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Research On The Operational Efficiency And Development Mode Of Airport Clusters

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Abstract
Airports are an important support for building a strong civil aviation country, and the development of airport clusters is of paramount importance in accelerating the development of civil aviation. The paper selects the Yangtze River Delta Airport Clusters, Beijing Tianjin Hebei Airport Clusters, Pearl River Delta Airport Clusters, Chengdu Chongqing Airport Clusters, Paris Airport Clusters, Berlin Airport Clusters, Frankfurt Airport Clusters, New York Airport Clusters, Washington Airport Clusters, Chicago Airport Clusters, and Los Angeles Airport Clusters as research objects. The operational data and input-output data of the sample airport Clusterss are collected, and the DEA model is used to evaluate the operational efficiency of the sample airport clusterss. The differences in operational efficiency of airport clusterss under different development models are compared, and the conclusion is that the operational efficiency of multi center airport clusterss is generally better than that of single center airport clusters.

Keywords – *airport cluster, operational efficiency, development model*

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I. Introduction

In recent years, with the rapid development of global air transportation, competition between airports has become increasingly fierce, and this competition is also reflected in the competition between airport clusters. Therefore, in order to improve the operational efficiency and competitiveness of airports, it is necessary to conduct in-depth analysis of the efficiency differences, operational status, and various potential influencing factors of major airport clusters. Analyzing the operational efficiency and development model of airport clusters has important practical significance for promoting the high-quality development of national airport clusters. Firstly, it can identify the shortcomings of each airport in ground services, hardware configuration, security checks, and other aspects, thereby improving and enhancing the service quality of airports. Secondly, it is possible to plan the air transportation network reasonably, optimize the route layout, and improve the efficiency and economy of air transportation. Thirdly, it can better leverage the role of airports in promoting regional economy. Fourthly, in the context of increasingly fierce competition in the global air transport market, improving the operational efficiency and competitiveness of airport clusters is of great significance for enhancing a country's international status and influence. Fifth, it can promote the research and application of new technologies and methods, and drive technological progress in the aviation transportation industry.

II. Terminology Related To Airport Clusters

The concept of airport clusters

Airport cluster refers to a civilian multi airport system consisting of two or more airports, all located near urban clusters and relying on comprehensive transportation systems to provide services for urban clusters. In addition, airport clusters can also refer to a multi airport system formed with regional hub airports as the core and trunk and branch airports as auxiliary.

Operational efficiency of airport clusters

The operational efficiency of an airport cluster refers to the ratio of operational resources invested to operational output. Specifically, it is a comprehensive system of airport resources, route resources, airspace resources, ground transportation resources, and external development environment resources operating efficiency of the airport cluster. The operational efficiency of airport clusters is also a comprehensive indicator for measuring their competitiveness, resource allocation capabilities, and sustainable development capabilities. The maximization of airport cluster operational efficiency represents the need to use multiple means to promote the coordinated development of subsystems such as airlines, airports, air traffic control, and ground transportation within the airport cluster, in order to achieve Pareto optimality in airline operational efficiency, airport operational efficiency, aviation network operational efficiency, and ground transportation operational efficiency, thereby enhancing the comprehensive competitiveness of the airport cluster and driving the flow of social resources while maximizing its own development. The efficiency of airport clusters is a comprehensive indicator that not only reflects the ability of airport clusters to allocate various resources within the cluster, but also reflects the operational capability of airport clusters.

Development model of airport cluster

There are two development models for airport clusters. The first type is called a single center airport cluster. In this mode, the airport cluster is centered around an airport in a core city, formed based on a developed road transportation network or hub airport route network. Core airports have outstanding location advantages, developed social and economic conditions, and huge and diverse market demand. The second mode is called a multi center airport cluster. Unlike the single center airport cluster model, a multi center airport cluster consists of multiple hub airports and multiple non hub airports that jointly serve an economic region. Airports are interconnected through ground transportation systems to form a unified airport cluster system. In this article, in order to visually illustrate the different development models of airport clusters, the following definition is made: within an airport cluster, airports are ranked according to the number of aircraft takeoffs and landings. When the number of aircraft takeoffs and landings at the second airport accounts for more than 55% of the number of aircraft takeoffs and landings at the first airport, it is considered a multi center airport group. Conversely, it can be considered a single center airport group.

