Analysis on the difference of time and space allocation of slots at regional hub airports: A Comparative Case Study of CTU and CKG

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Abstract—Taking Chengdu Shuangliu(CTU) and Chongqing Jiangbei(CKG) as examples, using flight data with methods such as volatility and external connection degree, the difference in slots allocation between adjacent regional hub airports from the time and space dimensions is quantitatively depicted. It shows that the overall flight schedule of CTU and CKG is similar, but during peak hours, the strong passenger demand of CTU Airport makes its flight volume more stable, moreover CKG enters the peak hour one hour later than CTU. The morning and evening peak-shaped flight waves are formed in both airports, but the take-off and landing intervals of CTU during peak hours are shorter than that of CKG. In addition, the take-off peak period of CKG is shorter than that of CTU; those with high external connections between the two airports are provincial capitals or sub-provincial cities in domestic, although some cities in remote provinces are more inclined to connect to CTU. International cities with higher external connections are all over China, especially nearly half of the international flights from both cities are to Southeast Asia, and connection degree between CTU and Southeast Asia is higher than Chongqing.

1. INTRODUCTION

As a fundamental service for regional and national economic and social development, air transportation has become one of the most important modern transportation mode [1]. As a basic component of air transportation, the increased the number of flight in hub airport makes more shortness on limited slots. Moreover, due to the “grandfather inheritance” principle in time resource allocation, it is difficult for the airport to change its time resource allocation plan in the short term. Therefore, if the hub airport can effectively and reasonably use limited flight time resources to design its airline network, has influence on its social and economic benefits in the long term.

Normally, research on air transportation mainly focuses on the macro aviation network and the microscopic airport resource distribution. In the aviation network, Ernst et al. proposed the annealing algorithm to solve the problem of hub location in the aviation network [2], Wu Tongshui et al. designed the flight planning optimization model of the spoke route network layout model [3], some scholars have studied the structure and evolution of aviation networks in terms of topology and other aspects [4-6]. These studies have focused more on the whole aviation network, and few have studied the network of individual airport. On slot, Mashford and Sun Hong focused on the optimization of slot [7,8]; Ricardo and Wu Dingjie studied slot management [9,10]. With the deepening of the research on slot allocation, Wang Wei and Wang Chengjin discussed the time and space allocation of airport slot in Beijing, Shanghai, and Guangzhou from the perspective of geographic research [11-12]. Taken together, present literature on
the slot allocation network of a single airport is mostly focused on international hub airport, and there is little comparative analysis on the differences of the organization model of the time resource space-time network of regional hub airports. Therefore, from the perspective of time and space, we investigate the differences in resource allocation between different regional hub airports and try to find the general characteristics. The comparative study of the regional hub airports in the neighborhood area is beneficial for improving the division of labor within the multi-airport system. Also, it is helpful for the planning of the airport with each other’s reference to optimize resource allocation.

2. DATA AND METHOD

2.1. Data and Process
CTU and CKG both are the top ten national airports, and as the core of the CTU-Chongqing multi-airport group, they located in the hub of the Yangtze River Economic Belt and the new land and sea passages in the west. The distance between the two places is about 500km. The functional attributes of CTU and CKG are similar and the geographical location are near. Therefore, we analyze the differences on time-space organization pattern of slots between CTU and CKG, which are representative among regional hub airports.

The data used in this article comes from the official website of CTU Shuangliu International Airport and Chongqing Jiangbei International Airport (www.cdairport.com, www.cqa.cn/u/jichang), including arrival and departure flights, as well as international and domestic flights. The statistical data processing time range is one week, and the time span is from January 6, 2020 to January 12, 2020. For the connecting domestic flights, the flight time is counted to the layover city. For flight from CTU to URC via LHW, the slot is counted for CTU to LHW. For the international flights layover at CTU or CKG, only the international part of the flight are counted. For example, for flight from SHA to FRA via CKG, the slot data of CKG is counted as international. In this way, operations (take-off and landing) on CTU and CKG within one week are counted. In this paper, the flight data of each period is counted in 30-minute.

2.2. Methodology
2.2.1. Flight fluctuation analysis
The flight volume of the airport is constantly changing with time. In order to quantitatively compare the fluctuation of the flight volume of the two airports with time, the fluctuation rate \( x_i \) is used:

\[
  x_i = \left( \frac{a_i - a_{i-1}}{a_{i-1}} \right) \times 100\%
\]

(1)

In which, \( a_i \) represents the number of flights taking off and landing in every half hour, where \( i=2,3,\ldots,n \). Therefore, the relative fluctuations of the flight movements of airport every half hour can be obtained, that is, whether the flight movements increase or decrease every half hour can be judged from the positive or negative of the fluctuation rate. Positive fluctuation means the increase of movement number.

