Evaluation and Comparative Study on the Facilitation of Air Rail Transport in China cities

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Abstract. Since 2010, following the completion of Shanghai Hongqiao Hub, Air-Rail Intermodality Transport (ARIT) service has been built and operated in more and more cities in China. On the basis of connotation and practical significance of ARIT, this paper analyses the development of ARIT in major airports in China, compares the convenience of airports in terms of facilities and operation services. Use the sub-and-objective comprehensive evaluation of the convenience of ARIT by using AHP and entropy weight method. In view of the result, suggestions are given to fully play the efficiency role of rail gathering and distribution and to realize the application and popularization of ARIT at a higher level and a wider range.

1. Background

1.1. Development path
Air-Rail Intermodality Transport (ARIT) rooted from Western Europe in the middle of 20th Century. Currently, among the top five busiest airports in Europe, except London Heathrow Airport which locates outside the European continent, all of the rest have been equipped with high-speed rail line facilities and implemented various air-rail service products.

In recent years our country’s traffic infrastructure is booming. Freight turnover passengers of High-Speed Railway(HSR) and civil aviation maintained double-digit growth for five consecutive years under the world's largest high-speed rail network and the world's second largest aviation network [2]. Due to the increasing density of high-speed rail laying and the increasing tension of aviation airspace resources, the passenger flow of the short and medium flight distance gradually diverted to high-speed rail [3]. When the Wuhan-Guangzhou section of Beijing-Guangzhou HSR was opened, it once reduced classes and even stopped flying in Wuhan-Guangzhou, Wuhan-Changsha, Changsha-Guangzhou among central and southern China [4]. Dialectically speaking, the benign market competition between HSR and civil aviation also makes civil aviation turn its precious capacity from the less profitable short-haul routes to the more economic and long-and-medium-haul routes. The efficient and dense transportation network of HSR itself delivers more high-quality passenger flow timely and quickly. In the development of rail and civil aviation, the typical airports in Europe and the US experienced the decrease of domestic passengers and the increase of international passengers. In the division of transportation and modes by scholars, the transportation advantages of HSR and civil aviation are respectively reflected in the range of 300-800 km and over 800 km [5-7]. Since 2012, under the background of the double growth of HSR civil aviation, the average railway distance has been shortened and civil aviation distance has been
increased. Moreover, the construction of urban rail transit is also thriving. The number of cities opening rail transit has been increasing year by year with the total mileage has been getting longer and longer. In 2017, 18 cities have completed the rail transit investment of over 10 billion yuan, and the average annual growth rate from 2011 to 2017 of the number of locomotives, passengers, the mileage of opened and under construction exceeded 15%.

ARIT is conducive to give full play to the advantages of airport hubs with a wide range of radiation and the advantages of railway distribution in a larger range, large volume, fast and timely, so as to realize the complementary advantages of both, avoid disorderly competition and improve the convenience of flight service. With the passenger transfer time and the city traffic flow interference increased, the airport becomes a comprehensive traffic hub connecting the domestic and foreign and the cities in a large-scale.

1.2. **Theory Thesis**

ARIT refers to a joint mode of transport between air and rail transport, involving airports, airlines and railway systems. There are two main forms of international ARIT: based-on-joint-infrastructure and based-on-combined-services. Based-on-joint-infrastructure mode is also called two poles pass-through mode connecting the rail infrastructure to airport terminal as the end of the air transport capillary, implementing a variety of rapid, timely concentration of large capacity transport facilities layout. The airlines act as the artery and the rail lines act as the branch to the complement of each other respectively. Narita and Haneda airport in Tokyo is a typical example. And relying on combined services, mainly in the ticketing, baggage, allopatty check-in between enterprises and departments. Frankfurt, Germany on behalf of the formation of the "zero meters high regional aviation", through the code sharing railway trains and planes, makes passengers by Luftansa booking online booking train ticket, train schedule and flight takeoff and landing cohesion. Passengers can check in at the railway station with one-step security. Combined transport expands the airport's radiation range and hub cluster effect, improves the convenience of passengers' travel and overall social and economic benefits, and makes the development of urban cluster's internal transportation more clearly.

The ARIT mode includes three types of railway: high-speed railway (national high-speed railway, intercity railway), general railway, urban railway (airport express line, subway or light rail). In China, the existing types mainly consist of HSR and urban railway.

