Research Article

Evaluation of Airport Environmental Carrying Capacity: A Case Study in Guangzhou Baiyun International Airport, China

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In order to clarify the comprehensive operational capabilities of the airport and better plan the sustainable development mode of the airport, this paper studies the evaluation method of airport environmental carrying capacity. First, this paper proposes the concept of airport environmental carrying capacity by taking into account the complex characteristics of airports affected by multiple factors and then selects 16 representative evaluation indicators to construct an indicator system based on the Driving Force-Pressure-State-Response (DPSR) framework. Finally, the accelerated genetic algorithm-projection pursuit model is established to model a comprehensive evaluation index, which is used to calculate the airport environmental carrying capacity (AECC). The results of the case study show that the AECC of Guangzhou Baiyun International Airport (CAN) decreased year by year from 2008 to 2017, which is in line with the coordinated development level of CAN. By analysing the changing mechanism of AECC and indicators, we get 6 key influencing indicators that led to the continuous decline of AECC and put forward some political suggestions to improve the AECC.

1. Introduction

Air transportation has been developed unprecedentedly in China, and the resulting resource consumption and environmental pollution issues have become prominent. The increasing air traffic flow has brought about a series of problems, such as the lack of airspace resources, the heavier controllers' workload, and environmental pollution. These problems have restricted the further development of the air transportation. The airport is an important hub for air transportation; the continuous growth of airport traffic volume has led to frequent occurrences of airspace congestion, inefficient operations, and the deterioration of local air quality. The root cause of these issues is that the demand does not match the carrying capacity; such a development model will hinder the airport sustainability and the regional economy. Therefore, the correct evaluation of the airport environmental carrying capacity (AECC) is the basis for airport stakeholders to plan the scale and mode of airport sustainable development.

About two decades ago, the concept of environmental carrying capacity (ECC) is proposed to study the impact of

human activities on the environment, plan the development scale of human activities, and promote the coordinated development of social economy and ecological environment [1]. The increasing awareness of environmental protection has made many scholars pay more attention to the research of environmental carrying capacity. With the integration of sustainability, ECC has derived different concepts in different research fields, including atmospheric ECC [2], water ECC [3], tourism ECC [4], and traffic ECC [5], and the studies of their evaluation method have also been carried out.

Nowadays, more attention of traffic environmental carrying capacity (TECC) had been paid to the land transportation. As an important component of the transportation, air transportation has fewer research achievements related to its ECC [6, 7]. As a key node of air traffic network, the development of the airport is connected with air traffic flow. The demand of air traffic increases with the economic growth and the scale of airport needs to be expanded; however, it will cause the shortage of natural resource, ecology environmental pollution, and other issues which have aroused widespread attention from

scholars. The mismatch between airport development and airport environmental carrying capacity (AECC) has become a bottleneck in the development of future airports [8]. Therefore, the planning of the airport development should fully consider the relationship between AECC and the peripheral economy when rebuilding and expanding airports and planning land use [9]. But there are few related researches on AECC; in order to better plan the sustainable development mode of the airport, it is necessary to further study AECC.

At present, some researchers have studied the evaluation method of the airport operating limit based on the airspace resources, environmental pollution, and human factors. In terms of airspace resources, some studies evaluate the airport operating capacity considering the terminal airline structure [10] and delay [11]. In terms of human factors, some studies evaluate the airspace sector capacity considering the controller's workload [12, 13]. In terms of pollution, some studies calculate the maximum allowable air traffic volume considering polluted gas and noise emissions [14]. These researches are related to AECC, but mainly focus on the maximum air traffic volume of airport under different single constraints from the perspective of airport operations, rather than comprehensively considering the carrying level of the airport air traffic system from the perspective of sustainable development.

In addition, in order to meet the needs of air traffic services, the scale of airport development is also closely related to the regional economic level and social support [15, 16]. The scale of airport development and air transportation hub in economic developed area is usually larger than that in other areas, which can provide more motivation and demand and promote the continuous expansion of airport development scale. Therefore, the evaluation of the AECC should be conducted in a comprehensive way of multivariate influencing factors.

This paper will comprehensively study the evaluation method of AECC by considering the interdependent of economy, society, environment, operation, and development of airport to ensure the requirements of sustainability. In this paper, we construct the evaluation framework for AECC: comprehensively consider sustainable development factors to select evaluation indicators, establish an indicator system based on the Driving Force-Pressure-State-Response (DPSR) model, utilize the projection pursuit model to evaluate AECC, and use the coupling coordination degree (CCD) model for comparative analysis.

The contributions of this paper can be summarized as follows: First, we proposed a concept of AECC based on the content of environmental carrying capacity and sustainable development. Second, we selected 16 evaluation indicators from economic, social, environmental, and operational aspects by analysing the content of AECC and constructed an indicator system based on the DPSR model. Third, we built an evaluation framework and formed a systematic evaluation method by using the DPSR model, CCD model, projection pursuit model and accelerated genetic algorithm to evaluate AECC, and verified by a case study. Finally, we made some political suggestions to improve the AECC.

2. Concept and Evaluation Framework

2.1. Environmental Carrying Capacity (ECC). The concept of environmental carrying capacity can be traced back to Malthus' theory of resource finiteness [17]. It usually refers to "the threshold of human activities that the environment of a certain area can withstand in a certain period, a certain state or condition." The focus is limited to the environment's tolerance for biological populations. With the outbreak of the global resource and environmental crisis and the proposal of sustainable development theory, the focus of ECC research has gradually shifted to the relative tolerance of human activities under the constraints of resources and environment. Many international organizations have successively put forward the concept of ECC in the aspects of ecology, water and marine resources, and scholars have also carried out the evaluation study of ECC [18–20]. In China, more and more scholars pay attention to the extension of environmental carrying capacity in different fields and have achieved some results. For example, many studies in China have found the ecological carrying capacity in various aspects [21–23]; however, there is limited literature that focuses on the evaluation of airport environmental carrying capacity.

