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Performance evaluation of China's air routes based on network data envelopment analysis approach

Yanmin Shao [a, b, *], Changfu Sun [c]

[a] Academy of Mathematics and Systems Science, Chinese Academy of Sciences, China
[b] Center for Forecasting Science, Chinese Academy of Sciences, China
[c] School of Economics and Management, Beijing Jiao Tong University, China

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ABSTRACT

Air routes are among the most important elements of civil aviation transport. Airlines' operations are mainly dependent on the structure and layout of air routes. This paper first divides the production process of air routes into two stages, allocation and transport, based on air route operational characteristics. Then, two network data envelopment analysis (DEA) models are proposed to analyze the efficiency of the system, allocation, passenger transport, and freight transport of 477 air routes. The research result demonstrates that the different constraints on intermediate measure in the network DEA models do affect the air routes' efficiency significantly; Most air routes have high allocation efficiency and passenger transport efficiency, while they have low freight transport efficiency. Furthermore, the efficiencies of 82 airports are also analyzed after aggregating the efficiencies of the air routes.

1. Introduction

With the development of society and economy, civil air transportation has become the most efficient and effective way to transport passengers and cargo. In recent years, China's civil aviation industry has developed rapidly. Its civil aviation transport turnover and passenger volume ranked the second in the world for several years, which follows the United States. In 2013, the total civil aviation passenger and freight volume reached 353.97 million persons and 5.61 million tons, increasing 103 and 63 times, respectively, compared to the data in 1980. In the same year, the domestic passenger turnover and cargo and mail turnover reached 451 billion person-kilometers and 6.11 billion ton-kilometers, increasing 143 and 121 times, respectively, compared to the data in 1980. Table 1 shows some detailed data on China's civil aviation transportation.

Since the beginning of China's economic reform in 1978, China's Civil Aviation Administration (CAAC) has taken several measures to change the way it regulates the civil aviation industry. For example, in 2005, the CAAC permitted private investors to invest in the civil aviation sector, and the number of private airlines has grown rapidly, with new airlines being established for the expanding local markets (Wang et al., 2016). To create a favorable business environment for airline companies, CAAC formulated and promulgated "The Approach on Further Reform of Domestic Air Routes' License for Flight Operation and Management" in 2010, which puts forward that the management of domestic flight routes should follow the principle of decentralization to improve the airline companies' operations. In line with the new approach, the license for operating flight on air routes in Beijing, Shanghai (Hongqiao and Pudong airports), and Guangzhou cities should adopt the approval/registration policy, while the license for operating flight on air routes in other airports should follow the registration management policy.[1] This means that the CAAC is only responsible for the approval of air routes' license for operating flight in the four airports, relaxing the access conditions of domestic air routes to give the airlines more autonomy, which is helpful to create a better competition environment for the operation of air routes. Air route is one of the most important elements of civil aviation transport. The operation of airlines is mainly dependent on the structure and layout of air routes. However, the existing studies mainly treated the airline

* Corresponding author. Institute of Systems Science, Academy of Mathematics and Systems Science, Chinese Academy of Sciences, Beijing, 100190, China.
E-mail address: yanminshao@amss.ac.cn (Y. Shao).

[1] http://www.gov.cn/gzdt/2010-02/04/content_1527959.htm.

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Table 1
China's civil aviation transport data.

Indicators	Unit	1980	1990	2000	2010	2012	2013
Passenger throughput	Million people	3.43	16.6	67.22	267.69	319.36	353.97
Passenger throughput of domestic routes	Million people	2.93	13.46	60.31	248.38	296	327.42
Passenger throughput of international routes	Million people	0.29	1.14	6.9	19.31	23.36	26.55
Passenger turnover	Billion person-kilometers	3.96	23.05	97.05	403.9	502.57	565.68
Passenger turnover of domestic routes	Billion person-kilometers	2.81	15.77	73.77	328.01	403.38	451.1
Passenger turnover of international routes	Billion person-kilometers	1.07	5.17	23.28	75.89	99.2	114.58
Cargo and mail throughput	Million tons	0.09	0.37	1.97	5.63	5.45	5.61
Cargo and mail throughput of domestic routes	Million tons	0.07	0.24	1.47	3.7	3.89	4.07
Cargo and mail throughput of international routes	Million tons	0.01	0.08	0.49	1.93	1.57	1.55
Cargo and mail freight turnover	Billion ton-kilometers	0.14	0.82	5.03	17.89	16.39	17.03
Cargo and mail freight turnover of domestic routes	Billion ton-kilometers	0.07	0.32	2.11	5.36	5.74	6.11
Cargo and mail freight turnover of international routes	Billion ton-kilometers	0.06	0.44	2.92	12.53	10.65	10.92
Total turnover	Billion ton-kilometers	0.43	2.5	12.25	53.84	61.03	67.17
Total turnover of domestic routes	Billion ton-kilometers	0.28	1.45	7.6	34.55	41.58	46.1
Total turnover of international routes	Billion ton-kilometers	0.14	0.83	4.65	19.3	19.45	21.07