Among the large civil aviation airports in China, Shanghai Hongqiao Airport is the earliest GTC transfer center. Since then, Haikou, Changchun, Wuhan, Zhengzhou and other cities have connected HSR stations with other urban railways through the airport intercity line. Differ from Hongqiao Airport, other airports auxiliary stations is in lower grade with the limited locomotives and throughput capacity, all need to be connected with higher grade HSR hub for conversion, so the number of transfer.

2. **Establishment of index system of ARIT convenience**

2.1. **Evaluation index selection**

Taking the high-speed railway or inter-city cities which have opened airports as examples (Shanghai Hongqiao Station is a special station on the main line of China Railway, without any comparison), this paper makes a horizontal comparison of the air-rail intermodal transport on the infrastructure level of each city, and analyzes the current development status and horizontal gap of air-rail intermodal transport in several major hub airports in China through the indexes such as track type, passenger transport capacity, airport throughput and train interval.

Drawing on the experience of the classification of air rail intermodal transportation, it mainly includes infrastructure and transportation services. In the design index system, the level of air-rail intermodal transport convenience should be established according to the infrastructure conditions and operational service capabilities. Considering the availability of data, an evaluation index structure is set up as follows:
The evaluation indexes of convenience of air rail intermodal transportation include: infrastructure condition \( a_1 \) (platform scale \( a_{11} \), high speed rail hub distance \( a_{12} \), track type \( a_{13} \), number of reachable station \( a_{14} \)), operational service capability \( a_2 \) (railway daily capacity \( a_{21} \), daily capacity of urban rail transit \( a_{22} \), average train interval \( a_{23} \), railway capacity ratio \( a_{24} \)).

Among them, \( a_{13} = \begin{cases} 1, & \text{National Rail} \\ 2, & \text{Intercity Rail} \\ 3, & \text{Urban Rail} \end{cases} \), \( a_{14} \) represents the number of stations within the 3h of the airport departure train. The formula for calculating railway daily capacity \( a_{21} \) is:

\[
a_{21} = r_t \times n_r \times 2 + r_e \times n_r
\]

Variable in the formula:
- \( r_t \): daily through parking times;
- \( r_e \): Daily start to the train number;
- \( n_r \): average passenger capacity of railway trains;
- \( n_c \): average passenger capacity of urban rail trains.
- \( L \): train operation time on that day;

2.2. Index empowerment and evaluation method

In order to comprehensively evaluate the convenience of ARIT, the paper adopt the method of subjective and objective comprehensive weighting. In the index empowerment, subjective weighting includes AHP, Delphi method, comparative ranking and so on, among them, the Analytic Hierarchy Process (AHP) is the most widely used. Objective weighting includes standard deviation method, regression analysis method, entropy weight method and so on. Subjective weighting focuses on expert experience, and objective weighting focuses on information of index values. Due to the lack of authoritative evaluation on the indicators of air-rail intermodal transport, subjective and objective
A comprehensive weighting method is conducive to comprehensive consideration of the score gap between subjective experience and objective data, and the results are more comprehensive and reliable.

When using the objective weighting method, data processing should be carried out first, and the benefit data and cost data, as well as 0-1 integer variables are converted into standardized data range $[0,1]$. The transformation formula is:

Assuming that the index score is $z_i$, the maximum value of the index (i.e. the upper limit effect measure) is $M_i$, the minimum value (i.e. the lower limit effect measure) is $m_i$, and the standard value of the index is $r_i$, the standardization process is as follows:

The value of lower limit effect measurement calculates standardization of benefit data:

$$ r_i = \frac{M_i - z_i}{M_i - m_i} $$

The value of upper limit effect measurement calculates standardization of cost data:

$$ r_i = \frac{M_i - z_i}{M_i - m_i} $$

In this index system, $a_{11}$, $a_{13}$, $a_{14}$, $a_{21}$, $a_{22}$, $a_{24}$ are benefit indicators, the other are cost-based. The types included in $a_{13}$ are calculated by the combined score of 0.4 national high-speed rail, 0.4 intercity rail and 0.2 urban rail according to the concentration and passenger carrying capacity.

$$ E_j = -(\ln m)^{-1} \sum_{i=1}^{m} p_{ij} \ln p_{ij}, i = 1,2, \ldots, m, j = 1,2, \ldots, n $$