III. Sample Selection Of Domestic And International Airport Clusters

Introduction to sample airport clusters

This article selected 12 airport clusters from China, Europe, and the United States for comparative research. In each airport group, the airport with the highest ranking of aircraft takeoffs and landings was selected. The total number of aircraft takeoffs and landings at these airports accounts for 80% or more of the total number of takeoffs and landings in the entire airport cluster, which is typical and can be used as further analysis objects. The specific sample airport clusters and sub airports are shown in Table 1.

Table 1 Airport clusters and sub airports

Area	Airport clusters	Main sub airports	Number of aircraft takeoffs and landings	The proportion of aircraft takeoffs and landings at the second ranked airport to the number of aircraft takeoffs and landings at the first ranked airport
China	Yangtze River Delta	Shanghai Pudong	430000	69.20%
		Shanghai Hongqiao	270000	
		Hangzhou Xiaoshan	297600	
		Nanjing Lukou	223027	
		Ningbo Lishe	56148	
		Hefei Xinqiao	56893	
	Beijing-Tianjin-Hebei	Beijing Capital	379400	76.98%
		Beijing Daxing	292100	
		Tianjin Binhai	136000	
		Shijiazhuang Zhengding	72000	
	Pearl River Delta	Guangzhou Baiyun	456052	86.25%
		Shenzhen Bao'an	393380	
		Zhuhai Jinwan	59230	
	Chengdu Chongqing	Chengdu Tianfu	331024	92.13%
		Chengdu Shuangliu	209177	
		Chongqing Jiangbei	305000	
		Southern suburbs of Mianyang	188712	
		Guangyuan Panlong	121508	
		Bazhong Enyang	59805	
Europe	Paris	Charles de Gaulle	183844	32.79%
		Ollie	60300	
		Burch é	30182	
	Berlin	Sch ö nefeld	42652	57.29%
		Brandenburg	102639	
	Frankfurt	Frankfurt	181156	63.55%
		Munich	285028	
		Dusseldorf	53280	
America	New York	Kennedy	218036	91.06%
		Newark	198560	
		LaGuardia	180056	
		New Haven	93095	
	Washington	Reagan	147332	42.79%
		Baltimore	63042	
		Dulles	61010	
	Chicago	O'Hare	328654	26.48%
		Midville	87054	

		Clarence	31292	
	Los Angeles	Los Angeles	243274	58.61%
		Ontario	142600	
		Brentwood	62766	

(1) The Yangtze River Delta Airport Cluster: The Yangtze River Delta City Cluster is the most important urban cluster in China, and therefore plays a key role in the development of China's aviation industry. It is mainly composed of five major sub airports: Shanghai Pudong, Shanghai Hongqiao, Hangzhou Xiaoshan, Nanjing Lukou, Ningbo Lishe, and Hefei Xinqiao. This not only provides convenient domestic and international aviation services for the region, but also promotes economic development and international exchanges in the Yangtze River Delta region.

(2) Beijing Tianjin Hebei Airport Cluster: The Beijing Tianjin Hebei region is one of China's political and economic centers, and the construction and development of airport clusters help promote the integrated development and coordinated development of urban clusters in this area. The four major airports of Beijing Capital, Beijing Daxing, Tianjin Binhai, and Shijiazhuang Zhengding have strengthened the connections between Beijing, Tianjin, Hebei Province, and the whole country and the world.

(3) Pearl River Delta Airport Group: The Pearl River Delta is one of the most developed economic regions in southern China. The Pearl River Delta Airport Group not only serves Guangdong Province, Hong Kong and Macao, but also connects the mainland of China and the rest of the world, providing important support for the international development of the the Pearl River Delta.

(4) Chengdu Chongqing Airport Cluster: As an important aviation hub cluster in southwestern China, it mainly includes airports with numerous aircraft takeoffs and landings, such as Chengdu Tianfu, Chengdu Shuangliu, Chongqing Jiangbei, Mianyang Nanjiao, Guangyuan Panlong, and Bazhong Enyang. The development of the Chengdu Chongqing Airport Cluster helps promote economic growth and opening up to the outside world in cities such as Chengdu and Chongqing, and strengthens the connections between the Southwest region and other regions at home and abroad.

