SE-DEA-based Approach to Determining the Hub Growth Potential of Airports

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Abstract. Determining which airports can grow to hubs in a transportation system is a basis of hub-and-spoke network design. From the perspective of airport operation efficiency, this paper presented a SE-DEA (super-efficiency data envelopment analysis)-based approach to identify those airports that possess the hub growth potential. Firstly, the urban population, urban GDP, and the number of navigation points were considered as input variables. The throughput, the proportion of transit passengers, the proportion of international passengers, the normal rate of airport release and the proportion of base airline were treated as output variables. An empirical analysis with the data of several main American airports in 2018 was solved by DEA-SOLVER Pro 5.0 software. The results show us: (1) the top three airports are LAS (McCarran International Airport), ATL (Hartsfield-Jackson Atlanta International Airport) and MIA (Miami International Airport), (2) the results are consistent with the reality and this proposed method could lay theoretical basis on finding airports which have the potential to become hub ones.

1. Introduction

Hub airport is one of a main characteristic of civil aviation power strategies. Identifying whether an airport can grow to a hub not only assist the civil aviation authority to determine the airport's development direction, but also can make the airport to find its development orientation itself. Therefore, it is of great importance to develop an effective approach to determine the hub growth capability. Quantifying the different growth capability for airports is a complicated problem involving many influence factors. Therefore, more and more focuses are shown in this field.

Carlos Martin and Concepcion Roman presented a game theoretic model to analyze the hub location in the intercontinental aviation markets [1]. Xiong and Yu utilized AHP (Analytic Hierarchy Process) model to study the selection problem of hub airport [2]. Daisuke, Takahiro Majima, etc. used Weber problem to study the location problem of cargo hub airport [3]. However, these approaches have shortcomings, for instance, most previous studies only evaluate the operation efficiency. In those studies about the selection of hub airports, methods are subjective and elements are simplified. In addition, more findings appeared in railway industry. For decades, There have been exited many scholars in China who show great interests in exploring land transportation hub selection using DEA method. Huang and Duan evaluated the efficiency of railway passenger hub [4]. Zheng et al. analyzed the transfer efficiency between high-speed railway hub and urban transit [5]. Guan, Wang and Fang studied the city comprehensive transportation hub [6-7]. Yang had done DEA fuzzy evaluation of the central freight yard selection of the railway hub [8]. There also had many findings on the efficiency of aviation hub. Ma used DEA to evaluate the efficiency of the operation of major hub airports in China [9]. Yang and Wang utilized the combination of cluster analysis and DEA to conduct hub airport evaluation research [10]. The DEA method can't show the difference between the effective DMUs because their results all equal to 1.
Ground hubs differ from air hubs in two ways. (1) There will be more international passengers in an air hub than in ground hubs. (2) Normal release rate is an important characteristic quality of air hubs. So this paper attempts to add the proportion of transit passengers, the proportion of international passengers, the normal rate of airport release, etc. as evaluation indicators, establish a SE-DEA model. Then we rank the efficiency values to draw conclusions.

The following contents are organized as follows. The second chapter is the selection and construction of the model. The third chapter is the establishment of the index system, the selection of data and the calculation using software and analysis. The fourth chapter is the conclusion of this paper.

2. Modeling

2.1 Model selection

The initial DEA model was so-called as the CCR model and it is a comprehensive technical measure with CRS (constant returns to scale). It was further improved into a BCC (R. D. Banker & A. Charnes & W. W. Cooper) model with VRS (variable returns to scale). It decomposes the comprehensive efficiency into pure technical efficiency and scale efficiency. However, these methods above cannot distinguished the difference between those effective DMUs equaling 1, which cannot identify efficiency gap among these effective DMUs. This shortcomings lead to a poor decision-making on airport growth potential in reality. SE-DEA model can overcome the above deficiency in which it can further compare efficiency for all DMUs, including effective ones. SE-DEA is divided into radial SE-DEA and non-radial SE-DEA. Radial SE-DEA still reduces input or expands output at same rate when calculating slacks, which is inconsistent with reality. The non-radial SE-DEA mainly refers to the SBM (slacks-based measure) SE-DEA, and the slack problem is considered as much as possible when calculating the efficiency. Based on the above analysis, this paper adopts the SE-SBM-VRS DEA model with no angle.

2.2 Model construction

The basic idea of traditional DEA is to estimate the effective production frontier based on the observations of the input and output of a set of data. It determines whether each DMU is valid or not for DEA is based on the distance of DMU from the production frontier. It is effective when the efficiency value is equal to 1, and otherwise it is ineffective. The principle of SE-DEA is to delete the effective DMU evaluated from the production potential set (PPS), then measuring the distance from DMU to PPS. The distance is the super-efficiency value.