2.2.2. Connection degree
In order to study network of CTU and CKG, first we build the relationship matrix among each airport and its connected airports to obtain the connectivity of the network, which is:

\[
  I_{ij} = R_{ij} + R_{ji} (i, j = 1, 2, \ldots, n)
\]

(2)

In which, \( I_{ij} \) is the number of connecting flights between airport node \( i \) and airport node \( j \) of an airline’s network, \( R_{ij} \) represents the number of flights departing from airport node \( i \) to \( j \), and \( R_{ji} \) represents the number of flights from airport node \( j \) to \( i \), \( n \) is the number of airports. To summarize the number of flights connecting CTU and CKG with other airports in the network, that is, the connection degree, which is:
\[ D_{ij} = \sum_{i} I_{ij} \]  

In which, \( D_{ij} \) is the connection degree of airport \( i \) and airport \( j \), and \( n \) is the number of airports. The connection degree of the airport reflects the ability of the airport node to directly communicate with other airport nodes in the network, that is, the strength of the connection\[^6\].

3. OVERALL DIFFERENT ON SLOT STRUCTURE

The provider of slot resources is an airport, and its essence is the allocation of flights in different time periods. Therefore, the value of resources at all times can be evaluated by the time of take-off and landing and the number of flights. We calculate the slot distribution of CTU and CKG at various times of the week in 30-minute.(See Figure 1).

![Flight time structure](image)

Figure 1. Flight time structure

Comparing the slot distribution of the two airports, it can be found that the distribution of slot has a certain similarity in this period. In the first 7 hours, the slot distribution shows a "U" shape, and there is a steep increase and decrease trend. In the subsequent time period, the number of flights will fluctuate within a certain range. It is noticeable that within 3:00 to 6:00 am, the flight volume of CTU is maintained within 20 to 40 and most of them are international flights, while CKG has about one international flight, reflecting CTU is more busy than CKG and CTU has more significant characteristics as a international hub. In the follow-up period, the number of flights in CTU changed less than in CKG. Due to the limitations of airport and airspace capacity on the supply of slots, passenger demand has become an important factor in the slot allocation. For CTU, the strong demand for passengers and the high level of aviation service capabilities make the distribution of slots more even.

By analyzing the volatility of flights of the two airports, it can be found that the volatility of the two is significantly different in specific time periods (See Figure 2). During the time period from 0:30 to 4:00, the number of flight increasingly decrease, which is more significant in CKG. After 4:00, the number of flights in CTU increase significantly, and the amplitude of increase doubles in the first half hour, the amplitude begin to decrease at about 7:00. The fluctuation of subsequent flights has not exceeded 25%; however, the number of flights in CKG increase significantly after 6:00. The number of flights in the first half hour is four times that of the hour before, the amplitude of increase decline after 7:30. The volatility is still 56% after. Comparing the two airports, it can be seen that the flight volume of CKG fluctuates relatively at every period, and CKG enters the rush hour about one hour later than CTU. After 6:00, CTU gradually enters the state of maximum flight volume, and the number of subsequent flights is relatively stable. This is because of its dense flight arrangements and high flight density, which is also one of the reasons why its throughput is higher than CTU.
4. DIFFERENCE ON ARRIVAL AND DEPARTURE SLOT

In order to investigate the formation of flight waves in CTU and CKG and distribution characteristics of flight take-off and landing at every time period, we make a statistical analysis on arrival and departure flights (See Figure 3). In which, the study of formation of flight wave can help to organize flight accordingly, flexibly arrange the take-off and landing slot of transit flights, improve airport utilization and transit efficiency.

After statistics, it was found that the number of weekly takeoffs and landings at CTU and CKG both exceeded 3,000, the number of CTU is 3674, and CKG is 480 less. For the flight waves of the two airports, they belong to the morning and evening peak-shaped flight waves, that is, they have obvious morning departure peaks and night arrival peaks, and during the day arrival and departure peaks alternate. However, there are differences in the arrival and departure intervals between the two airports during peak hours. The average arrival and departure intervals during peak hours in CTU are 1.5h and 1h respectively, while CKG is higher than that of CTU. The average time between arrival and departure intervals during peak hours are 1.9h and 1.7h, to a certain extent, reflects that the current CTU is busier than CKG. As for the flight distribution characteristics of the two airports, the distribution of arrival and departure flights has a certain similarity. However, in the peak period of departure, CTU reached the departure peak within 3h from 6:30-9:30, accounting for 28% of departure flights. In CKG departure flights within 1.5h from 7:00-8:30 accounting for 19.8% of total. It can be seen that for the peak, the length of the CKG time period is much shorter than that of CTU, and departure flights is relatively less. Most departure flights are distributed in other time periods. In the landing period, both maintained a high flight volume at night, mainly due to the concentration of international flights during this period. For the formation of this type of flight structure, the travel time and physiological characteristics of
passengers have a greater impact, resulting in a relatively concentrated peak flight segment of the arrival and departure flights of the two airports.