Among them, $m$ is the number of objects being evaluated, $n$ is the number of evaluation indicators, and $p_{ij} = \frac{b_{ij}}{\sum_{i=1}^{m} b_{ij}}$ in order to make $\ln p_{ij}$ meaningful, assuming $p_{ij} = 0$,

$$ \lim_{p_{ij} \to 0} \ln p_{ij} = 0. $$

Entropy is used to calculate the entropy weight of evaluation index.

$$ W_j = \frac{1 - E_j}{n - \sum_{j=1}^{n} E_j}, j = 1,2, \ldots, n $$

3. Solution and evaluation of the convenience of ARIT

Since the original data of the daily transmission capacity of the railway or urban rail has not released, this paper obtains the total number of daily passengers' transmission capacity according to the relevant passengers and the number of grouped carriages. As for the number of reachable stations, Zhengding Airport and Shuangliu Airport are located on the main line of the National Railway with more parking, but the passengers in Zhengzhou and Taiyuan, which are far away from the station, generally do not choose the station for ARIT. Therefore, only the stations with a railway advantage range of 800 km (within 3 hours) are selected as the reachable stations of the ARIT station for comparison. The final results are shown in Table 1.(Chengdu Shuangliu-CTU, Zhengzhou Xinzeng-CGO, Changsha Huanghua-CSX, Wuhan Tianhe-WUH, Haikou Meilan-HAK, Sanya Fenghuang-SYX, Changchun Longjia-CGQ, Shijiazhuang Zhengding-SJW)

| Airports /rankings | $a_{11}/$ (platform/routes) | $a_{13}$ | $a_{14}$ | $a_{21}/10^4$ | $a_{22}/10^4$ | $a_{23}/$min | Daily passenger throughput/$10^4$ | $a_{24}$ |
|---------------------|---------------------------|---------|---------|-------------|-------------|-----------|-----------------------------|---------|
| CTU / 4             | 2 / 6                      | 10      | 2+3     | 2.25        | 33.7        | 39        | 13.64                      | 16.5%   |
| CGO / 13            | 2 / 4                      | 17      | 2+3     | 4.75        | 22.3        | 30        | 6.66                       | 71.4%   |
| CSX / 14            | 1 / 2                      | 19.5    | 3       | 0           | 7.26        | 18        | 6.51                       | 111.5%  |
| WUH / 16            | 2 / 4                      | 12      | 2+3     | 1.80        | 26.1        | 39        | 6.34                       | 28.4%   |
| HAK / 17            | 2 / 4                      | 8       | 2       | 2.60        | 0           | 19        | 6.19                       | 42.0%   |
As can be seen from the above table, except longjiaxi and zhengding airports, domestic airports with
HSR and intercity direct access are basically the hub airports with the top 20 passenger throughput.
Through the questionnaire survey, the impact of each indicator on passenger touring experience was
gotten, and the judgment matrix and consistency test indicators were obtained. The subjective weight
calculated by AHP is \( w_1 = [0.07, 0.16, 0.34, 0.03, 0.09, 0.04, 0.02, 0.25] \);

After the index score in table 1 is normalized, the entropy value and corresponding entropy weight of
each index are calculated. The objective weight determined by entropy weight method is \( w_2 = [0.07, 0.10,
0.02, 0.10, 0.12, 0.34, 0.07, 0.18] \);

The difference between the two weighting methods is mainly reflected in the rail type \( a_{13} \), the number
of reachable stations \( a_{14} \), the daily capacity \( a_{22} \) of urban rail, mainly due to the smaller variance, and
more attention is paid to subjective scoring, urban rail daily transmission capacity and the number of
reachable stations in the index of the airport sample score variance is larger, the entropy method of
weight distribution is higher.