Supposing there are \( n \) DMUs:

\[
\delta^* = \min \frac{1}{m} \sum_{i=1}^{m} \bar{x}_i \quad \frac{1}{s} \sum_{r=1}^{s} \bar{y}_r
\]

(1)

\[
\bar{x} \geq \sum_{j=1}^{n} \lambda_j x_j
\]

(2)

\[
\bar{y} \leq \sum_{j=1}^{n} \lambda_j y_j
\]

(3)

\[
\sum_{j=1}^{n} \lambda_j = 1
\]

(4)

\[
x \geq x_0
\]

(5)

\[
y \leq y_0
\]

(6)

\[
\lambda \geq 0
\]

(7)

\[
\bar{y} \geq 0
\]

(8)
3. Empirical analysis

3.1 Construction of index system

Proper index system is the key to evaluate the efficiency of DEA model. Integrating geographic location and operational data of United States airports, this paper selects the urban population, urban GDP and the number of navigation points as input variables, with the proportion of transit passengers, the proportion of international passengers, the normal rate of airport release and the share of base airline as output variables. Based on the advantage that DEA does not require the specific production functions, the data can be directly input into the DEA-SOLVER Pro 5.0 software.

Table 1. Variable classification, name, unit and meaning.

| Variable classification | Variable name and unit                     | Variable meaning                                      |
|-------------------------|--------------------------------------------|-------------------------------------------------------|
| Input variables         | Urban GDP (million)                        | Total annual GDP of the city where the airport is located, reflecting the economic situation about the region. |
|                         | The number of navigation points            | Number of airports accessible, reflecting the potential of the airport to open routes. |
|                         | Urban population                           | The number of people in the city where the airport is located. |
| Output variables        | Throughput (person times)                  | Total annual throughput of the airport, reflecting the degrees of approval and the popularity of the airport. |
|                         | The proportion of international passengers | International passengers as a percentage of total passengers, reflecting the internationalization of routes opened from the airport. |
|                         | The proportion of base airline             | Base airlines as a percentage of total seats, reflecting the current that airline base selection about the airport. |
|                         | The proportion of transit passengers       | Transit passengers as a percentage of total passengers, reflecting the status of the airport as a transit port. |
|                         | The normal rate of airport release         | On-time flight as a percentage of all flights, reflecting the operational situation about flights of the airport. |

3.2 Source of data

Considering the timeliness of the data, this paper selects the data of the American airport in 2017. Taking into account the authority and availability of data, the urban population data comes from the United States Census Bureau. The urban GDP data comes from U.S. Bureau of Economic Analysis. The number of navigation points comes from Wikipedia. The data about the proportion of base airline and the normal rate of airport release come from the website of the United States Department of Transportation. The data about the proportion of international passengers and proportion of transit passengers come from OAG (Official Airline Guide). These data are shown in Tab.2 and 3.

Table 2. Original data (Input).

| DMU | Urban GDP (million) | Urban population | The number of navigation points |
|-----|---------------------|------------------|---------------------------------|
| ATL | 334488              | 486290           | 220                             |
| BWI | 460026              | 693972           | 91                              |
| BOS | 379499              | 685094           | 176                             |
| CLT | 146630              | 859035           | 179                             |
| MDW | 583137              | 2716450          | 79                              |
### Table 3. Original data (Output).

| DMU | Throughput (person times) | Proportion of international passengers | Proportion of base airline | Proportion of transit passengers | The normal rate of airport release |
|-----|---------------------------|----------------------------------------|----------------------------|---------------------------------|-----------------------------------|
| ATL | 104258612                 | 0.2090                                 | 0.9145                    | 0.6480                          | 0.8083                           |
| BWI | 26369411                  | 0.0920                                 | 0.9398                    | 0.2404                          | 0.7950                           |
| BOS | 38412419                  | 0.2527                                 | 0.8620                    | 0.0734                          | 0.7740                           |
| CLT | 45909899                  | 0.1526                                 | 0.6605                    | 0.7152                          | 0.8271                           |
| MDW | 22460236                  | 0.0507                                 | 0.9951                    | 0.3153                          | 0.7654                           |
| DEN | 61379396                  | 0.0897                                 | 0.8544                    | 0.3870                          | 0.8136                           |
| DTW | 34701497                  | 0.1793                                 | 0.8027                    | 0.4505                          | 0.8337                           |
| LAS | 48500194                  | 0.1118                                 | 0.7739                    | 0.1038                          | 0.7787                           |