The transportation field, which was born to meet the needs of expanding the scope of human activities, has gradually been restricted by resources and the environment with the further development of economy and society, so ECC has also been extended to the transportation field. Scholars have proposed a series of concepts to indicate the TECC in different scenarios, such as urban traffic carrying capacity [24], traffic resource environmental carrying capacity [25], traffic environmental carrying capacity [26], urban traffic noise environmental carrying capacity [27], road network carrying capacity [28], and comprehensive traffic carrying capacity [29]. These concepts mostly take resources and environment as constraints and rely on the theory of sustainable development to study the carrying capacity of the transportation system.

2.2. Airport Environmental Carrying Capacity (AECC). The development of the airport will also be affected by various factors such as economy, society, and environment. Population growth and social progress have promoted the development of airports, but also brought about a lot of resource consumption: the continuous increase in aircraft movements occupies more airspace resources [30], the air traffic services provided for aircraft consumes a lot of human resources [31], and the reconstruction and expansion of the airport takes up more and more land resources [32]. At the same time, aircraft, ground support equipment and surface vehicles, as the main pollution sources, will emit pollutant gas, leading to the gradual deterioration of the airport and its surrounding environment; furthermore, resource consumption and environmental pollution will hinder the sustainable development of human society, thus restricting the development of the airport. Therefore, an airport is a complex system that integrates economic, social,

environmental, and other factors, and its carrying capacity is inevitably affected by multifactors. For achieving sustainability, the carrying capacity assessment is an important yardstick to gauge the level and state of sustainable development [33].

As an important part of the air transportation system, the airport provides activity venue for aircraft by airlines and surface taxiway and provides air traffic services. The aircraft flies along the preplanned route (Figure 1(b)) in the airport, which is similar to the motion mode of vehicles in urban traffic, and the air route network of airport also has a similar structural feature to the urban transportation network, as shown in Figure 1. The influencing factors of urban development are natural, social, economic, and human activities [34], and airport development will also be affected by these factors. Therefore, the airport air traffic with aircraft as the main body can be compared to a small urban traffic network. The concept of airport environmental carrying capacity can refer to the definition of urban traffic carrying capacity.

Considering the interaction between airport development and economy, society, and environment, and combining the operational characteristics of aircraft approach, taxiing, take-off, and climb, the airport environmental carrying capacity (AECC) can be defined as based on the concept of urban traffic carrying capacity [35]. The concept of AECC is as follows: "The carrying level of the airport air traffic system under a certain operational condition, and the airport air traffic system does not develop in a vicious direction, the operational environment of airport air traffic system can meet sustainable development." AECC reflects the connotation of sustainable development such as society, economy, and environment and provides a theoretical basis for the construction of evaluation framework.

2.3. Evaluation Framework. The evaluation methods of ECC mainly include indicator system method [36, 37], system model method [38], and supply-demand comparison method [39]. This paper selects the indicator system method to evaluate the airport environmental carrying capacity. In order to better reflect sustainable development of airport and the comprehensive carrying level of each dimensions of AECC and dig out the internal changes characteristics of the evaluation object, the Pressure-State-Response (PSR) framework model is chosen to construct the indicator system. PSR framework model is good at analysing the interaction between airport operation activities and influencing factors of different dimensions to promote the sustainable development of airport, and the driving force factor can be added to describe the impact of economic development and population on the airport development.

The socioeconomic growth of city or region where the airport is located is the main driving force (D) for the establishment and development of airport. The increase in throughput brought about by airport development has put pressure (P) on airport operations. The emissions and delay reflect the state (S) of airport daily operations. Some improvement measures are adopted as response (R) to improve

the operational ability of airport. The DPSR model completely describes the lift cycle of the airport operation process. Therefore, this paper selects the Driving Force-Pressure-State-Response (DPSR) model to construct the indicator system of AECC. In order to quantitatively evaluate and analyse the AECC, the method models the comprehensive index with the projection pursuit model and accelerated genetic algorithm to calculate AECC and uses the coupling coordination degree (CCD) to verify and explain AECC from the perspective of airport development coordination. The next step is to analyse the key influencing factors with the historical and hypothetical data to mining the change mechanism of AECC and then use it as a basis to propose the political suggestions to promote the AECC. The process of the evaluation framework is shown in Figure 2.

3. Materials and Methods

3.1. Study Area. Guangzhou Baiyun International Airport (CAN; CAN is the airport code of Guangzhou Baiyun International Airport) is one of three major aviation hubs in China. Its route network covers five continents in the world. It has opened air traffic with more than 220 destinations at home and abroad. CAN has developed rapidly in recent years, and air traffic flow has increased significantly. Some problems have already been exposed in economic, social, and environmental aspects. Accurately assessing the AECC of Guangzhou Baiyun International Airport can enable the stakeholders to better understand the state of the airport's operations. And the stakeholders can purposefully coordinate the relationship between the airport's economic development and the ecological environment, thereby promoting the sustainable development of CAN.

3.2. Data Collection. The original data is available from the Statistical Yearbook of Guangzhou, Airport Annual Report of CAN [40], Civil Aviation Industry Development Statistical Bulletin, and National Civil Aviation Flight Operation Efficiency Report from 2008 to 2017 [41]. In addition, the pollutant emission indicators are calculated using the formula in AEDT. The Aviation Environmental Design Tool (AEDT) is a modelling system to estimate fuel consumption, air pollutant emissions, and air quality and noise impacts. It is currently the Federal Aviation Administration (FAA) officially approved assessment tool for aviation emissions and gas diffusion [42]. The noise calculation method refers to ICAO Annex 16 [43].