companies or airports, rather than air routes, as decision-making units (DMUs). Since customers, competitors, and operating environments differ among air routes, managerial policies and operational analysis are best discussed from a route-based perspective by treating each route as a "strategic business unit" rather than merely employing a whole-company view (Chiou and Chen, 2006), which help gain insight into operational problems that arise along each route.

The objective of this research is to develop a comprehensive methodology to investigate the efficiency of air routes from a managerial perspective. Formulating multi-production processes is appropriate because the air routes use the operating expense and infrastructure to provide passenger transport service and freight shipment. Based on the functional analysis of the air routes, after establishing an index system in line with China's civil air operational status, two network DEA models are proposed to evaluate the performance of a group of air routes in China, where the constraints of the intermediate measure is distinguished, and the system efficiency obtained using the two network DEA models can be decomposed into a weighted average of the sub-functional efficiencies. The remainder of the paper is organized as follows. The second section briefly reviews the related literature. Section 3 proposes two network DEA models to study China's air route efficiency. Section 4 presents the data and results. Section 5 concludes.

2. Literature review

2.1. DEA model

The DEA based on nonparametric techniques (Farrell, 1957) is proposed by Charnes, Cooper, and Rhodes (Charnes et al., 1978). It is an effective methodology to evaluate the relative efficiencies of a set of comparable entities, which is referred to as decision-making units (DMUs). For each DMU, the input-oriented and constant returns to scale (CRS) DEA model can be expressed as follows:

$$\begin{aligned} &\max \frac{u'y_k}{v'x_k}, \\ &s.t. \frac{u'y_j}{v'x_j} \le 1, j = 1, 2, \ldots, n, \\ &u, v \ge 0. \end{aligned} \tag{1}$$

where x_k and y_k represent the input and output vectors of the evaluating k-th DMU; v and u are their weight vectors, respectively. To calculate the efficiency of the k-th DMU, it involves finding values for u and v, which maximize the efficiency of the k-th DMU. Meanwhile, they are subject to the constraint that all efficiency measures must be less than or equal to one. The equation can be transferred into a linear programming problem, and we can get the efficiency score for the k-th DMU under CRS assumption.

The DEA has been widely used in studies on civil air aviation's efficiency analysis. Specifically, some studies have evaluated the efficiency of China's airlines (see Cui and Li, 2015b; Cao et al., 2015) and airport (Fan et al., 2014; Fung et al., 2008; Cui and Li, 2015a).

2.2. Network DEA models in air aviation transport performance evaluation

The DEA method has been widely employed in studies on civil air aviation, and provides meaningful insights. Nowadays, after accounting for the intermediate sub-production process, some literatures have paid attention to the efficiency of the sub-function of the civil air aviation. Yu (2010) first proposed a slacks-based measure network data envelopment analysis (SBM-NDEA) model to evaluate the efficiency of the production process, airside service process, and landside service process of airports in Taiwan in 2006. Wanke (2013) used a two-stage approach to calculate the airport's operation efficiency, which focused on the efficiency of physical infrastructure and flight consolidation. Adler et al. (2013) provided a network DEA model after considering airport's production process from a managerial perspective. Mallikarjun (2015) and Li et al. (2015) proposed a three-stage un-oriented network DEA to measure the airport's efficiency of operation, service, and sales. The efficiencies of airlines were also carried out using network DEA models. Merkert and Hensher (2011) examined the impact of strategic management and fleet panning on technical, allocative, and cost efficiency of the airline. Lu et al. (2012) applied a two-stage DEA model to evaluate the production and marketing efficiencies of airlines. Tavassoli et al. (2014) estimated the technical and service efficiencies of airlines using a SBM-NDEA model in the presence of shared input.The explosive air transportation of China has raised the concern on its air transport efficiency. Zhang et al. (2012) and Chang et al. (2013) applied the DEA framework to the efficiency evaluation of the China's airport. Fan et al. (2014) evaluated the airport's efficiency after considering flight delays using directional distance function. Chi-Lok and Zhang (2009) investigated the influence of competition and aviation policy reform on the efficiency of Chinese airports. Some studies also focused on the efficiency and the determinants of Chinese airlines (Cao et al., 2015; Chow, 2010;