In order to balance the subjective experience preference and the authenticity and differentiation of
decision-making, based on the principle that the difference between the subjective and objective weights
of the comprehensive weight distance is the smallest, the dispersion function is introduced, and the
following definite weighted least squares optimization model is established.

\[
\min \sum_{k=1}^{m} \sum_{j=1}^{p} \alpha_k \left( w_j - w_{kj} \right)^2 \]  \tag{1}

s.t. \( \sum_{j=1}^{p} w_j = 1, w_j > 0 \ (j \in M) \)

Where \( w_j (j \in M) \) is the combined weight, and \( w_{kj} \) is the \( j \) index weight of the \( k \) weighting method.
\( \alpha_k \) is the weight coefficient of the \( k \) index weighting method. Among them:

\[ \sum_{k=1}^{p} \alpha_k = 1 \]

The Lagrangian function is constructed:

\[ L(w, \lambda) = \sum_{k=1}^{m} \sum_{j=1}^{p} \alpha_k \left( w_j - w_{kj} \right)^2 + 2\lambda \left( \sum_{j=1}^{p} w_j - 1 \right) \]  \tag{2}

Taking the partial derivative of both sides of the above equation, the optimal solution of the model
can be obtained according to the necessary conditions for the existence of extremum:

\[ w_j = \sum_{k=1}^{p} \alpha_k u_{kj} \quad j \in M \]

\[ h(u_i, u_j) = \sum_{l=1}^{m} u_{il} \log \frac{u_{il}}{u_{jl}} \]  \tag{3}

According to the theory of optimum conclusion, when it has the global optimal solution, optimal solution \( d^* = (d_1^*, d_2^*, \ldots, d_m^*) \) meet the following conditions:

\[ d_i^* = \frac{\Pi_{j=1}^{m} (u_{ij})^{\beta}}{\sum_{i=1}^{m} \Pi_{j=1}^{m} (u_{ij})^{\beta}} \quad i = 1, 2, \ldots, m \]  \tag{4}

From this, the fitness degree \( h(u_i, d^*) (i = 1, 2, \ldots, p) \) of each weighting result and the reliability of
each weighting result are calculated. The greater the fitness degree of the \( k \) weighting result and the
aggregation weight vector, the more obvious the effect is in the combination weight. Its credibility
weight can be expressed as below:

\[ \alpha_i = \frac{h(u_i, d^*)}{\sum_{i=1}^{p} h(u_i, d^*)} \quad i = 1, 2, \ldots, p \]  \tag{5}

Using \textit{MATLAB} to solve the optimal solution, the subjective and objective weighting coefficients are
calculated, and finally solve the combined weights \( w \).
The final scores of airports are shown in Table 2 below.

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

The results obtained from the comprehensive weighting formula are in the interval [0,1], the extended interval value is [0,100] when converted into percentage system. It can be seen that the current status of convenience of ARIT airports is distributed between (30, 70), indicating that the current each regional hub airport has its own advantages, and there is no ARIT system with absolute lead. CTU, WUH, CGO and other airports are dominated by infrastructure. The “intercity+subway” double-track direct access to the airport, and the number of trains is dense. The low-cost medium-low-speed maglev used in CSX can fully adapt to the existing passenger flow demand. However, after the passenger flow increases in the later stage, there is pressure on the single-line magnetic levitation intermodal vehicle encryption, and the medium-low-speed maglev cannot realize the convenient service of transfer within the railway station. Moreover, the convenience of gathering and collecting passengers outside Changsha City is relatively weak. As a passenger airport with a small passenger flow, CGQ has sufficient capacity for intermodal transportation.

Comparing the scores of various indicators, the following conclusions can be drawn:

1) In terms of daily transport capacity of airport railway, CGO, CSX and CGQ have relatively large daily transport capacity, which can satisfy more than 50% of existing passengers. This is mainly because the two railways are intercity special line or maglev special line, with more trains and airports locating at the terminal.

2) For types of urban rail, there are more stops along the subway, and a considerable part of the passenger capacity should serve the city's traffic. Therefore, the actual number of passengers serving the airport is limited. Moreover, for passengers required for business travel, the cheap, crowded, slower subways' experience is slightly worse than the Airport Express.

3) The existing airport stations are second or third class stations. The station in low level is small, which mainly meets the passengers' transit and inbound and outbound resources.

4) During the operation of the train, the intervals between CGO, CSX and HAK are within 15 minutes, which can fully meet the demand of passengers and reduce the waiting time of passengers. However, some flights are too early or too late. For example, the summer inflow and outbound peak of CTU lasts from 5:30 to 23:00.

5) Compared with urban rail, the intercity rail in air-rail transit covers a larger area and population scale, while the existing airport HSR is generally more than 10 minutes’ drive from the high-speed railway hub. Compared with SHA, the connection convenience of the above major airports in regions are still not mature.