3.3. Indicator System Based on DPSR Model. The DPSR model is based on the PSR framework and adds driving factors. Economic development and population growth have led to changes in the natural resources and environment of the airport and its surroundings. The population density (y_1) and per capita GDP (y_2) are more important features of socioeconomic development [36]. Therefore, the driving force subsystem (D) selects these two parameters as indicators to reflect the driving force of airport development.
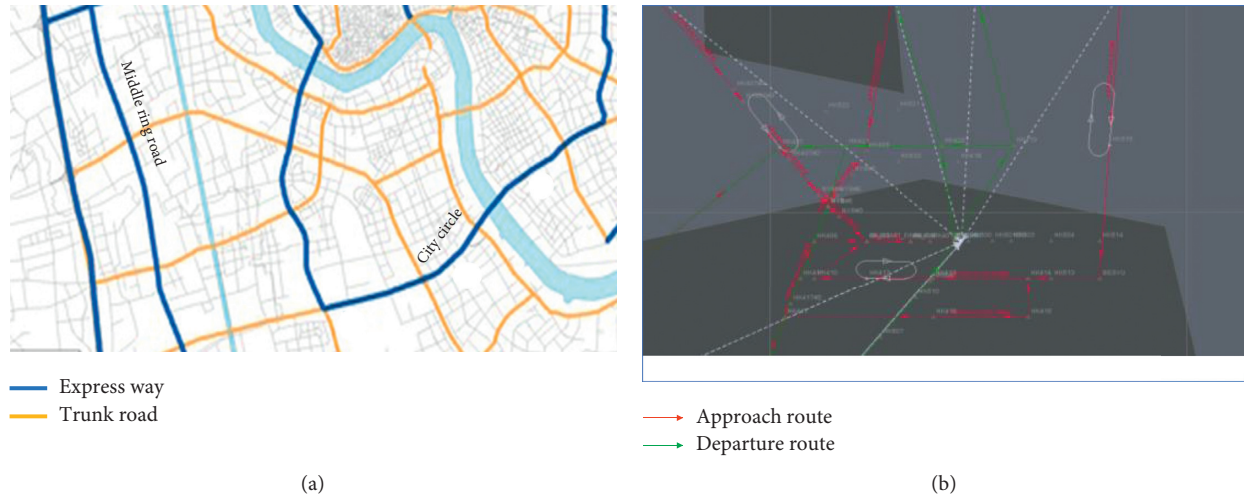
(a)

(b)

FIGURE 1: Comparison of urban transportation network and air route network. (a) The urban transportation network. (b) The airport air route network.
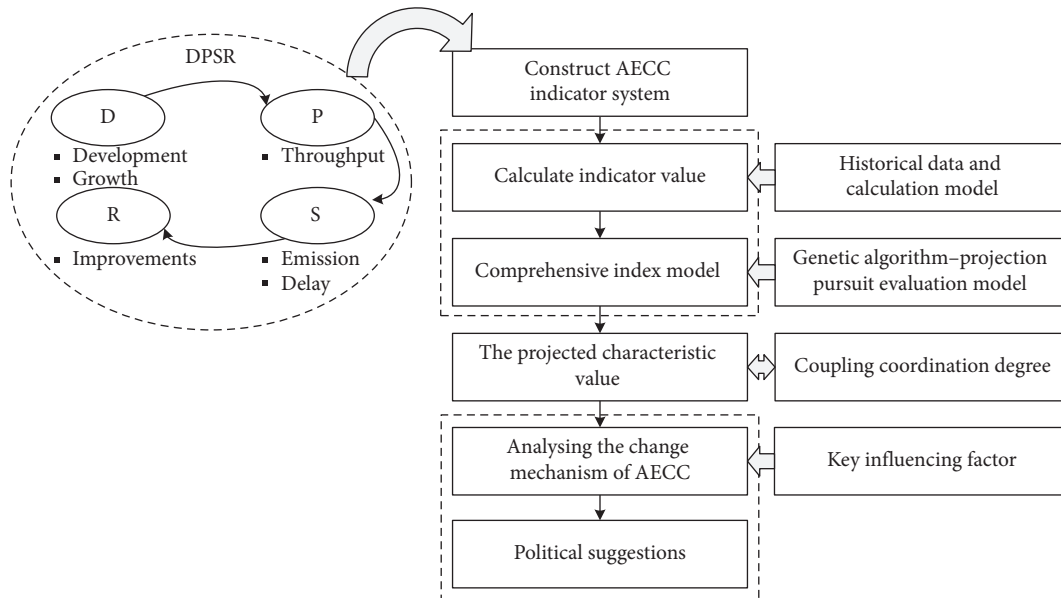

FIGURE 2: Evaluation framework of AECC.

The development of the aviation economy has brought internal and external pressures to airport operations, and the most obvious of which is the increment of air traffic demand. The annual cargo and mail throughput, annual passenger throughput, and annual aircraft movements [44] are usually chosen to characterize the air traffic volume caused by demand of airport development. Increase or decrease in air traffic volume will change the pressure of airport operation, so the pressure subsystem (P) uses these parameters to embody the pressure on transportation demand brought by driving forces.

The continuous growth of air traffic volume has resulted in various environmental pollutions and reduced operating efficiency. These effects will lead to changes in the operational status of the airport. The state subsystem (S) selects sewage discharge, annual emissions of CO,

NO_x, HC, and PM, on-time flight clearance rate, and noise pollution area above 57 dB as indicators to reflect the current situation of the airport environment and operation [45].

In order to protect the airport environment and improve the operating conditions of the airport, some relevant departments have taken some effective measures to cope with a series of phenomena brought about by the increase in air transportation. The response subsystem (R) uses indicators such as green coverage rate, passenger satisfaction, growth rate of on-time flight clearance rate, and reduction rate of energy consumption per passenger as the response layer indicator.

Therefore, this paper considers the characteristics of airport operation and the influence of economy, society, and environment, follows the basic principles of indicator

selection, and constructs the indicator system of AECC based on the DPSR model, as shown in Table 1.

3.4. Projection Pursuit Model.

It is necessary to use a comprehensive evaluation method or model to evaluate the carrying capacity. This paper uses the projection pursuit model [46], which is widely used and handled the characteristic of high-dimensional data well without calculating indicator weights separately. In the process of dimensionality reduction, this model combines accelerated genetic algorithm to optimize the results.

The process of evaluating AECC using the projection pursuit model is as follows: Firstly, construct the projection eigenvalue function. Secondly, normalize the evaluation indicator. Thirdly, construct the projection objective function and combine with the accelerated genetic algorithm to solve the optimal projection vector. Finally, the projected characteristic value is obtained by calculating the normalized value and the best projection vector.

