Comprehensive Evaluation of Airspace and Ground Operation Simulation in Large-Scale Airport

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Abstract: The evaluation model of airport airspace and ground operation was constructed by using analytic hierarchy process (AHP). 5 airspace operation indexes were selected: potential impact to military aviation, airspace demand range, number of arriving and departure routes, flow equilibrium of entry and exit point, arrival air delays time. 7 evaluation indexes of ground operation were selected: number of daily departure and arrival flights, equilibrium of runway usage, departure ground delays time, ground taxiing time, usage equilibrium of main taxiway, turnover frequency of contact gate, air bridge ratio. The index scale method was used to determine the weight of each index, which had better ordering, consistency and uniformity. Taking Beijing New Airport as an example, the airspace and ground operational efficiency was evaluated comprehensively. The results show that the “3+1” runway configuration is better than “4+0”.

1. 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 growth of aviation demand results in huge pressure on the operation of large hub airports in China. The simulation technology is often used through the process of evaluating the status of the airport or the renovation plan to enhance its operational efficiency, so as to build up the computer model for terminal airspace and airfield ground[1-4]. By analyzing the simulation results, lots of operating data can be obtained.

However, in order to make an effectively comprehensive comparison and selection, it is necessary to select the appropriate evaluation index, determine the weighting factor of each index and give the comprehensive selection results with indexes of the alternatives. But there is still a lack of reference to this research at present. In this occasion, this paper put up with the calculation method of each index and determined the corresponding weight value by building comprehensive evaluation analytic hierarchy model of the airspace and ground based on the analytic hierarchy process (AHP) of operational research[5]. Taking the “3+1” and “4+0” runway configurations of the four runways in Beijing New Airport as an example, this paper made a comprehensive evaluation towards the airspace and ground operational efficiency.
2. Description of the Evaluation Index

It is necessary to evaluate the operational efficiency of an airfield planning scheme from both airspace and ground in terms of flight operation. As for airspace operation, the planning stage mainly includes the terminal airspace occupation area in airport, coordination between civil aviation and military, departure routes diversion, and the air delays time, etc. As for ground operation, the main considerations are the runway efficiency, taxiing smoothness, flight efficiency and ground delays time, etc. Based on the analysis above and the stimulation results, an analytic hierarchy model is constructed. It can be seen from Figure 1 that it is divided into four hierarchies: target layer, criterion layer, index layer and scheme layer.

![Fig. 1 Hierarchy Structure of Evaluation of Operational Efficiency](image)

The calculation methods of the above indexes can be referred to the reference [6], and this paper will not go into details. For evaluation index in airspace operation, the greater the index value, the more favorable for airspace operation. The greater the value of \( A_i \) is, the smaller the potential impact to military aviation is. The smaller the value of \( A_i \) is, the greater the airspace demand range is. The greater the value of \( A_i \) is, the greater the number of routes is, which is conducive to the diversion of departure and landing flights. The greater the value of \( A_i \) is, the greater the flow equilibrium of entry and exit point is. The greater the value of \( A_i \) is, the less time the arrival air delays is.

For evaluation index in ground operation, the greater the index value, the more favorable for ground operation. The greater the value of \( G_i \) is, the greater the airport daily capacity is. The greater the value of \( G_i \) is, the stronger the equilibrium of runway usage is. The greater the value of \( G_i \) is, the less time the departure ground delays is. The greater the value of \( G_i \) is, the less time the average taxiing spends. The greater the value of \( G_i \) is, the stronger the usage equilibrium of main taxiway is.

3. Determination of Index Weight

With the application of analytic hierarchy process, this paper made a paired-comparison of indicators in different levels, obtained the judgment matrix, calculated the weighting factors of various indexes and conducted the consistency test. The basic thought and calculation of the analytic hierarchy process can be referred from [5, 7] and will not be elaborated in this paper.

In the analytic hierarchy model of airspace and ground operational efficiency evaluation, the hierarchies involved airspace operation and ground operation. In terms of the flight operation in airport terminal, both the airspace and ground operation are of great importance. Thus, the airspace operational efficiency weights will be set as \( w_A = 0.5 \), and the ground operational efficiency weights as \( w_G = 0.5 \).

