Research of Take-off-and-land Waveform Based on Flight Plan Data

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ABSTRACT: The flight schedule of mega-airports has become a scarce resource. The research of the flight take-off-and-land waveform is conductive to rationally organizing flight operations and improving airport service efficiency. Based on OAG flight plan data, this paper analyzed, concluded and classified the take-off-and-land waveforms of daily passenger flights in the world’s mega-airports, and finally obtained four types of flight waveforms, namely, zigzag shape, trapezoidal shape, morning-and-evening-peak shape and superimposed shape. Meanwhile, this paper put forward four characteristic indexes to evaluate the flight take-off-and-land waveform, namely, occupied ratio of peak take-off/landing flight, standard deviation ratio of flight sorties, time interval of take-off/landing peak, and paired quantity of landing-take-off peak. Taking China’s airports whose passenger throughput ranking top ten as an example, this paper analyzed the flight take-off-and-land waveforms and characteristic indexes of each airport. The research result shows that the take-off-and-land waveforms of the passenger flight in China’s mega-airport shall be subject to the flight wave with the morning-and-evening-peak shape; the mean value of occupied rate of the peak take-off flight and peak landing flight is respectively 64.1% and 59.0%; the standard deviation ratio of flight sorties is 0.12; there is no obvious landing-take-off peak pair during the daytime operation period and there is a certain gap with the flight operation mode of large international hub airports.

Keywords: air traffic control; flight wave; OAG flight plan data; airport; flight schedule

1 INTRODUCTION

According to the latest statistical data of Airport Council International (ACI), among China’s top 20 airports of passenger throughput in 2014, there are three airports in China, namely, Beijing Capital International Airport ranking the second, Guangzhou Baiyun International Airport ranking the fifteenth and Shanghai Pudong International Airport ranking the nineteenth, with the annual passenger throughput of 86.13 million, 54.78 million and 51.69 million passengers, respectively. With the increase of airport passenger volume and sharp increase of flight take-off-and-land sorties, the resource of airport flight schedule is increasingly lessened. In particular, the flight schedule of mega-airports has become a scarce resource. The quantitative distribution curve of the flight take-off-and-land time in 24 hours a day forms the airport flight take-off-and-land wave. Therefore, to carry out the flight take-off-and-land waveform, especially the research on the passenger flight take-off-and-land waveforms in mega-airports is of great significance in rational and effective organization of flight operations and enhancement of the air-
port service efficiency. The current research on the flight schedule or flight take-off-and-land waveform is mainly from following aspects: (1) Research the overall management and equitable distribution of flight schedule from the perspective of policies and regulations [2-4]; (2) research the optimal allocation of flight schedule, and reduction in flight delays from the perspective of theoretical algorithm and mathematical model [5-9]; (3) research the optimal adjustment of the flight take-off-and-land waveforms from the perspective of constructing a hub airport [10-12]; (4) research the arrangement of flight schedule or layout of airline network for the specific airports and airline companies [13-16]. Overall, the research on the flight schedule or take-off-and-land waveform lays more emphasis on the optimal adjustment of airport flight schedule and analysis of flight waveform reconstruction, but there is rare system analysis and research on the existing flight take-off-and-land waveforms and characteristics of mega-airports.

Based on the flight plan data of OAG (namely, Official Airline Guide, which is a professional and authoritative data provider of the global flight schedule, passenger traffic of civil aviation and dynamic information of flight [17]), this paper carries out an in-depth analysis, conclusion and classification of take-off-and-land waveforms of passenger flight during peak months and peak days in world’s mega-airports, and then applies this research to the analysis of take-off-and-land waveforms of the passenger flight in China’s mega-airports.

2 CLASSIFICATION OF FLIGHT TAKE-OFF-AND-LAND WAVEFORM

For the world’s top 50 international mega-airports of annual passenger throughput, this paper applies the flight plan analysis tool of OAG to extract data related to take-off-and-land sorts of daily passenger flight during peak months in 2014 for analysis, and it finally creates take-off-and-land waveform of daily passenger flight. This paper can also draw conclusions about the following four types of representative flight waveforms according to the waveform characteristics of each airport:

(1) Flight wave with zigzag shape

The flight take-off-and-land peaks appear alternatively. As shown in Figures 1-3, more than three groups of take-off-and-land flight crest (trough) pair are formed in one day. The passenger flight take-off-and-land sorts of representative airports such as Paris Charles de Gaulle Airport, Frankfurt International Airport and Dubai International Airport during peak days are respectively 1,275, 1,306 and 1,017. The airport with take-off-and-land flight which is zigzag shape usually has distinct characteristics of hub airports. An intensive period of incoming flight is followed by an intensive period of outbound flight. With a close convergence between the incoming flight and outbound flight, it is helpful for the connecting flight to flexibly arrange the take-off-and-land time and improve the transfer efficiency.