3.4.1. Projected Characteristic Value.

The projected characteristic value of the projection pursuit model (Z) is the AECC. The projection pursuit value of sample i (Z^i) can be expressed as

$$Z^i = \sum_{j=1}^{m} Z_j^i = \sum_{j=1}^{m} X_j^i \cdot a_j, \tag{1}$$

where Z_j^i represents projected characteristic value of indicator j in sample i, X_j^i is the normalized value of the indicators j in sample i, m represents the number of indicator j, a_j is the optimal projection vector of the indicator j, and the value range of a_j is $[-1, 1]$.

3.4.2. Normalization of Indicators.

In order to unify the dimension of the evaluation indicator, it is necessary to normalize the evaluation indicator values. According to the attribute of the evaluation indicator, the evaluation indicator is divided into positive indicator and negative indicator.

The attribute of the positive indicator is proportional to the AECC, such as $y_2, y_3, y_4, y_5, y_{12}, y_{13}, y_{14}, y_{15}$, and y_{16}. The calculation formula is

$$X_j^i = \frac{y_j^i - y_{j\min}}{y_{j\max} - y_{j\min}}. \tag{2}$$

The attribute of the negative indicator is inversely proportional to the AECC, such as $y_1, y_6, y_7, y_8, y_9, y_{10}$, and y_{11}. The calculation formula is

$$X_j^i = \frac{y_{j\max} - y_j^i}{y_{j\max} - y_{j\min}}. \tag{3}$$

In the formulas (2) and (3), y_j^i is the original value of the indicator j in sample i, and $y_{j\max}$ and $y_{j\min}$ are the maximum and minimum values of y_j in sample i. X_j^i is the normalized value of y_j^i. The normalized values of 16 indicators are shown in Table 2.

3.4.3. Calculating the Best Projection Vector a_j.

In order to solve the optimal projection vector a_j in the projection pursuit model, a projection objective function $Q(a_j)$ is constructed. The related formulas are expressed as follows:

$$Q(a_j) = S(a_j) \cdot d(a_j),$$

$$S(a_j) = \left[\sum_{i=1}^{n} \frac{(Z^i - \overline{Z})^2}{n} \right]^{1/2},$$

$$d(a_j) = \sum_{i=1}^{n} \sum_{k=1}^{n} (R - r^{ik}) \cdot f(R - r^{ik}),$$

$$f(R - r^{ik}) = \begin{cases} 1, & R - r^{ik} > 0 \\ 0, & R - r^{ik} \leq 0. \end{cases} \tag{4}$$

Among them, $S(a_j)$ is the interclass distance. $d(a_j)$ is the inner class density. $\overline{Z}$ is the mean value of the projected characteristic value Z^i. R is the window width of the density. There is no systematic theoretical basis to determine R currently; it can be $0.1, 0.01, 0.001S(a_j)$, and $0.1S(a_j)$ is generally adopted [47]. n is the total amount of sample i. $r^{ik} = \|Z^i - Z^k\|$, $i, k \in [1, 2, \ldots, n]$, and $f(R - r^{ik})$ is the unit step function.

In order to explore the structural characteristics of the evaluation indicator, the distribution of projected characteristic values should have the following features: local projection points should be as dense as possible; the whole projection points should be dispersed as much as possible. Therefore, the optimal projection vector a_j can be obtained when the value of the objective function $Q(a_j)$ is the largest. The constraint conditions for solving the optimal projection vector combined with the accelerated genetic algorithm are expressed as follows:

$$\begin{aligned} \text{Max} \quad & Q(a_j) = S(a_j)D(a_j), \\ \text{s.t.} \quad & \sum_{j=1}^{m} a_j^2 = 1. \end{aligned} \tag{5}$$

After the optimal projection vector a_j is solved, the projected characteristic value Z^i can be calculated according to formula (1).

3.5. The Coupling Coordination Degree Model.

Since the standard for the evaluation value of AECC has not been established, this section introduces the coupling coordination degree model (CCD) to analyse the development of AECC. CCD is generally used to describe the degree of development coordination of the research object in various dimensions [48], and it can describe the coordinated development of the airport. The higher coordination level of airport's socioeconomic, environmental, and operational dimensions after coupling and integration can provide greater AECC accordingly. Therefore, CCD of airport development can reflect the AECC to some extent. CCD is divided into five levels [49], as shown in Table 3.

TABLE 1: The indicator system of AECC.

System	Subsystem		Indicators	Select meaning	Attributes
	D	y_1	The population density (person/km^2)	Driving force of the population density to AECC development	Negative
		y_2	Per capita GDP (yuan)	Represent the individual's use of airport resources	Positive
		y_3	Annual cargo and mail throughput (ton)	Pressure of cargo and mail transportation on AECC	Positive
	P	y_4	Annual passenger throughput (person)	Pressure of passenger on AECC	Positive
		y_5	Annual aircraft movements (sorties)	Pressure of air traffic flow on AECC	Positive
		y_6	Sewage discharge (10^4 tons)	State of water resources	Negative
A		y_7	Annual CO emissions (g)	State of air quality	Negative
E		y_8	Annual NO$_x$ emissions (g)	State of air quality	Negative
C	S	y_9	Annual HC emissions (g)	State of air quality	Negative
C		y_{10}	Annual PM emissions (g)	State of air quality	Negative
		y_{11}	Noise pollution area above 57 dB (km^2)	State of noise	Negative
		y_{12}	On-time flight clearance rate (%)	State of airport operation	Positive
		y_{13}	Green coverage rate (%)	Response actions for reducing emissions	Positive
		y_{14}	Passenger satisfaction (score)	Response actions for improving passenger service	Positive
	R	y_{15}	Growth rate of on-time flight clearance rate (%)	Response actions for improving efficiency	Positive
		y_{16}	Reduction rate of energy consumption per passenger (%)	Response actions for reducing energy consumption	Positive

TABLE 2: The normalized values of 16 indicators.

