Simulation Analysis of Airport Parallel Runway Capacity under Different Operating Modes

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Abstract. Efficient ground operation of aircraft directly impacts airport's courses of energy conservation and green operation. The parallel runway system is the most popular configuration in airport multi-runway construction. Four types of representative parallel runways (space between 400m, 760m, 920m and 1525m) and corresponding operation modes were simulated by using Simmod. The Ultimate Capacity (UC) and Factual Operation Capacity (FOC) of parallel runways were analyzed taking consideration of runway crossing and non-runway crossing. The simulation result shows that in instrument flight rule, the FOC of widely spaced parallel runways is about 74 sorties per hour, the FOC of medially spaced parallel runways is about 65 sorties per hour, and that of closely spaced parallel runways is about 50 sorties per hour. In condition of non-runway crossing, the capacity of parallel runway system can be increased by 13%.

Introduction

The continuous growth of social economy drives China air transport on the fast-growing track, during which China civil aviation has become the second largest air transport system in the world. The growing demand for air transport leads to the increasing scale of airport system in a response to the higher requirement. As of the end of 2016, China has more than 10 airports with multiple runways. Currently, the majority of large airports in the said scale have constructed or planned several parallel runways to relieve the pressed demands on traffic volume. Therefore, it is of great significance to research the capacity of airport multi-runways system, particularly of parallel runways system, which will be used to instruct the construction of China airports in the future.

Runway is an important part of the air traffic system, which determines the capacity of the airport. Three methods are usually employed to evaluate the capacity and operational efficiency of airport runways, i.e.: statistical data analysis, mathematical analysis and computer simulation. (1) Statistical data analysis is used to estimate the airport capacity based on the capacity envelope diagram drawn against the statistical flow data of existing airports, a model usually performed in the early stage of capacity analysis, but the disadvantage is that it can only evaluate the capacity of existing airport runways system[1]. (2) Mathematical analysis is used to obtain the capacity of runways by establishing the mathematical equation set of airport and airspace operational parameters through the appropriate hypothesis, which is mainly used for macro-level
capacity evaluation[2]. (3) Computer simulation is an alternative in the most extensive application to evaluate the airport capacity and operational efficiency, which turns out the capacity level and efficiency index through the analysis of simulated operational data[3]. Simmod (Airport and Airspace Simulation Model) and TAAM (Total Airspace & Airport Modeler) are the most popular simulation software for the evaluation of airport capacity[4].

However, the majority of present works as to airport capacity focuses on single runway, or the single operational mode of runways in the specific airport, while above study falls in short of intensive research on the capacity and operational efficiency of parallel runways at different distances. In summary, this paper applies the Simmod software to establish the computer simulation model, and makes quantitative and qualitative analysis on the capacity of several typical parallel runways, which may be theoretically referenced for the future planning and construction of parallel runways.

**Parallel Runway Configuration**

Subject to the regulations of ICAO (International Civil Aviation Organization), parallel runways mean the uncrossed runways with parallel runway centerlines or the angle between the extending lines of centerlines is smaller than 15°, as in [5].

With relevant rules of FAA and CAAC, the operation mode of parallel runways and required runway spacing summarized below, see Table 1.

<table>
<thead>
<tr>
<th>Runway center line spacing</th>
<th>Operating rules</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 760m</td>
<td>Similar to the single runway</td>
<td></td>
</tr>
<tr>
<td>≥ 760m</td>
<td>Isolated operation, or independent take-off</td>
<td>Considering the threshold even or staggering condition</td>
</tr>
<tr>
<td>915~1035m</td>
<td>Dependent landing</td>
<td>Cannot meet the requirements of independent operation</td>
</tr>
<tr>
<td>&gt;1035 ~ 1525m</td>
<td>Independent landing</td>
<td>Requirements for surveillance and navigation equipment</td>
</tr>
</tbody>
</table>

Based on the above mentioned rules, and referring to the existing multi runway airport mainstream configuration, this paper selects the following four typical parallel runway configurations as the research object.

(1) Two runways spacing 400m, take-off and landing separate operation

In the model, the center distance of the two runways is 400m, the entrance of the runway is even, and the sufficient taxiway is arranged between the runway and the terminal area. This configuration belongs to the category of closely spaced parallel runways. The runway adjacent terminal area is for takeoff, another runway for landing, as shown in Fig. 1. In the case of the basic number of take-off and landing flights, the runway utilization rate of the highest operating mode[6]. Continuous landing or take-off flights must be equipped with wake interval. Then landing flight is given two options: ① After landing, crossing over the inside take-off runway to the terminal area; ② After landing, bypass-taxiing to the terminal area.

(2) Two runways spacing 760m, isolated operation

In the model, the distance between the two runways is 760m, and the other conditions are the same as those of the 400m model. This runway spacing can be isolated and run independently of parallel running. Take-off and landing are not related, take-off and landing flights are equipped with the corresponding flight interval, as show in Fig. 1.
(3) Two runways spacing 920m, take-off and landing mixed operation

In the model, the distance between the two runways is 920m, as shown in Fig. 1. The model assumes that the runway near the terminal area is mainly used to take off, with a small number of landing flights, and the other runway is mainly used for landing.

![Figure 1. Two runways spacing 400m, 760m, 920m and 1525m.](image)

(4) Two runways spacing 1525m, take-off and landing independent operation

In the model, the distance between the two runways is 1525m, as shown in Fig. 1. The runway configuration of the two runways can be independent parallel instrument approach. The terminal area is usually located in the middle of the two runways, so it can avoid the runway crossing. For a few large airports (such as Dallas, Beijing, etc.), there are also a long distance parallel runways on one side of the terminal area, so the occurrence of the runway crossing which influence the runway capacity is also analyzed.

