Analysis of Low-Altitude Airspace

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Abstract. Low-altitude airspace resources have been the bottleneck of the development of general aviation industry and one of the key factors restricting the development of general aviation in China. Through theoretical research and on-the-spot investigation, this paper constructs a low-altitude airspace resource availability evaluation index system, uses multiple linear regression method to carry out systematic analysis, and determines the index weights at all levels. Taking Jiangsu Province as an example, the present situation of low-altitude available resources in Jiangsu Province is deeply analyzed, the actual situation and a large amount of data in various regions are summarized, the influence values of various factors on the region are calculated, and finally the availability results of low-altitude airspace resources are obtained. The research results demonstrate the scientificity and effectiveness of the method, which can provide reference for the rational utilization of low-altitude airspace resources and the declaration of general aviation activity airspace in China.

1. Introduction
With the continuous increase of low-altitude airspace activities, the voice of opening low-altitude airspace is getting higher and higher, and the research on the availability of low-altitude airspace resources in China is also gradually launched. Ref.[1] [2] give a detailed introduction to the definition of China's low-altitude airspace and the characteristics of general aviation activities. On this basis, Ref.[3] Proposes an evaluation index system that includes such influencing factors as military training flights. Ref.[4] analyzes the current situation of low altitude in China and the main influencing factors from the operational level. Ref.[5] Establishes a safety evaluation index system for low-altitude airspace operation based on the characteristics of low-altitude operation. However, the existing literature does not fully consider the influence of military and civil aviation on the analysis of low-altitude airspace resources, and cannot fully reflect the overall characteristics of low-altitude operation. The analysis results are also somewhat different from reality.

Based on the preliminary analysis of the current situation of the available resources in the low-altitude airspace in Jiangsu province in Ref.[6], this paper comprehensively considers the factors that may affect the operation of the low-altitude airspace, including the influences on the low-altitude airspace of the route routes in Jiangsu province, civil aviation terminal areas, approach airspace, hazardous areas, restricted areas, military aviation flight control boundaries, airports, etc., and jointly obtains the available resources range of the available low-altitude airspace. This paper intends to establish a low-altitude airspace resource evaluation index system based on the current research and the needs of low-altitude airspace users, and analyze the calculated and collected sample data to obtain the utilization of airspace resources. The feasibility of the model is verified by an example, which provides a reference for the research and analysis of low-altitude airspace resources.
2. Regression Analysis

2.1. Multiple Linear Regression Theory

In practical problems, if a variable is affected by multiple independent variables at the same time and the overall relationship is linear, a multiple linear regression model is introduced [7]. The mathematical expression is:

\[ y = C_0 + C_1X_1 + \cdots + C_nX_n + e \]

Where \( m \) is the number of explanatory variables, \( C_i \) is the regression coefficient, \( e \) is the random error term, and its mean value \( E(e) = 0 \) and variance \( D(e) = \sigma^2 \).

In order to make the regression model have good explanatory power, before establishing the multiple linear regression model, the independent variables should be selected first, and the following points should be paid attention to:

- There is a definite linear relationship between independent variables and dependent variables;
- Independent variables are independent of each other, i.e. there is no influence relation between variables;
- The error should obey normal distribution and expect to be 0;
- Independent variables shall ensure that complete sample data can be collected.

2.2. Algorithm Flow

As a mathematical statistical model, regression analysis has strict applicable conditions. In the process of analysis, the model should be continuously judged. The specific process is shown in figure 1:

The specific steps of regression analysis are as follows:

Bulleted list

- Sorting out the original data, making scatter plots, observing the relationship between independent variables and dependent variables, and determining the linear relationship.
- Multiple linear regression analysis was conducted. Through the goodness of fit (R test), the overall linear significance of the equation (F test) and the significance of independent variables (t test), it is finally determined whether the selection of indicators is correct and whether the linear relationship of the equation is significant.

3. Calculating Evaluation Index

3.1. Determine the Influencing Factors

The factors affecting the availability of low-altitude airspace resources are the sources of airspace resources evaluation indexes, which reflect the characteristics of airspace resources and largely determine the scientificity and perfection of the index system. Therefore, it is necessary to analyze the factors from multiple angles and in all directions.

According to the particularity of low-altitude airspace resources, after the investigation of military and civil aviation airports, the following seven main influencing factors are finally analyzed according to the principles of integrity, operability and systemativeness of index selection, combined with relevant issues to be considered in the location selection of general airports and the use and approval process of low-altitude airspace:

- danger zone;
- military flights procedure;
- the adjacent areas of military airports;
- the airspace of the civil airport;
- military aviation flight control zone / subarea boundary;
- approach airspace;
- air route.
3.2. Extraction of Key Indexes

The availability of low-altitude airspace resources is affected by many factors [8], but the more index sets are selected, the better. Due to mutual influence and even inclusion, the evaluation results are far from the actual ones. Therefore, according to the simplified criteria for index sets:

- Indexes that reflect less target information should be deleted.
- Index sets should be independent of each other.