Subsystem	Indicators	Normalized values									
		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
D	y_1	1	0.97	0.38	0.37	0.35	0.32	0.30	0.18	0.06	0
	y_2	0.04	0	0.13	0.26	0.37	0.57	0.69	0.82	0.88	1
P	y_3	0	0.25	0.42	0.45	0.51	0.57	0.70	0.78	0.88	1
	y_4	0	0.11	0.23	0.36	0.46	0.59	0.66	0.67	0.81	1
	y_5	0	0.15	0.26	0.37	0.50	0.62	0.71	0.70	0.84	1
S	y_6	1	0.96	0.89	0.78	0.71	0.56	0.46	0.34	0.24	0
	y_7	1	0.86	0.74	0.63	0.51	0.40	0.31	0.31	0.17	0
	y_8	1	0.85	0.74	0.63	0.50	0.38	0.29	0.30	0.16	0
	y_9	1	0.93	0.75	0.63	0.51	0.40	0.31	0.31	0.17	0
	y_{10}	1	0.85	0.74	0.63	0.50	0.39	0.30	0.31	0.13	0
	y_{11}	0.87	0.77	0.83	0.90	1	0.97	0.93	0.93	0	0.66
	y_{12}	1	0.95	0.51	0.61	0.43	0.37	0.00	0	0.75	0.74
R	y_{13}	0	0.16	0.36	0.49	0.64	0.67	0.79	0.85	0.92	1
	y_{14}	0.27	0.18	0.45	0.32	0.68	0.5	0.59	0	0.73	1
	y_{15}	0.26	0.29	0	0.41	0.19	0.28	0.03	0.33	1	0.32
	y_{16}	0.69	1	0.89	0.68	0.76	0	0.67	0.72	0.78	0.80

The DPSR indicator system comprehensively considers the impact of social economy, environmental resource, and operation on AECC. The selection of evaluation indicators covers three dimensions. Therefore, the DPSR evaluation indicator is used to construct the CCD of airport development to reflect the degree of coordination between airport development and economic, social, and environmental aspects. The calculation formula is expressed as

$$CCD = \sqrt{C \times T},$$

$$C = \left[\frac{\left(U_{So} \times U_{En} \times U_{Op} \right)}{\left(U_{So} + U_{En} + U_{Op} \right)/3} \right]^{1/3}, \quad (6)$$

$$T = \alpha U_{So} + \beta U_{En} + \gamma U_{Op}.$$

Among them, C is the coupling degree among the three dimensions of social economy, environmental resource, and

airport operation, and the value range is [0, 1]. $U_{So}, U_{En},$ and U_{Op} are the development indexes of three dimensions, respectively, the calculation methods are the same, take U_{So} as an example, $U_{So} = \sum_{j=1}^{m_{so}} X_j^i \cdot \omega_j$, $\omega_j = a_j / \sum_{j=1}^{m} a_j$, m_{so} is the total number of indicators in the socioeconomic dimension. $\alpha, \beta,$ and γ are the weight of each dimension, and it is generally considered that all dimensions interact equally, $\alpha = \beta = \gamma = 1/3$ [50].

4. Results and Discussions

4.1. The AECC of CAN from 2008 to 2017.
This paper takes CAN as a case study and applies the proposed method to evaluate the AECC of CAN from 2008 to 2017. The normalized values of 16 indicators (Table 2) were put into the accelerated genetic algorithm–projection pursuit model. The projected characteristic values Z^i are obtained by equation (1). The results are shown in Table 4. The normalized values

TABLE 3: Classification standard of coupling coordination degree.

CCD	0.00–0.20	0.21–0.40	0.41–0.60	0.61–0.80	0.81–1.00
Coordination grade	No (V)	Low (IV)	Basic (III)	Good (II)	Excellent (I)

TABLE 4: The comprehensive evaluation result of AECC.

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Z^i	2.684	2.631	2.165	2.062	1.939	1.488	1.470	1.427	1.436	1.292

of 16 indicators and a_j were put into the coupling coordination degree model. The results and grades are shown in Figure 3.

From Table 4, it can be seen that the AECC of CAN (Z^i) decreased from 2008 to 2017. The results indicate that even if the air traffic volume continues to rise, the AECC of CAN still has been declined year by year. The main reason is that the AECC is measured from multidimensional factors of airport sustainability, and the current resource shortage and environmental pollution have affected the development of CAN, thus limiting the AECC of CAN.

Analysing the impact of the subsystem on AECC of CAN, the projected characteristic values of the four subsystems (Z_D, Z_P, Z_S, and Z_R) from 2008 to 2017 are shown in Figure 3. Among them, Z_S and Z_D have continued to decrease over the past ten years; Z_S has a greater decline, while Z_P and Z_R have relatively slight growth. Therefore, the projected characteristic values of AECC have a similar change as Z_S, and the AECC of CAN is mainly determined by the state subsystem (S).

Meanwhile, the CCD of airport development has also been declining year by year, and it was basically coordinated before 2011 and then became low coordination, indicating that while the CCD between airport's socioeconomic, environmental, and operational development decreases, AECC also decreases. In addition, CCD and AECC have similar trends, indicating that the coordination degree of airport development is closely related to the level of AECC. The coordinated development of airport's social economy, environmental resource, and operation is of great significance to improving the AECC.

From 2015 to 2016, the AECC of CAN increased slightly by 0.62%. The reason is that the increase of Z_R and Z_P is greater than the decrease of Z_D and Z_S. Z_R has increased by 57.78%. Affected by the response subsystem (R), AECC of CAN is on the rise. In addition, the third runway of CAN was put into use in 2015. The increase of the runway has expanded airport capacity and improved operational efficiency, indicating that the airport's reconstruction and expansion project can effectively improve AECC.