(5) Paris Airport Cluster: As one of the important aviation hubs in Europe, the Paris Airport Cluster provides convenience for international exchanges and economic development in France and other European countries. Among them, Charles de Gaulle International Airport is one of the most important aviation transit hubs in the world.

(6) Berlin Airport Cluster: As the capital and important cultural center of Germany, Berlin's airport cluster provides convenient transportation support for the economic development and international exchanges of the northeastern region of Germany. Brandenburg Airport and the newly completed Sch ö nefeld Airport will gradually shoulder the responsibility of serving as aviation hubs for Germany and Europe in the future.

(7) Frankfurt Airport Cluster: Frankfurt Airport is not only the largest airport in Germany, but also the most important and busy aviation hub in Europe. The development of the three main sub airports of Frankfurt Airport Cluster: Frankfurt, Munich, and Dusseldorf Airport, is crucial for the economic growth and international tourism development of Germany and Europe.

(8) New York Airport Cluster: The New York Airport Cluster is one of the busiest aviation hubs in the eastern United States, providing important support for economic activities and international exchanges in New York City and surrounding areas, and is also one of the global commercial and cultural centers.

(9) Washington Airport Cluster: The Washington Airport Cluster serves the political center of the United States, Washington D.C., and its surrounding areas, providing important transportation convenience for government and commercial activities, as well as an important gateway for international tourists to visit the capital of the United States.

(10) Chicago Airport Cluster: The Chicago Airport Cluster is one of the most important aviation hubs in the Midwest of the United States, providing critical transportation infrastructure for the region's economic development and international trade.
(11) Los Angeles Airport Cluster: The Los Angeles Airport Cluster is one of the most important aviation hubs on the West Coast of the United States, connecting the aviation network between the United States and the Asia Pacific region, providing important support for economic activities and international exchanges in California and the West Coast region.

Analysis of the development model of airport cluster

By analyzing the operational status data of domestic and foreign airport clusters and comparing them, it can be seen that the Berlin and Frankfurt airport clusters in Europe, the New York and Los Angeles airport clusters in the United States, as well as the Yangtze River Delta, Beijing Tianjin Hebei, Pearl River Delta, and Chengdu Chongqing airport clusters in China, all have a second ranked airport with over 55% of the first ranked airport's aircraft takeoff and landing ratio. Therefore, they can be seen as a development model of multi center airport clusters. In the Paris airport cluster, Washington airport cluster, and Chicago airport cluster, the second ranked airport accounts for less than 55% of the first ranked airport's total number of aircraft takeoffs and landings. Therefore, it can be seen as a development model of a single center airport cluster.

IV. Evaluation Of Operational Efficiency And Development Mode Of Airport Clusters

Research method

This article applies DEA model to study the operational efficiency of airport clusters.

The DEA (Data Envelopment Analysis) model is a non parametric linear programming method used to evaluate the relative efficiency of various decision units, such as airports, hospitals, and enterprises. The DEA model was originally proposed by Farrell (1957) and Charnes, Cooper, and Rhodes (1978), and can be used to evaluate the efficiency of various decision units. It evaluates the performance of units by comparing their inputs and outputs. The goal of DEA is to determine the maximum output that a unit of input can produce under given input conditions, or the minimum input required for a unit of output at a given output level. In this process, DEA allows multiple input and output indicators to be considered simultaneously, and evaluates the efficiency of the decision-making unit by constructing a data envelope, that is, whether the performance of the decision-making unit is within this data envelope. If a decision unit is located outside the data envelope, it is considered to be less efficient compared to other decision units. DEA has a wide range of applications in evaluating the efficiency of decision units and comparing performance between different decision units.

In the DEA model, each decision unit is treated as a production unit with multiple inputs and outputs, and its efficiency can be measured through linear programming problems. The DEA model has many variations, but no matter how it changes, its most basic model framework is only two: one is the CCR model, which is mainly used to measure comprehensive technical efficiency. Another type is the BCC model, which is more flexible compared to the CCR model. It can not only measure comprehensive technical efficiency, but also be used to measure pure technical efficiency.