The index scale method serves as the reference to the importance of two indexes in the paired-comparison in judgment matrix. This method is better in order-preserving, consistency and
uniformity compared with the traditional 1-9 scale method [8]. The difference of two methods can be shown in table 1.

| Difference Description | 1-9 Scale Method | Index Scale Method |
|------------------------|------------------|--------------------|
| Same important         | 1                | $e^{0.4}$          |
| Tiny important         | 2                | $e^{1.4}$          |
| Slight important       | 3                | $e^{2.4}$          |
| Important              | 4                | $e^{3.4}$          |
| Obviously important    | 5                | $e^{4.4}$          |
| Quite important        | 6                | $e^{5.4}$          |
| Very important         | 7                | $e^{6.4}$          |
| Great important        | 8                | $e^{7.4}$          |
| Extreme important      | 9                | $e^{8.4}$          |

3.1 Index Weight of Airspace Operational Efficiency

With comprehensive consideration including the airspace plan in airport terminal, approaching traffic control, opinions of flight personnel and experts of airport planning and design, this paper made paired-comparison of 5 airspace operational efficiency indexes consisting of potential impact to military aviation $A_1$, airspace demand range $A_2$, the number of arriving and departure routes $A_3$, flow equilibrium of entry and exit point $A_4$ and the arrival air delays time $A_5$. The obtained judgment matrix is shown in table 2.

| $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ |
|-------|-------|-------|-------|-------|
| $A_1$ | 2.718 | 0.472 | 1.649 | 0.287 |
| $A_2$ | 0.368 | 1     | 1.284 | 0.174 |
| $A_3$ | 2.117 | 4.482 | 1     | 0.606 |
| $A_4$ | 0.606 | 0.779 | 0.368 | 1     | 0.174 |
| $A_5$ | 3.490 | 5.755 | 1.649 | 5.755 | 1     |

Calculate the weight value of airspace operational efficiency indexes $A_i \sim A_i$ by sum algorithm. The weight value is $w_1=0.141$, $w_2=0.072$, $w_3=0.268$, $w_4=0.078$, $w_5=0.441$ respectively. Conduct the consistency check. $\lambda_{max}=5.069$, $CI=0.017$, $RI=1.12$, and $CR=0.015<0.1$ is obtained, which meet the consistency requirement.

3.2 Index Weight of Ground Operational Efficiency

With comprehensive consideration including the ground management in airport terminal, air tower traffic control, opinions of flight personnel and experts of airport planning and design, this paper made paired-comparison of 7 ground operational efficiency indexes including number of daily departure and arrival flights $G_1$, equilibrium of runway usage $G_2$, departure ground delays time $G_3$, ground taxiing time $G_4$, usage equilibrium of main taxiway $G_5$, turnover frequency of contact gate $G_6$ and air bridge ratio $G_7$. The obtained judgment matrix is shown in table 3.
Table 3 Judgment Matrix of Ground Indexes

|   | \( G_1 \) | \( G_2 \) | \( G_3 \) | \( G_4 \) | \( G_5 \) | \( G_6 \) | \( G_7 \) |
|---|---|---|---|---|---|---|---|
| \( G_1 \) | 1 | 2.718 | 0.606 | 2.117 | 2.718 | 3.490 | 2.718 |
| \( G_2 \) | 0.368 | 1 | 0.472 | 0.606 | 2.117 | 1.649 | 1.284 |
| \( G_3 \) | 1.649 | 2.117 | 1 | 2.718 | 3.490 | 4.482 | 3.490 |
| \( G_4 \) | 0.472 | 1.649 | 0.368 | 1 | 1.649 | 2.117 | 1.649 |
| \( G_5 \) | 0.368 | 0.472 | 0.287 | 0.606 | 1 | 1.284 | 0.779 |
| \( G_6 \) | 0.287 | 0.606 | 0.223 | 0.472 | 0.779 | 1 | 0.606 |
| \( G_7 \) | 0.368 | 0.779 | 0.287 | 0.606 | 1.284 | 1.649 | 1 |

Calculate the weight value of ground operational efficiency indexes \( G_i \) by sum algorithm. The weight value is \( w_i = 0.232, w_2 = 0.113, w_3 = 0.299, w_4 = 0.132, w_5 = 0.074, w_6 = 0.062, w_7 = 0.088 \) respectively. Conduct the consistency check. \( \lambda_{max} = 7.085, CI = 0.014, RI = 1.32, and CR = 0.013 < 0.1 \) is obtained, which meet the consistency requirement.

### 3.3 Weight Based on Total Objective

The weight of each index multiplying the corresponding membership criterion weights equals the weight value of the index relative to the total target. The weight value of the evaluation index of airspace and ground operational efficiency relative to the high-efficient operational plan is shown in table 4. Consistency inspection index turned out to be \( CR = 0.013 < 0.1 \), showing that the weight based on total objectives can meet the consistency requirement.