4.2. Analysis of Influencing Indicators.
Comparing the optimal projection vectors a_j of each indicator, as shown in Figure 4, it can be seen that y_1, y_7, y_8, y_9, and y_{16} are the top five indicators that have great impact on AECC of CAN. a_8 is 0.3437 and the attribute is negative, reflecting that measures to reduce NO_x emissions (y_8) can increase the AECC of
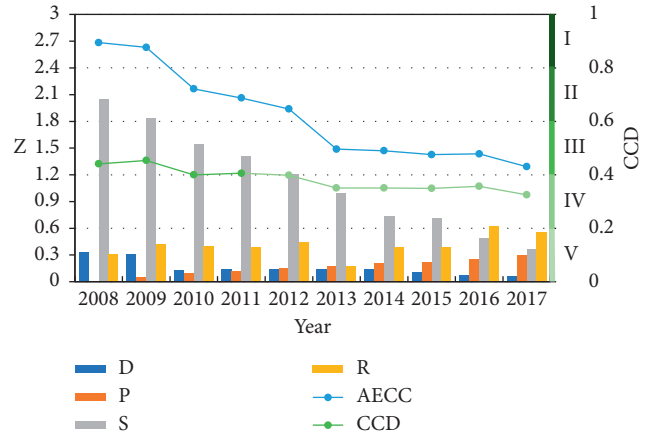

FIGURE 3: The changes of each subsystem from 2008 to 2017.

CAN; a_{16} is 0.3390 and the attribute is positive; it means that saving fuel consumption (y_{16}) will also improve the AECC of CAN; a_1, a_9, and a_7 are 0.3244, 0.3151, and 0.3102, respectively, indicating that the increase in population density and air pollutant emissions will make the AECC of CAN status deterioration. y_2, y_4, and y_5 are the three indicators that have little impact on AECC. a_2, a_4, and a_5 are 0.0627, 0.0751, and 0.0988, respectively, indicating that the increase in per capita GDP, annual passenger throughput, and annual aircraft movements cannot significantly improve the AECC of CAN.

The colour distribution of Figure 4 illustrates that the state subsystem (S) has the greatest impact on AECC of CAN, while the driving force subsystem (D) has relatively the smallest impact on AECC of CAN.

Comparing and analysing the projected characteristic value Z_j^i of the D, P, S, and R subsystems, the results are shown in Figure 5.

In Figure 5(a), the downward trend of Z_D and Zy_1 is roughly the same, while Zy_2 shows a slowly increasing trend. In addition, Z_D dropped significantly by 58.1% in 2010, mainly due to the 26.8% increase in population density, which led to a decrease in Zy_1 and a sharp drop in Z_D. The change reflects that population growth (y_1) was the root cause of the resources shortage and the environment deterioration around the airport, and although the per capita GDP has increased year by year, it has little impact on the overall driving force subsystem (D), indicating that the airport's investment in improving the AECC of CAN has not increased. Therefore, reasonable population control and
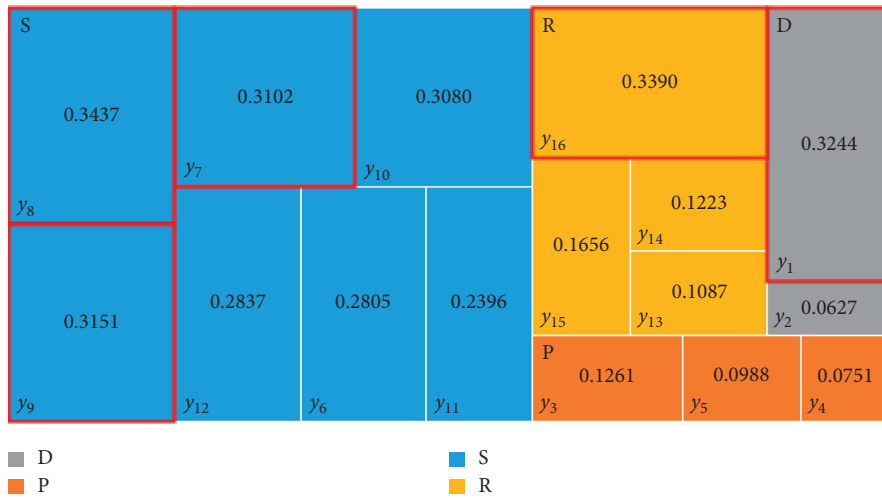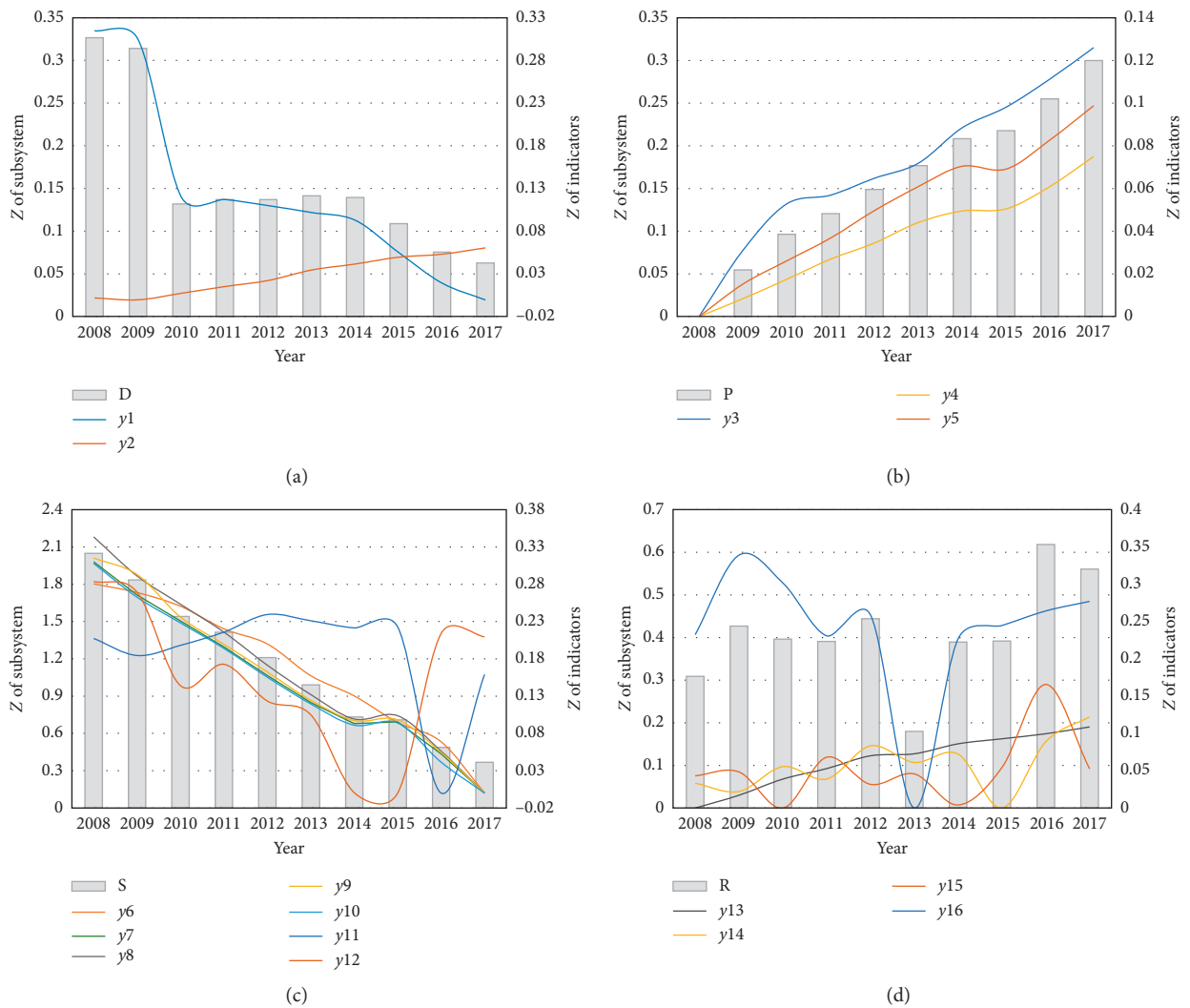
Figure 4: Projection vector (a_j) of indicators.