Determination of input-output indicators

Overall, there are roughly two forms of investment for an airport: tangible asset investment and intangible asset investment. Among them, tangible asset investment is divided into fixed asset investment and variable asset investment. Fixed assets mainly include airport hardware facilities such as terminals, runways, taxiways, security equipment, boarding equipment, special vehicles, etc. Variable assets mainly include airport business expenses and investments in human resources. Intangible assets mainly include the routes developed by the airport, the reputation and evaluation of the airport, etc.

This article considers the availability of data and the authenticity and validity of data sources. The selected airport cluster input indicators are terminal area, runway length, and runway quantity, while the selected output indicators are passenger throughput, cargo throughput, and aircraft takeoff and landing.

Efficiency analysis of airport cluster operations

The paper calculates the average input-output indicators of each sample airport cluster using the BCC model. The BCC model studies the input-output efficiency when the return to scale is variable. The BCC model divides the comprehensive efficiency into technical efficiency and scale efficiency. The model parameters are described as follows: Firstly, the technical efficiency value reflects the efficiency brought about by technological factors. A value equal to 1 indicates that the element is being used reasonably, while a value less than 1 indicates that the technical efficiency of the element can continue to improve.

Secondly, the scale efficiency value reflects the efficiency brought by scale. If the value is equal to 1, it indicates that the scale return remains unchanged, and the goal has reached its optimal state. A value less than 1 indicates an increasing return to scale. At this point, if the target scale is too small, it can be expanded to increase efficiency. A value greater than 1 indicates a decreasing return to scale. In this case, if the target scale is too large, it can be reduced to increase efficiency.

Thirdly, the comprehensive efficiency reflects the efficiency of the decision-making unit elements, which is equal to the technical efficiency multiplied by the scale efficiency.

Fourthly, the slack variable S- represents "how much input is reduced to achieve the target efficiency", while the slack variable S+ represents "how much output is increased to achieve the target efficiency".

Fifth, by combining the comprehensive efficiency indicators, S- and S+, a total of three indicators, the effectiveness of DEA can be determined. If the overall efficiency is 1 and both S- and S+ are 0, then DEA is strongly effective. If the overall efficiency is 1 but S- or S+ is greater than 0, then DEA is weakly effective. If the overall efficiency is less than 1, it is considered “non DEA effective”.

The analysis and calculation results of the operational efficiency of the airport cluster are shown in table 2 and table 3.

Table 2 Analysis of operational efficiency of various airport clusters in 2021

airport clusters	technical efficiency	Scale efficiency	Comprehensive efficiency	slack variable S-	slack variable S+	effectiveness
Yangtze River Delta	1.000	1.000	1.000	0.000	0.000	DEA strongly effective
Beijing-Tianjin-Hebei	0.785	0.985	0.774	1.676	42.468	non DEA effective
Pearl River Delta	1.000	1.000	1.000	0.000	0.000	DEA strongly effective
Chengdu Chongqing	1.000	1.000	1.000	0.000	0.000	DEA strongly effective
Paris	0.840	0.944	0.793	62.056	673.272	non DEA effective
Berlin	0.957	0.754	0.721	3.370	27.617	non DEA effective

Frankfurt	1.000	1.000	1.000	0.000	0.000	DEA strongly effective
New York	1.000	1.000	1.000	0.000	0.000	DEA strongly effective
Washington	1.000	0.596	0.596	0.000	8.439	non DEA effective
Chicago	1.000	0.858	0.858	4.001	1.150	non DEA effective
Los Angeles	1.000	1.000	1.000	0.000	0.000	DEA strongly effective

Table 3 Analysis of operational efficiency of various airport clusters in 2022

airport clusters	technical efficiency	Scale efficiency	Comprehensive efficiency	slack variable S-	slack variable S+	effectiveness
Yangtze River Delta	1.000	1.000	1.000	0.000	0.000	DEA strongly effective
Beijing-Tianjin-Hebei	0.681	0.597	0.407	3.405	0.000	non DEA effective
Pearl River Delta	1.000	1.000	1.000	0.000	0.000	DEA strongly effective
Chengdu Chongqing	1.000	1.000	1.000	0.000	0.000	DEA strongly effective
Paris	0.934	0.920	0.859	74.254	424.645	non DEA effective
Berlin	1.000	0.804	0.804	1.391	16.649	non DEA effective
Frankfurt	1.000	1.000	1.000	0.000	0.000	DEA strongly effective
New York	1.000	1.000	1.000	0.000	0.000	DEA strongly effective
Washington	1.000	0.739	0.616	0.000	9.128	non DEA effective
Chicago	1.000	0.934	0.934	6.908	2.522	non DEA effective
Los Angeles	1.000	1.000	1.000	0.000	0.000	DEA strongly effective