5. DIFFERENCE SPATIAL DIFFERENCE ON AIR CONNECTION

Distribution of slots is the allocation of time, and the airlines are the connection between different airports. The flight takeoff and landing form the spatial distribution differences of flight terminal airports, that is, the allocation of time resources further extends to a distribution of space resources. According to the statistics of CTU and CKG’s air-connected cities, the number of air-connected cities in the two places reached 197 and 159 respectively, of which 132 domestic and 65 foreign cities connected to CTU, while 117 domestic and 42 foreign cities are connected to CKG. The air contacts scope of CTU is stronger than that of CKG in both domestic and international aspect.

We make a statistical study on the spatial distribution of domestic aviation connection cities to CTU and CKG, number of flights reflected by the size of points (See Figure 4). It can be found in the figure that the connection strength of CTU and CKG are different in different places. The main connection cities of the two airports are mainly located in the Beijing-Tianjin area, the Yangtze River Delta, and the Pearl River Delta. Connections to the airports in Beijing, Shanghai, Guangzhou, and Shenzhen reach 1780 and 1464, each reaching 24% of their total flights. At the same time, the two also maintain certain urban connections in the Central Plains region and Yunnan, and these cities all have developed economic industries and are mostly provincial capitals and sub-provincial cities. However, in Xinjiang and Northeast China, CTU’s connection degrees have reached 222 and 198 respectively, and CKG’s connection degrees are 124 and 96. This shows that cities in remote areas are more likely to be connected to larger hub airport. For international air links cities, most contacts occur in Southeast Asia such as Thailand, Vietnam, Philippines, Cambodia, Malaysia, Indonesia, etc. For example, CTU’s connection degree is 492, with 48% of international flights, and CKG’s connection degree is 216, and the international flight accounts for 42%. This is because these countries have developed tourism resources and are close to China, bringing more flights to CTU and CKG. In addition, the analysis of the top ten airports of the airport's external connection, at this time, CTU and CKG's external connection degrees are 527 and 315, accounting for 51% and 62% of international flights. Except for Southeast Asia, CTU prefers to connect Hong Kong, Japan, South Korea, Taiwan and other countries or regions, while CKG has added Macau on this basis. It can be seen that the cities with high external connections between the two airports are located in the neighboring countries or regions of China, their connections with Europe and the United States are weak.

Figure 4. Air contact network structure (Note: Figure a shows CTU Airlines contact city and its flight volume, Figure b shows CKG Airlines contact city and its flight volume)
6. CONCLUSION
With the rapid development of air transportation, the hub airport's time resources are increasingly tense. Investigating the differences in slots allocation at different hub airports within the same area has positive academic significance and application requirements for optimizing resource allocation. Taking CTU and CKG as the research objects, the analysis of the difference in slot allocation from the aspect of time and space, the results show that the flight time of CTU is more densely allocated in time and space resources. Although the slot allocation of the two airport is similar in some respect, due to the strong passenger demand in CTU, the number of flights after the peak of its airport is more stable than that of CKG. CKG enters peak hour one hour later than CTU. Further analysis of the arrival and departure slot allocation of the two shows that the flight wave of the two airports are morning and evening peak-shaped. In the peak period of CTU, the take-off and landing intervals are shorter than that of CKG, and CKG’s peak period for take-off is shorter than that of CTU. But both airports maintain a high number of arrival flights at night. Finally, the study of spatial connection found that the two airports have relatively closer connections to the provincial capital or sub-provincial cities, but in some remote provinces, they are more inclined to connect to a larger hub, which is the CTU. Foreign cities with high connection degree to the two airports are more around China than in Europe and United States. Nearly half of the flights are to Southeast Asia, and CTU has a higher proportion, and the strength of contact with Southeast Asia is stronger. These studies have enriched the research on airport slot resources, but the further study on international flight slot is still needed.

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