1,* Danyang Shen
2 Ximeng Liu
3 Xiudi Li

Airport–Industry–City Integrated Accessibility Using Big Data Case View from Beijing Capital International Airport

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Abstract: - Big data technology can help collect, analyze, and process large-scale transportation, population, economic, and other relevant data, which has been proven to be more accurate in assessing the accessibility of different areas. An aerotropolis is composed of the airport as the core, airport-related industry as the link, and the airport-oriented city as the carrier, airport–industry–city (AIC) system. To better grasp the development quality of aerotropolises, an AIC integrated accessibility measurement model is constructed comprising the accessibility of airport route network, airport ground traffic, and airport information coverage. Using big data of traffic, network and information from 2001 to 2020, we apply the model to the Beijing Capital International Airport (PEK) aerotropolis. The results show that PEK's AIC connectivity exceeded 1 for the first time in 2008, reaching 1.0890, which the range of the scale is [0, +∞]. It fluctuated significantly from 2017 to 2020, showing a double life-cycle S-curve. So, the PEK aerotropolis' development can be divided into four stages: germination (before 2001), high-speed development (2002–2011), gradual formation (2012–2019), and "seeking change in the process of change" (after 2020). Our model offers a new tool for identifying the development stages of aerotropolises and for improving connectivity—namely, improving the accessibility of the airport node network, the layout of airside-preferring enterprises, and the network structure of new Internet-based airport cities. Obviously, the AIC integrated accessibility can indeed guide the scientific development of an aerotropolis.

Keywords: Aerotropolis, Airport–Industry–City (AIC) System, Integrated Accessibility, Big Data, Beijing Capital International Airport (PEK), Network.

I. INTRODUCTION

The aerotropolis is an inevitable product of urban development under rapid economic growth. Its development is based on the three core elements of airports, industries, and space, forming an airport–industry–city (AIC) system. As an important node of a city's internal radiation and external connection, the airport is no longer a place for passengers and goods to change transportation modes in the traditional sense; rather, it has evolved into an engine that drives regional social and economic development [1]. In the AIC system of an aerotropolis, travellers and goods flow through an integrated transportation system centred on the airport, resulting in the agglomeration of production, technology, capital, trade, and population; this in turn creates regional competitiveness through internal radiation and external connectivity [2]. Thus, airport accessibility is one of the most important indicators for measuring the internal and external interactions of an aerotropolis. Many studies have qualitatively discussed and quantitatively measured airport accessibility. However, such studies are typically based on infrastructure and do not measure accessibility in terms of the AIC system of aerotropolises. Based on the perspective of aerotropolis, this paper is intended to conduct a study on the integrated accessibility measurement of AIC, to provide a new tool for the classification of the development stage of aerotropolis, and to better support the high-quality development of aerotropolis.

Big data technology can help collect, analyze, and process large-scale transportation, population, economic, and other relevant data to more accurately assess the accessibility of different areas [3]. Using big data for AIC integrated accessibility analysis is an effective approach. Using big data for AIC integrated accessibility can provide more scientific and precise data support for urban planning and transportation management.

In February 2019, China's National Development and Reform Commission and the Civil Aviation Administration jointly issued the "Reply Letter on Supporting the Construction of the Capital Airport Airside Economic Demonstration Zone," stating that the zone would be in the northeastern part of the main urban area of Beijing and within the territory of Shunyi District. At its core is Beijing Capital International Airport (code: PEK). It has a planned area of 115.7 square kilometres, with the People's Government of Shunyi District as the main body conducting the planning, construction, and management.

Although it has only been four years since the approval of the Capital Airport Airside Economic Demonstration Zone, PEK and its surrounding areas are now the most mature and well-developed airside economic zones in China.

1 School of Transportation Science and Engineering, Civil Aviation University of China, Tianjin, China
2 School of Transportation Science and Engineering, Civil Aviation University of China, Tianjin, China
3 China Eastern Airlines Wuhan Co. LTD, Wuhan, Hubei, China
*Corresponding author: Danyang Shen

In 1993, the passenger throughput of PEK exceeded 10 million, marking the beginning of the spontaneous spillover effect of the airport's resources. In 2004, the first China Airside Economy Forum was held in Shunyi, Beijing, which proposed the development of an airside economy and planned a series of new functional zones, including the Airport Logistics Base, Tianzhu Comprehensive Logistics Park, and Guomen Business District. In 2010, the Housing and Construction Committee of Shunyi District proposed the idea of building a world aerotropolis. Thus, the Capital Airport Airside Economic Demonstration Zone presents a typical case of aerotropolis development and, with its long-time span and large industrial scale, has high longitudinal research value.