(a)

(b)

(c)

(d)

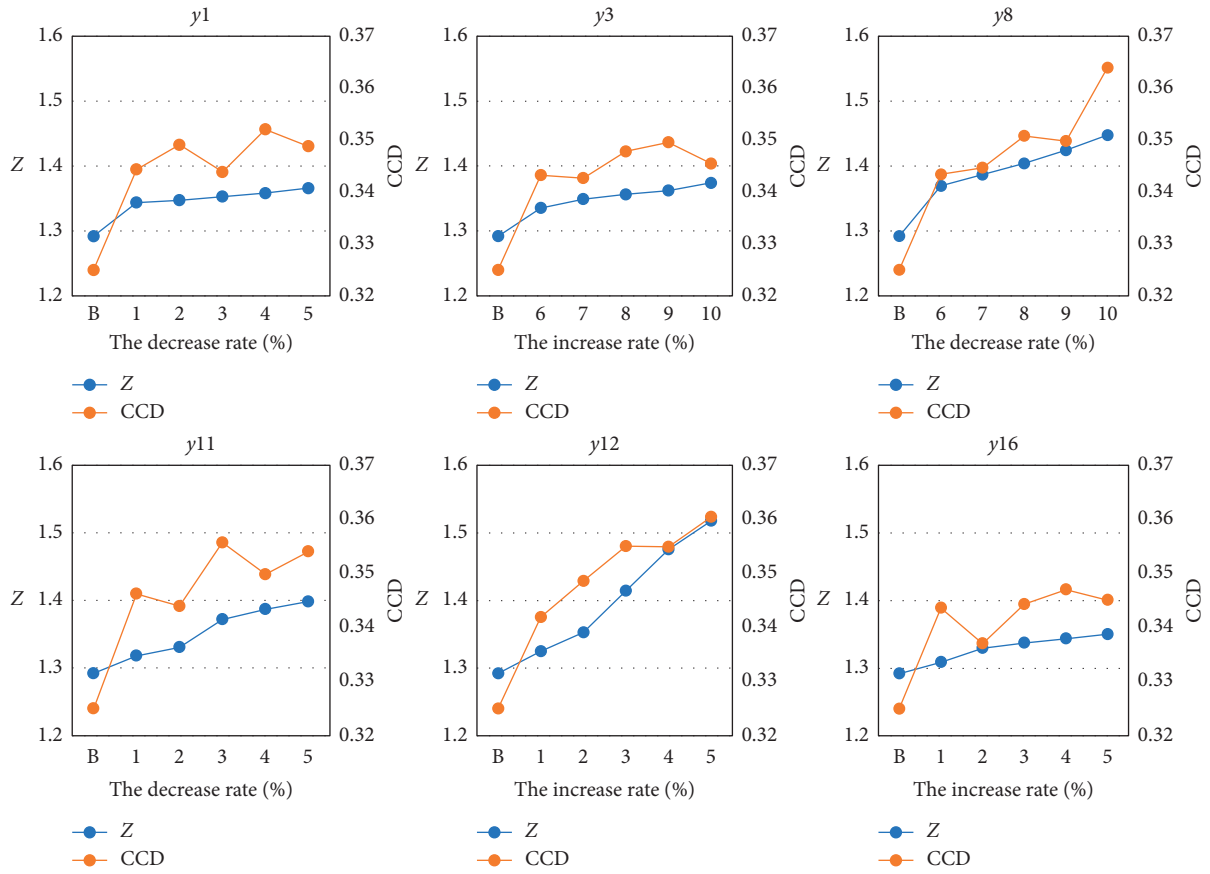Figure 5: The projected characteristic value of subsystem and indicators.

FIGURE 6: Z and CCD under the change rate of six key indicators.

increased investment in airport construction can improve AECC.

In Figure 5(b), Z_P shows a slow growth trend; at the same time, Zy_3, Zy_4, and Zy_5 have similar changing trends. They are also increasing year by year, indicating that the continuous increase of airport air traffic flow volume can improve the AECC. In addition, Zy_3, Zy_4, and Zy_5 are significantly correlated (Pearson's correlation >0.8), and y_3 has the greatest impact on AECC of CAN, so y_3 is selected as the representative indicator of P subsystem.

