have already built the ARMT. The intercity railways to support Beijing Daxing Airport and CAN are still under construction. Although some regional airport hubs have strong passenger demand, such as the airports in Xi’an, Kunming, Chongqing, Hangzhou and Nanjing of China and they are generally far away from the main urban areas, the planning and construction of supporting railways and stations have not started. Their local authorities should accelerate the construction of airport railways on the basis of scientific forecasting of long-term passenger flow.

With the reference to the development history of foreign airports, the air traffic from Madrid to Barcelona decreased by 40% in the first two years of Spain’s HSR, which did not reach the bottom. However, the passenger throughputs of the airports in both cities increased, which even led to airport expansion. Today, Madrid has become Europe’s gateway to Latin American and replaced Amsterdam Airport Schiphol in the Netherlands as Europe’s busiest airport. It can be concluded that ARMT has effectively contributed to the prosperity of civil aviation.

In the planning and construction of HSR stations, on one hand, the development space for airport reconstruction and expansion and station expansion should be reserved so that the service supply of ARMT can fully meet the passenger throughput demand in the rapid growth of civil aviation. For airports with strong passenger demand, high-level railway stations should be considered near the airports, such as Shanghai Hongqiao Station and Zhengzhou South Railway Station, to meet the demand of long-term airport expansion and to reduce the number of transfers from the airport to URT. On the other hand, the technical requirements and the financial costs are high for the construction of HSR stations and URT. Especially for airports far away from the main urban area, the URT lines are longer and more costly. In the cities with weak passenger demand at present, the development prospects of local finance and civil aviation should be considered to determine whether it is necessary to build URT lines to connect with the airport and how long the cost recovery period is. With CGQ as an example, it built the earliest airport HSR station in 2010, but its airport passenger throughput has only ranked around 30th in China for many years. The construction of the HSR station has promoted passenger flow, but the occupancy rate of intercity trains is generally low. It is difficult for CGQ to recover construction and operation costs based solely on farebox revenue, and its operation relies heavily on subsidies.

4.2 Rationally plan all types of rail transit facilities

Airport facilities have a long construction and renovation cycle. The planning of airport facilities should be moderately forward-looking based on long-term development and pay attention to the construction of railway lines and supporting airport facilities. The scale of the railway stations should fit the size of the main passenger population and the current handling capacity of the airport. For hub airports, special railway stations or first-class railway stations should be built near the airport railway station to serve more passengers in urban agglomerations or metropolitan areas. At the same time, facilities such as fast tracks and air–rail connection lines should be set up between the railway station and terminals to reduce the passengers’ walking distance and to facilitate connection.

Since the frequency of HSR trains is low and the departure intervals are long, URT projects should be introduced when airport HSR stations are built at the airports with large passenger throughput, so that the high-frequency multi-stop URT can be used to serve more local passengers. With CGO as an example, it has developed rapidly in recent years, and the annual passenger throughput increased from 10 million to 20 million within just five years. CGO has become the busiest airport in central China since 2017, which is closely related to the planning and construction of the rail transit network to collect and distribute passengers for the airport. Since 2014, three intercity railways from the airport to the urban area, Kaifeng, and Jiaozuo have been built. In the future, Zhengxu URT, the Zhengdengluo intercity railway, and the suburban railway to Zhengzhou South Railway Station will be built successively, which will further promote the growth of airport passengers and enhance CGO's regional driving function and its role as the only trunkline international airport in the Central Plains of China.

4.3 Optimize the strategy of train formation

The difference of the intercity railway's passenger-carrying capacity at different airports mainly lies in the number of train cars and the frequency of arrival and departure trains. The intercity railway for CGO has the highest passenger-carrying capacity, mainly because of more frequent trains and shorter departure intervals. However, there are also some problems, such as empty or half-load trips, during some time periods. Considering the current daily throughput of CGO and CGQ, the intercity railway has excessive capacity with poor economy.