This article will measure the AIC integrated accessibility using big data with the PEK as a case. This article will comprise the following sections: Section 2 analysising the composition of AIC integrated accessibility, Section 3 establishing the measurement model, Section 4 caculating the AIC integrated accessibility of PEK using big data, and Section 5 providing conclusions and insights.

II. Composition of AIC integrated Accessibility

Accessibility refers to the magnitude of the likelihood that nodes in a transportation network will interact with each other [4]. It can be divided into two categories: the ease of transportation availability, measured in terms of temporal or spatial distance, and the magnitude of opportunities for interaction, measured in terms of out-of-distance or weights between two nodes [5]. Airport accessibility is mainly categorized into ground transportation accessibility [6] and route network accessibility [7]. The former is mainly measured by the benefit–cost ratio index [8], cost function [9], gravity model [10], graph theory [11], mixed nested logit model [12], and other models that can be used to analyse an airport's industrial radiation to the local area. The latter is mainly measured using descriptive statistical data and related indexes [13-15], the shortest path length model [16-17], social network analysis, accessibility evaluation methods [18], the potential energy model, and utility models [19]. These can be used to analyse spatiotemporal changes in regional accessibility and the equilibrium of economic patterns [20], reflecting the connectivity of airports in the global route network. With the development of the digital economy, information economy, and virtual economy, information technology has become another "medium" after ground transportation and route networks, reconstructing the competitive advantages of aerotropolises. The higher the accessibility of information to airports, the more significant the reduction of geographic distance barriers to production activities, which strengthens the linkage of production activities in the AIC system of aerotropolises [21].

Based on traditional airport ground transportation accessibility and route network accessibility, introducing an information network to build AIC integrated accessibility from the standpoint of aerotropolises is more in line with the development trend of the information age. In the aerotropolis AIC system, the capacity of the "airport" is reflected in the accessibility of its nodes and the route network. The scale of "industry" is reflected in the layout of airside-preferring enterprises in the surrounding radiation area, which depends on the level of ground transportation to the airport. The development of the "city," meanwhile, can be measured based on the accessibility of information coverage [22].

Thus, AIC integrated accessibility includes airport route network accessibility, airport ground transportation accessibility, and airport information coverage accessibility. Airport route network accessibility indicates the airport's external connectivity, airport ground transportation accessibility indicates its internal radiation, and airport information coverage accessibility reflects the coverage of the "city" and the level of airport urbanization. Specifically,

$$Ac = \beta_1 Ac^{Air} + \beta_2 Ac^{Land} + \beta_3 Ac^{Information}, \quad (1)$$

where Ac denotes AIC integrated accessibility, Ac^{Air} represents the accessibility of the airport route network, Ac^{Land} denotes the accessibility of airport ground transportation, $Ac^{Information}$ is the accessibility of airport information coverage, and β_1, β_2, and β_3 are the contribution rates of each accessibility type.

III. AIC integrated accessibility measurement model

A. *Integrated Accessibility of Airport Route Networks*

Airport route network accessibility is the ease with which travellers/tourists and cargo/goods can reach destination airports from airports using the air transportation network. It evaluates the ease with which airports can be accessed by neighbouring areas, using airports as the target [23]. Airport route network accessibility is related to the size of landward and airward hinterland and involves the population size, industrial situation, economic development, and transportation accessibility of the service area, representing a combination of multiple indicators

[9]. Airport route network accessibility is affected by the number of routes, flight density, and other factors; the higher these indicators, the higher the airport route network accessibility:

$$Ac^{Air} = Num^{\alpha_1} \times Freq^{\alpha_2} \times NAirRoute^{\alpha_3}, \tag{2}$$

Where Num denotes the number of airports served by the airport, $Freq$ is the flight density of the airport, and $NAirRoute$ denotes the air miles served by the airport.

Taking 175 airports in China (as of the end of 2015) as a sample, we obtain the values of α_1, α_2, and α_3 based on regression using the passenger throughput data, number of airports, air miles, and flight density of each airport [24]; that is,

$$Ac^{Air} = Num^{0.949(19.1)} \times Freq^{0.85(21.4)} \times NAirRoute^{0.128(4.5)}, \tag{3}$$

Where the value in () is the t-test value; $R^2 = 0.989$.