According to the above-mentioned principles, the above-mentioned index set is simplified, and after many times of analysis and comparison, it is divided into the following five types of evaluation indexes:

| index | Introduction |
|-------|-------------|
| I     | Danger zone, arrival and departure route zone |
| II    | Military aviation adjoins airspace |
| III   | Civil aviation radar control airspace |
| IV    | Control boundary, approach control area |
| V     | The shortest distance from the boundary of the cloud route zone and the boundary of the danger zone to the surrounding army(If the airport center is located in such airspace, the distance is 0) |

In case of index superposition, only the influential index factors are considered, and eventually the sum of the area ratio of each index must be less than 1.

3.3. Evaluation Model of Low-Altitude Resource Availability

In order to quantify the impact of indicators on low-altitude airspace resources, considering the airspace range of the general airport with a radius of 5km, the ratio of each impact indicator in the airspace is taken as its impact value on the airspace, and regression analysis method is proposed to obtain the weight of each indicator.
Establishing regression weighting equation:

$$AA = C + \sum_{i=1}^{5} W_i \cdot A_i + \varepsilon$$  \hspace{1cm} (2)

Table 2. The meaning of each element in the equation

|   |   |   |   |   |
|---|---|---|---|---|
| $AA$ | the low-altitude airspace resource availability value |
| $C$ | a constant term |
| $W_i$ | weight of the indicator $i$ |
| $A_i$ | score of the indicator $i$ |
| $\varepsilon$ | the error term |

The low-altitude airspace resources are divided into 10 grades according to the occupied situation, and 1, 2, 3... 10 respectively represent the availability degree of airspace resources.

4. Case Analysis

Combined with the use of airspace resources, the five types of airspace, namely danger zone, shooting range, military aviation adjacent zone, civil aviation radar controlled airspace (the airspace of the navigation site) and control boundary, have the greatest impact on the use of low-altitude airspace resources, and are not recommended to be included in low-altitude airspace resources. Therefore, excluding the above airspace, the distribution of low-altitude airspace resources in Jiangsu Province can be drawn, as shown in figure 2:

![Low-altitude airspace resources distribution in Jiangsu Province](image)

The index scores of each airport and the airspace availability values (obtained by expert scoring method) are shown in table 3:

Table 3. The total sample of airspace resources evaluation

| Airport | Score | I  | II | III | IV  | V    |
|---------|-------|----|----|-----|-----|------|
| Baoying | 7     | 0  | 0  | 0   | 0   | 8.7665 |
| Binhai  | 4     | 0  | 0  | 0   | 0.9149 | 17.7 |
| Binjiang| 3     | 0  | 0.5755 | 0.2631 | 0   | 0    |
| Changchuan | 1 | 1  | 0  | 0   | 0   | 0    |
| ...     | ...   | ...| ...| ... | ... | ... |
| Changshu| 3     | 0  | 0  | 0   | 0.8615 | 7.2469 |
The analysis results are shown in figure 3:

According to the analysis results, Multiple $R=0.94246$ and Adjusted $R$ Square=$0.8781$, that is, the index set is highly positively correlated with low-altitude airspace resources and it can explain $87.81\%$. The Significance $F$ statistic in this case is far less than the significance level of $0.05$, so the overall regression effect of this model is better.

It is worth noting that column $E$ is the $P$ value of $t$ statistic of each index weight, and $E17$–$E22$ of this column are far less than the significance level of $0.05$. Therefore, the index set in this equation is related to the availability of low-altitude resources, that is, the regression coefficient of these index sets is significant.

As can be seen from figure 4, the model generally satisfies the equivariance requirement of residual error.

The final regression equation is:

$$y = 6.5688 - 5.468AC_1 - 4.857AC_2 - 4.797AC_3 - 3.701AC_4 + 0.038L$$

From the analysis results, it can be concluded that the danger zone and the cloud passage zone of military flights have the greatest impact on the availability of low-altitude airspace. The influence of the adjacent zones of military flights and the civil aviation radar airspace on the resources of low-altitude airspace is basically the same. Finally, comparing with the existing navigable airports, the actual operation of each navigable airport is basically consistent with the prediction results, which proves the practicability and effectiveness of the method.

5. Conclusion

In this paper, the regression analysis method is used to effectively analyze the low-altitude airspace resources, and the following conclusions are drawn:
The original data is easy to obtain, the operation method is simple, and the operability is strong. Using a large number of data analysis, the results are true and reliable.

Introduce the demand of airspace users and select five kinds of evaluation indexes to evaluate low-altitude airspace comprehensively and accurately.

The evaluation results give the availability value of low-altitude airspace resources, which can make clear judgment on the use of low-altitude airspace within the scope and provide scientific basis for the use of low-altitude airspace and the construction of navigable airports.

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