Based on the data in Tables 2 and 3, this article draws the following conclusions:
(1) The comprehensive efficiency values of the Yangtze River Delta Airport Group, Pearl River Delta Airport Group, Chengdu Chongqing Airport Group, Frankfurt Airport Group, New York Airport Group, and Los Angeles Airport Group are all equal to 1, which means DEA is effective. If the comprehensive efficiency values of the Beijing Tianjin Hebei Airport Group, Paris Airport Group, Berlin Airport Group, Washington Airport Group, and Chicago Airport Group are less than 1, it means that DEA is invalid.
(2) In 2021, the technical efficiency of the Beijing Tianjin Hebei Airport Group, Berlin Airport Group, and Paris Airport Group was less than 1. However, by 2022, except for the Beijing Tianjin Hebei Airport Group and Paris Airport Group, the technical efficiency of the other nine airport groups will be equal to 1. This means that the technical efficiency of the Berlin Airport Group has improved and is reasonable, while there is still room for improvement in the technical efficiency of the Beijing Tianjin Hebei Airport Group and Paris Airport Group.
(3) A scale efficiency value of 1 indicates that the scale benefits of the airport cluster remain unchanged at this

time. The Yangtze River Delta airport cluster, Pearl River Delta airport cluster, Chengdu Chongqing airport cluster, Frankfurt airport cluster, New York airport cluster, and Los Angeles airport cluster all have unchanged economies of scale, and at this point, these airport clusters have reached their optimal size. The scale efficiency values of the Beijing Tianjin Hebei Airport Group, Paris Airport Group, Berlin Airport Group, Washington Airport Group, and Chicago Airport Group within 2 years are all less than 1, indicating an increasing return to scale. This means that the scale of these airport groups is too small and can be increased by expanding their scale to increase efficiency.

Evaluation of Airport Cluster Development Model

Table 4 and table 5 comprehensively compare the operational efficiency of these airport clusters in 2021 and 2022. It can be seen from this that the average technical efficiency of multi center airport clusters is lower than that of single center airport clusters, while the average scale efficiency of single center airport clusters is higher than that of multi center airport clusters. Finally, based on their average comprehensive efficiency, the operational efficiency of multi center airport clusters is generally better than that of single center airport clusters.

Table 4 Comparison of operational efficiency and development models among airport clusters in 2021

airport clusters	development model	Average technical efficiency	average scale efficiency	average comprehensive efficiency
Yangtze River Delta, Beijing-Tianjin-Hebei, Pearl River Delta, Chengdu Chongqing, Los Angeles, Berlin, Frankfurt, New York	multi-center	0.947	0.967	0.937
Washington, Chicago, Paris	single-center	0.967	0.799	0.749

Table 5 Comparison of operational efficiency and development models among airport clusters in 2022

airport clusters	development model	Average technical efficiency	average scale efficiency	average comprehensive efficiency
Yangtze River Delta, Beijing-Tianjin-Hebei, Pearl River Delta, Chengdu Chongqing, Los Angeles, Berlin, Frankfurt, New York	multi-center	0.960	0.925	0.901
Washington, Chicago, Paris	single-center	0.978	0.844	0.803

V. Conclusion

The importance of the development of airport clusters to the country is self-evident. As an important hub for air transportation, airport clusters not only undertake the task of connecting passenger and freight transportation between various cities in China, but also play a crucial role in external communication. Therefore, researching and optimizing the operational efficiency and development mode of airport clusters is of great significance for promoting the high-quality development of civil aviation. This not only concerns the improvement of air transportation service level, but also the healthy development of the aviation industry and the prosperity of regional economy.

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