B. Airport Ground Transportation Accessibility

Airport ground transportation accessibility refers to the ease with which travellers/tourists and cargo/goods can reach the airport using the ground transportation system. Commonly used measurement methods include gravity modelling, the cumulative opportunity method, utility modelling, and space-time methods [25]. Airport ground transportation accessibility is affected by the availability of transportation infrastructure, the development status of the node itself, and other factors, while the node and the surrounding nodes of population and economic development levels are related as well. Based on the gravity model, the abovementioned factors can be quantified as generalized comprehensive travel impedance, road capacity, and node development gradient, which can reflect the level of development and the convenience of internode links after substitution into the model. The calculation steps are as follows:

1) Generalized Integrated Travel Impedance

Impedance is a function of comfort, travel time, and travel cost. The average of the generalized impedance of all roads between the same node pair is used as the input variable in the model—that is, generalized composite travel impedance:

$$C_{ij} = \frac{1}{K_{ij}}(T_{ij} \cdot VOT_i + F_{ij}), \tag{4}$$

$$C_i = \frac{1}{j}\sum_j C_{ij}, \tag{5}$$

where C_{ij} denotes the generalized impedance of the jth road between node i and the airport;K_{ij}, T_{ij}, andF_{ij} denote the comfort index, travel time, and travel cost of the$j$th road between node i and the airport, respectively; VOT_i denotes the value of the travel time between node i and the airport, which is calculated using the GDP per capita of node i and the administrative district where the airport is located; and C_i denotes the average generalized impedance of each road from node i to the airport.

2) Road Capacity

The ratio of road capacity between nodes to the average road capacity of the whole region is considered an influencing variable in the connectivity model:

$$V_i = \frac{\sum_j Q_j}{\frac{1}{n}\sum_n \sum_j Q_{ij}}, \tag{6}$$

where V_i denotes the capacity index of each road between node i and the airport, Q_{ij} denotes the capacity of the jth road between node i and the airport, and n is the number of pairs of nodes in the region.

3) Nodal Development Gradient

To quantitatively describe the existence of interconnections and mutual influences between different regions in terms of economy, resources, and industrial layout, we use the node development gradient indicator as a variable in the accessibility model to reflect the effect of the size of interactions between nodes on accessibility:

$$G_i = \left[\sum_{a=1}^{3}(X_a - X_{ia})^2\right]^{\frac{1}{2}}, \tag{7}$$

Where G_i denotes the development gradient between node i and the administrative district where the airport is located; X_1 and X_{i1} denote the proportion of GDP accounted for by the transportation, storage, and postal sector in node i and the administrative district where the airport is located, respectively; X_2 and X_{i2} denote the proportion of GDP accounted for by the secondary sector in node i and the administrative district where the airport is located, respectively; and X_3 and X_{i3} denote the proportion of GDP accounted for by the tertiary sector in node i and the administrative district where the airport is located, respectively.

The above three factors and their constituent key parameters are put into the gravity model and collated to obtain the airport ground transportation accessibility of a region:

$$A_i = \frac{V_i \cdot G_i}{C_i} = \frac{\frac{\sum_j Q_{ij}}{\frac{1}{n}\sum_n \sum_j Q_{ij}}\left[\sum_{a=1}^{3}(X_i - X_{ia})^2\right]^{\frac{1}{2}}}{\frac{1}{j}\cdot\frac{1}{K_{ij}}(T_{ij}\cdot VOT_i + F_{ij})}, \tag{8}$$

Where A_i denotes the accessibility between node i and the airport.

Normalize them as follows:

$$A_i^{\ *} = \frac{A_i}{A_i^{\ max}}. \tag{9}$$

Then, standardize them:

$$Ac^{Land} = \sum_i A_i^{\ *}. \tag{10}$$

C. Accessibility of Airport Information Coverage

Information coverage accessibility generally refers to the ability to interact or the degree of connectivity of information between individuals or regions. Airport information coverage accessibility is expressed using airport information technology investment, as follows:

$$Ac^{Informaction} = \frac{x_s}{Max(x_s)}, \tag{11}$$

Where x_s denotes the amount of investment in airport informatization in year s.