Rational train formation and scheduling should be subject to the constraint of full load to a certain extent and should maximize the passenger-carrying capacity as much as possible. With the increasing frequency and scope of China's railway network, the railway department of each city should timely adjust its railway operation plan according to its own conditions. In addition, the attraction of each station to airport passengers should be fully considered, and the stations and cities served by the airport railway should be determined reasonably based on the composition of airport passengers.

4.4 Promote the integration of air transportation and railway sectors and develop cooperative service products

In addition to infrastructure, the convenience of foreign ARMT is more reflected in the deep integration of transportation service products. Successful airports, such as Tokyo Narita Airport, London Heathrow Airport, and France Charles de Gaulle Airport, all benefited from market-based operations and in-depth cooperation of airlines and railway companies. This includes the package selling of the air ticket, train ticket and accommodation, joint ticketing discounts, and one baggage check-in. These air–rail interline service products enable the airports and railways to handle flight delays effectively and fully meet passengers' needs on baggage check-in, baggage claim, etc. They also optimize the travel environment and provide a complete chain of people-oriented services on transportation and transfer, assignment of the boarding gate, walking distance, baggage claim, information sharing platform, etc.

In the context of the rapid growth on the construction and operation of civil aviation and railways, the airlines' business models are becoming more flexible, and their operational efficiency and profitability are gradually improved. In the meantime, the railway sector is also accelerating enterprise restructuring to pursue more operational benefits. Civil aviation and railways are two high-efficiency and high-capacity transportation systems. To further strength the cooperation between them, the relevant departments should jointly coordinate and develop an overall plan to build a top-down strategic planning layout at the national level. In May 2018, the Civil Aviation Administration of China and China State Railway Group Co., Ltd. signed a strategic cooperation agreement to promote ARMT. The two sides will cooperate on five aspects: improve the ARMT infrastructure, innovate air–rail interline service products, advance the ARMT services, expand the air–rail information sharing, and promote the ARMT demonstration projects.

Airports, airlines, and railway systems should work together to innovate the air–rail interline service products, such as ticketing and passenger landing services, break down industry barriers, and turn their respective policies into full cooperation, which will effectively improve the efficiency of ARMT and reduce the travel and transfer cost. The integration of civil aviation and railways can improve the demand structure and supply level and expand high-value-added, high-profit, and high-openness emerging industries. Moreover, it can feed back modern services more effectively such as the cold chain, express goods, high-end manufacturing, cross-border e-commerce, and exhibition and tourism. It can also strengthen the aviation economy's effects of driving the industry and trade prosperity of the urban and regional economy.

5 Conclusion

This paper sorts out the evaluation indicators of the convenience of ARMT from the aspects of infrastructure and operational service capacity, establishes an evaluation indicator system, and quantitatively compares the level of ARMT in several second- and third-tier cities. Based on the development characteristics of different cities, this paper summarizes the influences of rail transit type, number of trains, distance to the HSR hub, and accessibility on the convenience of ARMT and proposes suggestions to improve service.

By the end of 2018, the Civil Aviation Administration of China had worked with several provinces to formulate strategic plans for the construction of international hub airports in Urumqi, Kunming, Zhengzhou, Harbin, and other cities. Compared with developed countries in Europe and the United States, China has great potential to grow the intensity of civil-aviation passenger flow continuously. With the rapid development of investment in HSR and civil aviation facilities, the integrations of “air + rail” and “air + intercity bus” will be deepened. Furthermore, an interline system of efficient hub airport composed of the HSR station next to the airport and an URT network centered on the airport and off-site terminal buildings will be established to achieve the efficient collection and distribution of airport passengers.

The convenience of ARMT is of great importance to the cultivation of passenger flow. The planning and construction departments should make scientific decisions on facility investments and operational capacities to ensure that the supply capacity of aviation services can fully meet the residents’ travel needs and support the social economic development.

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(Translated by CUI YB)