In Figure 5(c), Z_S has a similar downward trend with Zy_6, Zy_7, Zy_8, Zy_9, and Zy_{10}. It shows that the increase of annual emissions such as sewage, CO, NO_x, HC, PM and the noise overlimit area are the main reasons for the deterioration of AECC. In addition, Zy_{12} increased by 0.21 in 2016, but Z_S decreased by 0.22, which shows that even if the on-time flight clearance rate is greatly increased, the AECC of CAN cannot be changed when the Z-values of other state indicators are falling. Therefore, reasonably reducing the emission of pollutants and increasing the on-time flight clearance rate can improve AECC of CAN. The evaluation indicators Zy_6, Zy_7, Zy_8, Zy_9, and Zy_{10} are correlated (Pearson's correlation >0.8), and y_8 has the greatest impact on AECC of CAN, so y_8, y_{11}, and y_{12} are selected as representative indicators of S subsystem.

In Figure 5(d), the trend of Zy_{16} is roughly the same as Z_R, indicating that the rate of decrease in energy

consumption per passenger is the main influencing factor of the response subsystem (R). Moreover, Zy_{16} dropped significantly in 2013, because the proportion of A321 aircraft type has increased, so the energy consumption per passenger in that year increased by 15.0%, and Z_R decreased by 59.6%. Therefore, the reduction in energy consumption per passenger can improve AECC of CAN.

Based on the above analysis, combined with the optimal projection vector, this paper selects y_1, y_3, y_8, y_{11}, y_{12}, and y_{16} as the key influencing indicators to represent AECC.

4.3. Political Suggestions. According to the historic data from 2008 to 2017, this paper uses 2017 as the baseline and sets the change rate of y_1, y_{11}, y_{12}, and y_{16} from 1% to 5%, and the change rate of y_3 and y_8 from 6% to 10% to analyse the trend of AECC of CAN.

When the key indicators change at a certain rate, Z shows an upward trend, indicating that the AECC of CAN can be increased after improving the original values of the six key indicators, as shown in Figure 6, where B is the baseline. CCD has similar change trend as Z, indicating that the growth of CCD can promote the AECC of CAN.

When the population density (y_1) and noise pollution area above 57 dB (y_{11}) decrease by 5%, Z increases by 5.7% and 8.2%, and CCD increases by 7.3% and 8.9%, respectively. When the on-time flight clearance rate (y_{12}) and reduction

rate of energy consumption per passenger (y_{16}) increase by 5%, Z increases by 17.5% and 4.5%, and CCD increases by 10.9% and 6.2%, respectively. Compared with the growth rate, the increase in on-time flight clearance rate promotes the coordinated development of CAN and has a significant improvement on AECC of CAN.

When annual cargo and mail throughput (y_3) increases by 10%, Z and CCD only increase by 6.4% and 6.3%, indicating that the growth of throughput has the least impact on the improvement of the coordinated development of CAN and AECC of CAN. When NO_x emission (y_8) decreases by 10%, Z and CCD increase by 12.1% and 11.9%, respectively. It can be seen that greatly reducing NO_x emissions can effectively promote the coordinated development of CAN and improve AECC.

In summary, in view of the development state of CAN's AECC, we can consider the following political suggestions to promote the coordinated development of the airport and improve AECC:

(1) Airport reconstruction and expansion projects will improve the AECC of CAN. Therefore, airport stakeholders can rationally plan airport construction and increase investment in airport construction by considering the airport sustainability.

(2) The population density in the D subsystem is the main influencing factor. Therefore, we can keep the pace of economic development and urbanization process in line and reasonably control the population.

(3) Pollutant emissions and on-time flight clearance rate in the S subsystem are the main influencing factors, and it is necessary to reasonably reduce pollutant emissions and increase the on-time flight clearance rate to improve AECC.

(4) The reduction rate of energy consumption per passenger in the R subsystem is the main influencing factor, so measures can be taken in response to the current situation of AECC. The increase of on-time flight clearance rate can alleviate the operational pressure of the airport and effectively improve the AECC. In the short term, the response measures can be mainly aimed at the increase of on-time flight clearance rate. In the long term, energy-saving, emission-reduction, and noise reduction measures should be taken to alleviate the environmental pressure on the airport.

5. Conclusion

In this paper, an evaluation framework and method are proposed to determine the airport environmental carrying capacity. By researching the operational characteristics of airport and the relationships with economy, society and environment, this paper proposed a concept of AECC based on the content of ECC to represent the comprehensive carrying level of airport. 16 evaluation indicators were selected from economic, social, environmental, and

operational aspects by analysing the content of AECC, this paper constructed an indicator system with these 16 indicators based on the DPSR model. To evaluate the AECC, this paper built an evaluation framework and formed a systematic evaluation method by using the DPSR model, CCD model, and projection pursuit model and accelerated genetic algorithm according to the concept of AECC.

Taking CAN as a case study, this paper evaluated the AECC of CAN from 2008 to 2017. The results show that even if the air traffic volume continues to rise, the AECC of CAN still has been declined year by year. By comparing and analysing the evaluation results with CCD of CAN, mining the main influencing factors, this paper provides suggestions for improving the AECC of CAN: airport construction and population control can improve AECC. In the short term, the most effective measure is to increase the on-time flight clearance rate. In the long term, energy-saving, emission-reduction, and noise reduction measures should be taken to alleviate the environmental pressure on the airport.

In addition, the evaluation method of AECC in this paper is not limited to CAN. If other airports are researched as the object, the evaluation and analysis of AECC can be realized by changing the indicator data according to the actual operation of other airports.

Data Availability

The original data are available from the Statistical Yearbook of Guangzhou (http://tjj.gz.gov.cn/), Airport Annual Report of CAN (https://www.gbiac.net/byairport-web/index), Civil Aviation Industry Development Statistical Bulletin, and the National Civil Aviation Flight Operation Efficiency Report from 2008 to 2017 (http://www.caac.gov.cn/index.html).

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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