D. Determination of Individual Accessibility Contribution Rates

Principal Component Analysis (PCA) is a relatively basic method of data dimensionality reduction and an important part of multivariate statistics, which has a wide range of applications in data analysis and machine learning. PCA is an attempt to replace some of the original indicators with a new, uncorrelated composite indicator that is correlated and can reflect most of the information of the original multiple indicators. PCA is very helpful for integrating information, so it can be used to determine the contribution rate of each accessibility in the integrated accessibility of AIC. For the statistics of each accessibility type, we analyse the Kaiser–Meyer–Olkin (KMO) values and use Bartlett's test of sphericity to determine whether AIC integrated accessibility can be fitted by PCA to explore the relationship between route network, ground transportation, and information coverage accessibility and AIC integrated accessibility, as well as the contribution of each accessibility type. The specific steps are as follows:

1) Standardize Raw Data

The value of the jth ($j \in [1, m]$) indicator for the ith ($i \in [1, n]$) evaluation object is x_{ij}, and integrated AIC accessibility consists of three indicator variables (i.e., m = 3). Converting each indicator x_{ij} into a standardized indicator $x_{ij}^{\%}$, we obtain

$$x_{ij}^{\%} = \frac{x_{ij} - \bar{x}_j}{s_j}, \tag{12}$$

Where $\bar{x}_j = \frac{1}{n}\sum_{i=1}^{n} x_{ij}$, $s_j = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_{ij} - \bar{x}_j\right)^2}$; that is, $\bar{x}_j$, s_j are the sample mean and standard deviation of the jth indicator, respectively.

2) Calculate the Correlation Coefficient Matrix R

The matrix of correlation coefficients $R = \left(r_{ij}\right)_{m \times m}$ is

$$r_{ij} = \frac{\sum_{k=1}^{n} x_{ki}^{\%} g_{kj}^{\%}}{n-1}, (i, j = 1,2,3), \tag{13}$$

Where $r_{ii} = 1$, $r_{ij} = r_{ji}$, and r_{ij} are the correlation coefficients between the ith indicator and the jth indicator.

3) Calculate Eigenvalues and Eigenvectors

Calculate the eigenvalues $\lambda_1 \geq \lambda_2 \geq \lambda_3 \geq 0$ of the correlation coefficient matrix R and the corresponding eigenvectors u_1, u_2, and u_3, where$u_j = (u_{1j}, u_{2j}, \ldots, u_{n_j})^T$, which consists of the feature vectors, forming three new indicator variables:

$$\begin{cases} y_1 = u_{11}x_1^{\%} + u_{21}x_2^{\%} + \cdots + u_{n1}x_n^{\%} \\ y_2 = u_{12}x_1^{\%} + u_{22}x_2^{\%} + \cdots + u_{n2}x_n^{\%}, \\ y_3 = u_{13}x_1^{\%} + u_{23}x_2^{\%} + \cdots + u_{n3}x_n^{\%} \end{cases} \tag{14}$$

Where y_1 is the first principal component, y_2 is the second principal component, and y_3 is the third principal component.

4) Select p ($p \leq 3$) Principal Components and Calculate the Composite Evaluation Value

Calculate the information contribution rate and cumulative contribution rate of the eigenvalues λ_i ($i = 1,2,3$) by first calculating the information contribution rate of the principal component y_j:

$$\beta_i = \frac{\lambda_i}{\sum_{k=1}^{m} \lambda_k}. \tag{15}$$

Then, the cumulative contribution of the principal components y_1, y_2, ⋯, y_p is calculated:

$$\alpha_p = \frac{\sum_{k=1}^{n} \lambda_k}{\sum_{k=1}^{m} \lambda_k}. \tag{16}$$

When α_p is close to 1 ($\alpha_p = 0.85, 0.90, 0.95$), the first p indicator variables y_1, y_2, ⋯, $y_p$are selected as the p principal components instead of the original three principal components, so that the p principal components can be comprehensively analyzed.

Calculate the composite score:

$$Z = \sum_{i=1}^{p} \beta_i y_i, \tag{17}$$

Where β_i is the contribution rate of the ith principal component. From this, the values of β_1, β_2, and β_3 in Eq. (1) can be obtained.

IV. AIC Integrated Accessibility Analysis of Beijing Capital International Airport

A. *Case Selection and Data Sources*

Since there is no uniform statistical mechanism or standard for airside economies and aerotropolises, considering data availability and the logic of AIC in aerotropolises, we use data for Beijing's Shunyi District, where the airport is located, as a substitute.

Considering timeliness and representativeness, we select 2001–2020 for data collection. The data sources are mainly official statistics and online channels. The economic and social indicators mainly come from the Beijing Statistics Bureau, as well as research by various functional departments in Shunyi District, communication with the Bureau of Statistics, and statistical yearbooks. Data for air routes are provided by OAG (Ouaiji Aviation International Ltd.) of the UK. Data for information and investment are provided by the Capital Airport Group, and data related to ground transportation come from Internet searches.

B. *Integrated Accessibility Measurement Process*

1) *PEK Route Network Accessibility*

Table 1 shows the raw data for indicators related to the accessibility of PEK's route network.