4. Suggestions for the development of ARIT

4.1. Actively build hub airport HRS/intercity stations

Among the top 10 airports in China's passenger throughput, except for SHA and CTU, which have already completed the transfer of ARIT, Beijing Daxing New Airport’s and CAN’s Intercity Support are in the construction stage, while others include Xi'an and Kunming, Chongqing, Hangzhou, Nanjing and other regional hub airports have strong demand for passenger flow, which are far from the main urban area. Their local authorities should accelerate the construction of airport railways on the basis of scientific forecasting of long-term passenger flow.

In the construction and plan of the HSR station, on the one hand, the development space for airport expansion and station expansion should be reserved, so that the service supply of ARIT transport can fully adapt to the rapid growth of civil aviation. Airports with strong demand in the passenger market
should consider high-grade railway stations, such as Shanghai Hongqiao Station and Zhengzhou South Station. On the other hand, the technology and cost requirements for HSR stations and urban rail transit construction are high, cities with weak customer bases should consider the prospects of local finance and civil aviation development. Taking CQX as an example, as the airport HSR station built in 2010, the intercity trains have a low attendance rate all the year round, and it is difficult to recover the construction cost and the operating cost accounting for a large subsidy gap.

4.2. **Reasonable planning of various types of track support**
The construction and renovation of airport facilities takes a long time. In the planning stage, the airport facilities should be moderately advanced and based on long-term development. For the hub airport, there should be an oversize station near the airport to serve more passengers in the city cluster or region. At the same time, set up facilities such as rapid footpath or air-rail contact line between the terminal to reduce the passenger's walking distance.

4.3. **Optimize vehicle marshalling strategy**
The difference in intercity transmission capacity between different airports is mainly in the number of trains and the number of trains. With the increasing frequency and range of the railway network in China in recent years, the railway departments of various cities should adjust the train operation diagram in time according to their actual conditions.

It is also necessary to take into full consideration about the capacity of civil aviation passengers of each station, and rationally choose the stations and cities for stops according to the main passenger flow of civil aviation.

4.4. **Promote the integration of air and rail departments to create cooperative products**
In the context of the rapid growth of civil aviation and railway construction and operation in China, the airline's business model is increasingly flexible, operational efficiency and profitability are gradually improved, and the railway sector is also accelerating enterprise restructuring, giving more demands for operation benefits. Civil aviation and railway, two types of efficient mass transportation system, in order to further strengthen cooperation, must be combined together by related departments, format the national level of top-down strategic plan, build together including ARIT hotel selling packages, ARIT ticket discount, luggage one-piece consignment, etc.

The integration of air and rail services can improve the demand structure and supply level, expand the new industrial formats with high added value, high openness, more effectively feed back the cold chain and the modern service industries such as express logistics, high-end manufacturing, cross-border e-commerce, exhibition, tourism and so on, and strengthen the industrial drive of the aviation economy to the urban and regional economy.

5. **CONCLUSION**
Through the latest data, this paper combs the indicators used to evaluate the convenience of ARIT from the aspects of infrastructure and operational service capacity. An evaluation index system was established to makes a quantitative comparison of the existing level of ARIT in hub airports, as well as summarizing the influence of track type, number of locomotives, distance of HSR hub and reachability on the convenience of ARIT among different cities. Finally, suggestions for improvement have come up.

Up to now, the Civil Aviation Administration has worked out the strategic plans for the construction of international hub airports in Urumqi, Kunming, Zhengzhou and other cities in conjunction with many provinces and cities. Compared with the developed countries in Europe and America, the intensity of civil aviation passenger flow in China still has great potential for sustained growth. In the rapid development stage of investment in high-speed rail and civil aviation facilities, the integration and coordination of air-rail and air-bus will be more in-depth. Port high-speed rail stations, airport-centered rail transit network, allopatric airport terminals and so on will jointly form a hub
airport smooth intermodal transfer system to achieve efficient collection and distribution.

The convenience of air-rail transfer is very important for the cultivation of passenger flow. Planning and construction departments should make scientific decisions in terms of facilities input and operational capacity, so that the air service supply capacity can fully meet the needs of residents' travel and socio-economic development.

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