(2) Flight wave with trapezoidal shape

As shown in Figures 4 and 5, after the flight take-off-and-land sorts per hour reaching the initial peak, the daytime operation period maintains a narrow range of fluctuations until the trough is formed after the take-off-and-land flights are rapidly decreased at night. The passenger flight take-off-and-land sorts of representative airports such as London Heathrow International Airport and Haneda Airport during peak days are respectively 1,342 and 1,181. For the airport

In addition to above airports, other airports with the flight wave which is zigzag shape also include Amsterdam Airport Schiphol, Denver International Airport, Incheon International Airport, Hong Kong International Airport and Singapore Changi Airport and so on.
with flight wave which is trapezoidal shape, the take-off-and-land sorties during the operation period are relatively balanced; the overall operational sorties are maintained at a certain level of slight fluctuations; the airport service efficiency is high, which tends to operate at full load. In addition, another objective factor of forming the flight wave which is trapezoidal shape is that environment around the airport is more sensitive to noise, and there is substantial reduction or prohibition of nighttime flights.

Figure 4. London Heathrow International Airport.

Figure 5. Haneda Airport.

(3) Flight wave with morning-and-evening-peak shape

The extreme value of take-off-and-land flight wave peak is respectively in the morning and evening. The flight take-off-and-land sorties per hour during the daytime operation period have a certain fluctuation, and the peak and trough appear alternately, as shown in Figures 6-8. The passenger flight take-off-and-land sorties of representative airports such as O’Hare International Airport, Los Angeles International Airport, Soekarno-Hatta International Airport during peak days are respectively 2,611, 1,744 and 1,152. The airport with flight wave which is morning-and-evening-peak shape usually has distinct characteristics that set out early and return late, because this kind of airport is usually used as a base airfield of large airline companies with many overnight flights. The usage of airport and runway has a certain imbalance, and the operation pressure of the early departure flight and late incoming flight is great.

In addition to above airports, other airports with flight wave which is morning-and-evening-peak shape also include Beijing Capital International Airport, London Gatwick Airport, Guangzhou Baiyun International Airport and Shanghai Pudong International Airport and so on.

Figure 6. O’Hare International Airport.

Figure 7. Los Angeles International Airport.

Figure 8. Soekarno-Hatta International Airport.

(4) Flight wave with superimposed shape

As shown in Figures 9 and 10, the take-off waveform and the landing waveform are similar, the wave peak of take-off and the wave peak of landing are superimposed during some period, and a total of take-off-and-land sorties per hour have significant fluctuations. The passenger flight take-off-and-land sorties of representative airports such as Hartsfield-Jackson Atlanta International Airport and Sydney Airport during peak days are respectively 2,427 and 843. For the airport with flight wave which is superimposed shape, a total of flight take-off-and-land sorties per hour have strong fluctuations; the daily operation sortie of flight has a relatively large room to improve, which has not yet reached airport’s saturating capacity of operation.
3 WAVEFORM CHARACTERISTIC EVALUATION INDEX

For take-off-and-land waveforms of daily passenger flights in different airports, four characteristic indexes are selected to evaluate the flight waveform:

(1) Occupied ratio of the peak take-off-and-land flight

The calculation formulas about the occupied ratio of the peak take-off-and-land flight are shown as follows:

\[
\text{Occupied ratio of the peak take-off flight} = \frac{\text{a sum of the daily flight take-off sorties per hour during three busiest periods}}{\text{a sum of the total daily flight take-off-and-land sorties per hour during three busiest periods}} \quad (1)
\]

Occupied ratio of the peak landing flight = (a sum of the daily flight landing sorties per hour during three busiest periods) / (a sum of the total daily flight take-off-and-land sorties per hour during three busiest periods) \( (2) \)

This index is used to evaluate imbalance of using runways in take-off-and-land peak hours. The greater the index value is, the greater the occupied ratio of the take-off-and-land flight is. If the index value is close to 50%, it indicates that the take-off-and-land operation is relatively balanced during peak hours. The occupied ratios of the peak take-off flight in Paris Charles De Gaulle Airport and London Heathrow International Airport are respectively 65.4% and 51.8%, while the occupied ratios of peak landing flight are respectively 60.0% and 50.6%.

(2) Standard deviation ratio of flight sorties

The standard deviation ratio of flight sorties refers to a ratio between the standard deviation of take-off-and-land sorties in a total of 15 hours during the airport operation period (07:00-22:00) and take-off-and-land sorties of average hours all day long.