Table 4 Weight Based on Total Objective

| Hierarchies | Airspace Operation | Ground Operation | Weight Relative to Total Objective |
|-------------|--------------------|------------------|-----------------------------------|
| \( A_1 \)   | 0.141              | 0.070            |                                   |
| \( A_2 \)   | 0.072              | 0.036            |                                   |
| \( A_3 \)   | 0.268              | 0.134            |                                   |
| \( A_4 \)   | 0.078              | 0.039            |                                   |
| \( A_5 \)   | 0.441              | 0.221            |                                   |
| \( G_1 \)   | 0.232              | 0.116            |                                   |
| \( G_2 \)   | 0.113              | 0.057            |                                   |
| \( G_3 \)   | 0.299              | 0.149            |                                   |
| \( G_4 \)   | 0.132              | 0.066            |                                   |
| \( G_5 \)   | 0.074              | 0.037            |                                   |
| \( G_6 \)   | 0.062              | 0.031            |                                   |
| \( G_7 \)   | 0.088              | 0.044            |                                   |

### 4. Comprehensive Evaluation of Beijing New Airport Operation

Two representative runway configuration schemes are proposed in Beijing New airport at the planning stage. The scheme 1 is constituted with 3 longitudinal runways and 1 transverse runway (abbreviated as “3+1” configuration), and the scheme 2 is constituted with 4 parallel runways (abbreviated as “4+0” configuration). It can be shown in Figure 2.
The correlation factor value and index value of airspace and ground operation evaluation in “3+1” and “4+0” runway configuration is shown in table 5.

Table 5 Factor Value and Index Value for Evaluation

| Factor Value | Runway Configuration “3+1” | “4+0” | Index Value | Runway Configuration “3+1” | “4+0” |
|--------------|-----------------------------|--------|-------------|-----------------------------|--------|
| $A_1$        | 58                          | 57     | $A_1$       | 0.983                       | 1      |
| $A_2^{KP}$   | 26232                       | 26010  | $A_2$       | 0.992                       | 1      |
| $A_3^{K}$    | 70                          | 60     | $A_3$       | 1                           | 0.857  |
| $A_4^{G}$    | 4.47                        | 5.13   | $A_4$       | 1                           | 0.871  |
| $A_5^{AD}$   | 12.93                       | 57.53  | $A_5$       | 1                           | 0.225  |
| $G_1^{FM}$   | 127                         | 115    | $G_1$       | 1                           | 0.906  |
| $G_2^{RS}$   | 1.63%                       | 2.34%  | $G_2$       | 1                           | 0.697  |
| $G_3^{GS}$   | 4.23                        | 4.95   | $G_3$       | 1                           | 0.855  |
| $G_4^{TS}$   | 11.97                       | 13.34  | $G_4$       | 1                           | 0.897  |
| $G_5^{TS}$   | 119.13                      | 28.78  | $G_5$       | 0.242                       | 1      |
| $G_6^{AD}$   | 1                           | 1      | $G_6$       | 0.875                       | 1      |
| $G_6^{DG}$   | 0.75                        | 1      | $G_6$       | 0.875                       | 1      |
| $G_7^{IE}$   | 1                           | 1      | $G_7$       | 0.9                         | 0.9    |
| $G_7^{DB}$   | 0.8                         | 0.8    | $G_7$       | 0.9                         | 0.9    |

Combined with the weight value of each index, the comprehensive evaluation value of “3+1” and “4+0” runway configuration is 0.977 and 0.744 respectively. The calculation process is:

\[
\begin{bmatrix}
0.983 & 0.992 & 1 & 1 & 1 & 1 & 1 & 0.242 & 0.875 & 0.9 \\
1 & 1 & 0.857 & 0.871 & 0.225 & 0.906 & 0.697 & 0.855 & 0.897 & 1 & 1 & 0.9
\end{bmatrix} \times
\begin{bmatrix}
0.07 \\
0.036 \\
0.134 \\
0.039 \\
0.221 \\
0.116 \\
0.057 \\
0.149 \\
0.066 \\
0.037 \\
0.031 \\
0.044 \\
\end{bmatrix} = \begin{bmatrix}
0.962 \\
0.744 \\
\end{bmatrix}
\]
Therefore, the comprehensive evaluation of airspace and ground operation shows that the “3+1” runway configuration is better than the other one, making it the final determined runway configuration for Beijing New Airport.

5. Conclusions
The evaluation model of airport airspace and ground operation is constructed by using analytic hierarchy process (AHP), and the conclusions are as follows:

(1) In terms of the airspace operational efficiency, arrival air delays time and the number of arriving and departure routes serve as the main factors; while as for ground operational efficiency, departure ground delays time and daily number of departure and arrival flights are accounted for the main factors.

(2) The index scale method is applied to determine the weight of each index, which is better in order-preserving, consistency and uniformity, and it can also meet the evaluation requirements.

(3) The “3+1” configuration scheme recommended by the evaluation method is in line with the actual scheme of Beijing New Airport, suggesting that this method can be used for reference in future scheme selection.

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