**Simulation Modeling**

This paper operates Simmod Plus 7.6 to make a simulation analysis of the operational efficiency in different operational patterns of parallel runways. Simmod, one dynamic and comprehensive airport simulation micro-software firstly proposed by FAA in 1978, through the continuous upgrading and perfection, has become one of the most applied airport and airspace simulation software [4].

Given that this paper focuses on analyzing the capacity and efficiency of airport runways system, the simulation modeling will put aside the restrictive factors of airspace, taxiway and apron. Based on the analysis of the configuration of the typical parallel runway, 4 simulation models (simu-400, simu-760, simu-920 and simu-1525) are established in this paper, and each model is considered in the following two situations: runway crossing and bypass-taxiing.

In instrument flight rules, the separation of continuously take-off is controlled at 60~120 seconds according to the difference between front and follow aircraft type. For the flights continuously landing, the landing separation is mainly controlled by wake turbulence separation, as shown in Table 2.

<table>
<thead>
<tr>
<th>Follow</th>
<th>Heavy</th>
<th>Middle</th>
<th>Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy</td>
<td>8 km</td>
<td>6 km</td>
<td>6 km</td>
</tr>
<tr>
<td>Middle</td>
<td>10 km</td>
<td>6 km</td>
<td>6 km</td>
</tr>
<tr>
<td>Light</td>
<td>12 km</td>
<td>10 km</td>
<td>6 km</td>
</tr>
</tbody>
</table>
The model adopts the flight schedule, for only taking off or landing runway, peak time arrangement of flight 60 sorties per hour; for mixed operational runway per hour for 30 take-off and landing flights, respectively. The flight schedule far exceeds the maximum current single runway capacity, its purpose is to calculate the limit capacity of the parallel runways.

This paper assumes that the ratio of heavy and middle aircraft is $p_h=20\%$, $p_m=80\%$, respectively. In the course of runway crossing, the average taxiing speed is set to 12km/h, and the pilot reaction time is 8~10 seconds. Take the runway spacing 400m model as an example (simu-400), after running the simulation model, the video demonstration is shown in Fig. 2.

![Simulation model demonstration (simu-400)](image)

Figure 2. Simulation model demonstration (simu-400).

Analysis of Simulated Result

The parallel runway capacity obtained by the above simulation model is the ultimate capacity, or saturation capacity. The runway capacity limit means without considering the continuous demand delay under the runway system in unit time (1 hours) can serve the largest aircraft movements. The continuous demand refers to ready for take-off or landing aircraft flow existing, the phenomenon appears less in the actual operation, so the ultimate capacity reflects the service ability of theoretical maximum runway system[3,7].

The simu-400, simu-760, simu920 and simu-1525 four simulation models are run 5 times respectively, and the average value of the simulation results was calculated. Finally, the ultimate capacity of the parallel runway is obtained as shown in Fig. 3. Take-off, landing and total flights in runway crossing and bypass-taxiing conditions are analyzed.

On the basis of the ultimate capacity of parallel runways, the factual operation capacity can be obtained. The factual operation capacity is defined as the unit of time (1 hours), corresponding to an acceptable level of flight delays (usually the average delay time of 4 minutes / flight), aircrafts taking off or landing can be serviced by 85%~90% of the ultimate capacity[3,7]. In this paper, according to the factual operation capacity
of 90% ultimate capacity calculation, the actual running capacity of double runway is shown in Table 3.

![Figure 3. Simulation results of 4 models.](image)

<table>
<thead>
<tr>
<th>Runway Distance (m)</th>
<th>Ultimate capacity</th>
<th>actual running capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Runway crossing</td>
<td>Non-crossing</td>
</tr>
<tr>
<td>400</td>
<td>44</td>
<td>52</td>
</tr>
<tr>
<td>760</td>
<td>64</td>
<td>73</td>
</tr>
<tr>
<td>920</td>
<td>69</td>
<td>76</td>
</tr>
<tr>
<td>1525</td>
<td>75</td>
<td>82</td>
</tr>
</tbody>
</table>

By analyzing the simulation results of the above, it is not difficult to see that the runway spacing 1525m, two runways, about 74 movements per hour; when the runway spacing is 400m, the capacity is about 47 movements per hour, if we consider the runway crossing, its capacity is only 40 movements per hour. In the case of setting bypass taxiway or no runway crossing, the factual operation capacity of the dual runway system can be increased by about 13%. Under the simu-760 operating mode, the runway system capacity is more than 40% of the simu-400 operation mode. Simu-920 mode of operation compared with simu-760 mode, the capacity change is small, an increase of about 3~7%.

**Conclusions**

This paper operates Simmod simulation software to establish the computerized simulation model for different utilization patterns of parallel runways, and make systematic analysis and quantitative evaluation of airport factual operation and ultimate capacity, with the following conclusions:

1. For the far spaced parallel runways, two runways operate independently. The maximum factual operation capacity is about 74 movements per hour. Its shortcomings are more land use, higher cost of airport construction.

2. For closely spaced parallel runways (runway spacing is less than 760m), in instrument flight rules, the factual operation capacity of two runways is low, about 50 movements per hour. In order to improve the capacity of closely spaced parallel
runways, a reference operation experience of Europe and the United States, the visual flight rules can be used under appropriate weather conditions.

(3) It can effectively improve the running capacity of the double runway system that setting the bypass taxiway, and the runway capacity is increased by about 13% compared with runway crossing. At the same time, it is beneficial to increase the safety and flexibility of runway use.

The capacity of the parallel runway system is closely related to the standard of the control interval, the use of runway and the combination of aircraft type and so on. For a wide range of operating modes and conditions, the comprehensive and systematic analysis of the capacity of the runway is still to be further studied.

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References