### 3.3 Results and analysis

The efficiency values are shown as follows:

#### Table 4. Efficiency values.

| Rank | DMU   | CCR | SE-SBM-VRS DEA | Comprehensive efficiency | Pure technical efficiency | Scale efficiency |
|------|-------|-----|----------------|-------------------------|--------------------------|-----------------|
| 1    | LAS   | 1   |                | 1.258469964             | 1.403716                 | 0.896528        |
| 2    | ATL   | 1   |                | 1.248135427             | 1.264526                 | 0.987038        |
| 3    | MIA   | 1   |                | 1.233971923             | 1.276802                 | 0.966455        |
| 4    | BWI   | 1   |                | 1.180768403             | 1.245654                 | 0.947910        |
| 5    | CLT   | 1   |                | 1.159508903             | 1.168195                 | 0.992565        |
| 6    | MDW   | 1   |                | 1.115942683             | 1.116062                 | 0.999893        |
| 7    | DTW   | 1   |                | 1.034056703             | 1.045537                 | 0.989020        |
| 8    | DEN   |     | 0.710636782    | 0.710636782             | 1.016158                 | 0.699337        |
| 9    | BOS   | 0.374660353 |                | 0.374660353             | 0.377511                 | 0.992449        |

As shown in table above, the results include CCR and SE-SBM-VRS DEA models. The effective values of CCR model all equal to 1, we can't find the differences between them. However, according to the results of SE-SBM-VRS DEA model, we can sort them easily. For example: ATL is the world's largest passenger interchange and busiest airport. MIA is an important gateway to South America in the United States. We can't find the differences between the results of CCR model.

![Figure 1. Pure technical efficiency.](image1)

![Figure 2. Scale efficiency.](image2)

![Figure 3. Comprehensive efficiency.](image3)

The results of SE-SBM-VRS DEA model can be divided into three types of efficiencies: pure
technical efficiency, scale efficiency and comprehensive efficiency. The relationship between three types of efficiencies can be expressed as:

\[
\text{Comprehensive efficiency} = \text{pure technical efficiency} \times \text{scale efficiency} \quad (9)
\]

The comprehensive efficiency reflects the degree to resources utilized of the airports. The pure technical efficiency reflects the impact on production efficiency for management and technical reasons and the scale efficiency reflects the production efficiency due to scale factors of the airport.

(1) Fig.1 shows that just in terms of pure technical efficiency, the result of the BOS (General Edward Lawrence Logan International Airport) is less than 1, which is a relatively ineffective pure technical efficiency, indicating that this airport is weaker in management and technology than others. The remaining eight airports are pure technical effective and the four most efficient airports are LAS, ATL, MIA and BWI (Baltimore/Washington International Thurgood Marshall Airport), which all have reached more than 1.2. This suggests that these four airports are more advanced and efficient than others in terms of management and technology. (2) Fig.2 shows that in terms of scale efficiency, besides DEN (Denver International Airport), the values of several airports are without significant difference. It reveals that the company's scale economy is weaker than other companies. (3) Fig.3 shows that from the perspective of comprehensive efficiency, DEN and BOS have values which are less than 1, and are relatively ineffective comprehensive efficiency, indicating that the two airports have low degree of comprehensive utilization of resources. The main reason that the comprehensive efficiency of DEN is ineffective is the scale efficiency. The comprehensive efficiency of BOS is ineffective. The reason is the pure technical efficiency. The three more efficient airports are LAS, ATL and MIA, respectively. The efficiency values have reached 1.2 or more. It shows that the resources of these three airports are used in a better way.

According to these data, ATL is the world's largest passenger interchange and busiest airport. MIA is an important gateway to South America in the United States. It served as one of the four major hubs of American Airlines. LAS is used as a key hub by Allegiant Airlines, Southwest Airlines and US Airways. It is also the largest operating base of Allegiant Airlines and Southwest Airlines. This information is consistent with the results of this paper and shows evidence that the proposed model is applicable to select hub airport for an airline.

4. Conclusion
This paper established a SE-SBM-VRS DEA model, calculating the results and reaching conclusions. This paper mainly draw the following conclusions. (1) Comparing with the CCR model, the SE-DEA model can sort each effective result of airports. By comparing and analyzing the results of the two models, the SE-DEA model is more suitable for finding the airport which have the potential and strength to become hub airports. (2) The results of the verification are basically consistent with the reality. This method is feasible and could provide technical support for the airports and government. It is helpful for airports to understand their roles in the hub network and judge their position in the development strategy. By this method, the Civil Aviation Administration of China could determine which airports can grow into hub airports and balance the tendency for future investment.

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