This index is mainly used to evaluate the fluctuation of hourly sorties during the normalization operation of the airport. The greater the index value is, the greater the fluctuation of hourly operation number of flights is, or the smaller the fluctuation is. For the airport with saturated traffic flow, the fluctuation of hourly sorties is usually small, that is, the standard deviation of the appropriate flight sorties is small. The standard deviation ratio of the flight sorties for Singapore International Airport is 0.12, while the standard deviation ratio of the flight sorties for Hartsfield-Jackson Atlanta International Airport is 0.32.

(3) Take-off and landing peak interval

The take-off peak interval refers to the time interval between take-off flight peaks in the flight waveform; the landing peak interval refers to the time interval between landing flight peaks in the flight waveform, as shown in Figure 11. In case of multiple interval time, the arithmetic average value is taken. This index is mainly used to evaluate the connecting time of the flight wave with zigzag shape. Usually, there is a take-off wave peak between a pair of landing flight wave peak, and the connecting time of the flight is approximately estimated as a half of interval time of landing peak. For the airport without significant fluctuations of the flight wave peak and trough, this index has a small referential significance.

The take-off peak interval of Amsterdam Airport Schiphol and Paris Charles De Gaulle Airport is respectively 2.8 hours and 2.4 hours, while the landing peak interval of them is respectively 2.8 hours and 2.7 hours.

(4) Landing–take-off peak paired number

The landing flight wave peak and the subsequently adjacent take-off flight wave peak form a landing–take-off wave peak pair. Thus, the total number of the wave peak pair appeared in the take-off-and-land waveform all day long is the landing–take-off wave peak paired number, as shown in Figure 12. This index is mainly used to evaluate the frequency of the connecting flight appeared all day long. The greater the index value is, the more the frequency of the connecting flight wave is. The landing–take-off peak paired number of Denver International Airport and O’Hare International Airport is respectively 5 and 4.

4 ANALYSIS OF FLIGHT WAVEFORM OF CHINA’S MEGA-AIRPORT

Taking China’s top 10 airport of passenger throughput in 2014 as an example (as shown in Table 1 [18]), this paper analyzes the flight take-off-and-land waveforms and characteristic indexes of China’s mega-airport.
Table 1. Airport passenger throughput and aircraft movements.

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Airport</th>
<th>Passenger throughput (person-time)</th>
<th>Take-off-and-land sortie (sortie)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Beijing Capital</td>
<td>86,128,313</td>
<td>581,952</td>
</tr>
<tr>
<td>2</td>
<td>Guangzhou Baiyun</td>
<td>54,780,346</td>
<td>412,210</td>
</tr>
<tr>
<td>3</td>
<td>Shanghai Pudong</td>
<td>51,687,894</td>
<td>402,105</td>
</tr>
<tr>
<td>4</td>
<td>Shanghai Hongqiao</td>
<td>37,971,135</td>
<td>253,325</td>
</tr>
<tr>
<td>5</td>
<td>Chengdu Shuangliu</td>
<td>37,675,232</td>
<td>270,054</td>
</tr>
<tr>
<td>6</td>
<td>Shenzhen Baoan</td>
<td>36,272,701</td>
<td>286,346</td>
</tr>
<tr>
<td>7</td>
<td>Kunming Changshui</td>
<td>32,230,883</td>
<td>270,529</td>
</tr>
<tr>
<td>8</td>
<td>Chongqing Jiangbei</td>
<td>29,264,363</td>
<td>238,085</td>
</tr>
<tr>
<td>9</td>
<td>Xi’an Xianyang</td>
<td>29,260,755</td>
<td>245,971</td>
</tr>
<tr>
<td>10</td>
<td>Hangzhou Xiaoshan</td>
<td>25,525,862</td>
<td>213,268</td>
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</table>

The take-off-and-land waveforms of daily passenger flight of above airports during peak months in 2014 are shown in Figure 13; the evaluation indexes of waveform characteristics are shown in Table 2.
Through analysis of the flight take-off-and-land waveforms, the flight take-off-and-land waveform of China’s mega-airport basically belongs to the category of the flight wave with morning-and-evening-peak shape. Characteristics of the early departure port and the late incoming port during peak hours are obvious, and the take-off-and-land peaks appear alternatively during the daytime operation period, thus forming 2 to 4 groups of landing and take-off peak pairs.

The mean value of the occupied ratio of the peak take-off flight and peak landing flight in China’s mega-airport is respectively 64.1% and 59.0%. The use of runways in take-off-and-land peak hours has a certain imbalance, and the take-off peak is particularly prominent. The usage of runways during take-off-and-land peak in Chengdu Shuangliu International Airport and Beijing Capital International Airport has the most obvious imbalance, of which the occupied ratios of the peak take-off flight are respectively 75.8% and 70.7%, while the occupied ratios of the peak landing flight are respectively 68.5% and 65.6%. The usage of runways during take-off-and-land peak in Shenzhen Baoan Airport is relatively balanced, of which the occupied ratios of the peak take-off flight and peak landing flight are respectively 58.0% and 55.2%. The average level of the standard deviation ratio of the flight sorties in China’s mega-airport is about 0.12, the fluctuation of hourly sorties during the normalization operation of the airport is small, and the index value of similarly international mega-airports is in the range of 0.16 to 0.25. The index values of Chengdu Shuangliu International Airport and Beijing Capital International Airport are minimums which are only 0.05 and 0.06, and the daytime operational sorties become saturated, so Chengdu Tianfu International Airport and Beijing-Daxing International Airport are under planning and construction.

The mean value of the take-off peak interval and landing peak interval in China’s mega-airport is respectively 3.3 hours and 3.2 hours, which can be used for approximate estimation of the connecting time as about 90 minutes and basically meet the requirements of domestic and international flight connecting time (usually, it takes 45 to 60 minutes to complete transfer between domestic flights, 90 minutes to complete...
transfer from the domestic flight to international flight or from the international flight to domestic flight [12].

In the case analysis, a number of landing–take-off peak pair can be formed between the early departure flight and the late incoming flight in China’s mega-airports; however, compared with those airports with flight wave which is zigzag shape (such as Dubai International Airport, Paris Charles De Gaulle Airport, Frankfurt International Airport, Amsterdam Airport Schiphol and so on), their fluctuations are obviously inadequate, which have not yet been regarded as the true hub-typed operation airports.

5 CONCLUSION

This paper carries out a classified research on the take-off-and-land waveforms of passenger flights in the world’s mega-airport, which proposes characteristic evaluation indexes of four kinds of waveforms, and then it applies this research to the analytical research on the take-off-and-land waveforms of the passenger flight in China’s mega-airport, and draws following conclusions:

(1) According to the morphological characteristics of the flight take-off-and-land waveform, there are four types of flight waveforms, namely, the flight wave with zigzag shape, the flight wave with trapezoidal shape, the flight wave with morning-and-evening-peak shape and the flight wave with superimposed shape. The take-off-and-land waveforms of the passenger flight in China’s mega-airport shall be subject to the flight wave with the morning-and-evening-peak shape.

(2) The standard deviation ratio of flight sorties in China’s mega-airport is 0.12, slightly lower than the international average level. The fluctuation of hourly sorties during the normalization operation of the airport is small, and part of airport traffic flow has become saturated, such as Beijing Capital International Airport and Chengdu Shuangliu International Airport. (3) Currently, there is no obvious land-and-take-off peak pair when China’s mega-airports are operating during daytime; there is a certain gap with the flight operation mode of large international hub-airports (such as Dubai International Airport, Paris Charles De Gaulle Airport and Frankfurt International Airport).

(4) For the airport with a large-scale base, it is not easy to damage the characteristics of early take-off and late landing peak. Three to four incoming and departure zigzag-shaped flight wave peak pairs can be considered to rationally organize during the daytime operation period, so as to enhance the hub function of the airport. For the airports with regional advantages or the second city-wide airport, the zigzag-shaped flight wave can be referred to create a hub-typed operating mode.

ACKNOWLEDGEMENT

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<tr>
<th>Airport</th>
<th>Index 1 Occupied ratio of peak take-off/landing flight</th>
<th>Index 2 Standard deviation ratio of flight sorties</th>
<th>Index 3 Time interval of take-off/landing peak (hour)</th>
<th>Index 4 Paired quantity of landing–take-off peak</th>
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<tbody>
<tr>
<td>Beijing Capital</td>
<td>70.7%</td>
<td>65.6%</td>
<td>0.06</td>
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<tr>
<td>Guangzhou Baiyun</td>
<td>62.2%</td>
<td>55.7%</td>
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<tr>
<td>Shanghai Pudong</td>
<td>62.3%</td>
<td>56.0%</td>
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<td>Shanghai Hongqiao</td>
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<td>60.8%</td>
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<td>2.8</td>
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<td>59.3%</td>
<td>57.2%</td>
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<td>3.0</td>
</tr>
<tr>
<td>Hangzhou Xiaoshan</td>
<td>61.9%</td>
<td>57.6%</td>
<td>0.16</td>
<td>3.7</td>
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<tr>
<td>Mean value</td>
<td>64.1%</td>
<td>59.0%</td>
<td>0.12</td>
<td>3.3</td>
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