Table 1-Raw data on Indicators Related to the Accessibility of the Airport Route Network

Year	**Number of airports open to traffic (number)**	**Flight density (frequency/article*week)**	**Miles of navigation (million kilometers)**
2000	152	23.67	825.19
2001	160	26.64	900.41
2002	168	27.74	963.86
2003	159	28.27	1008.02
2004	167	35.11	1203.93
2005	177	37.12	1381.71
2006	186	39.17	1576.46
2007	194	39.57	1705.57
2008	215	38.43	1806.79
2009	226	41.52	1904.73
2010	234	42.54	2070.40
2011	245	41.85	2184.72
2012	263	40.59	3983.17
2013	269	40.44	4131.10
2014	281	39.69	4540.57
2015	289	39.14	4791.16
2016	301	38.59	5115.27
2017	307	37.29	5264.52
2018	302	38.97	5508.90
2019	304	37.47	5406.73
2020	288	19.40	2244.83

Data source: OAG

The accessibility of the PEK route network from 2001 to 2020 is calculated using Eq. (3), as shown in Figure 1.

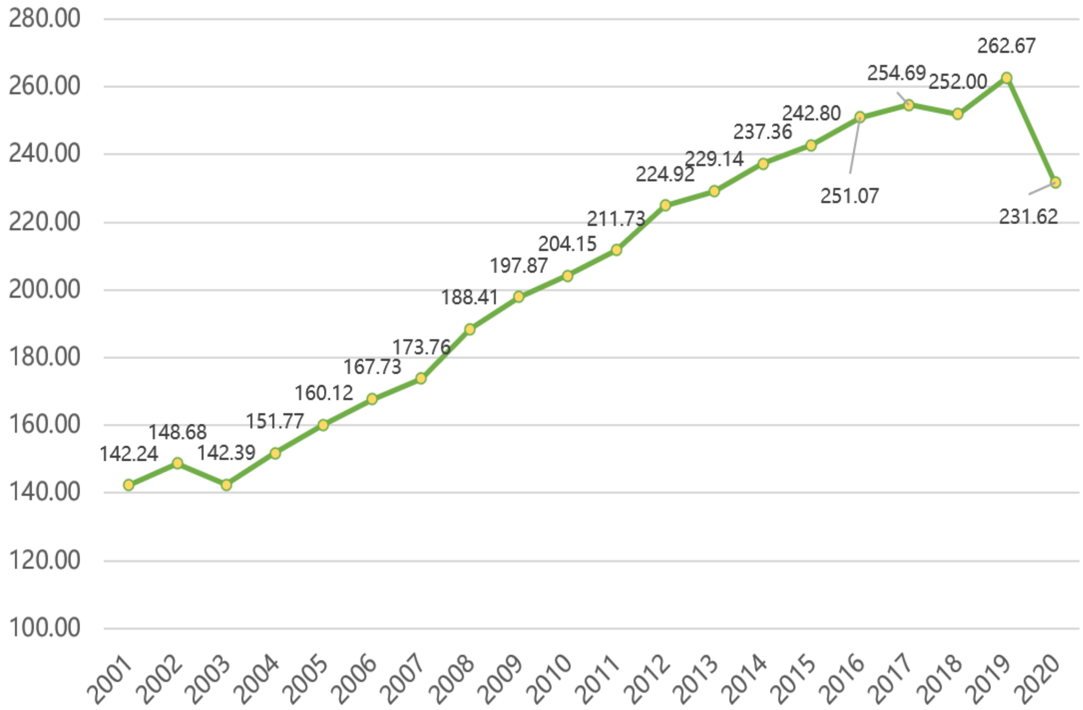

Figure 1-Accessibility trend of the PEK route network, 2001–2020

As can be seen in Figure 1, the accessibility of PEK's route network shows an overall upward trend, with a slight decrease in 2003, larger increases in 2008 and 2009, and a significant decrease in 2020, owing to COVID-19.

2) PEK Ground Transportation Accessibility

There are 16 municipal districts in Beijing. Table 2 shows the basic traffic data for the current highway network between the nodes of each district. Table 3 shows the economic data for the nodes. To conserve space, we take 2020 as an example to illustrate the calculation.

Table 2-Transportation basis data between PEK and other regions, 2020

Nodes (District)	**Roads**	**Designation**	**Hierarchy**	**Times/h**	**Cost/yuan**	**Comfort level**	**Road capacity/pcu**	**Time value /(yuan·a^{-1})**
Dongcheng	1	S51	Highway	0.75	88	0.8	6328	27.91
	2	S12	Highway	0.67	88	0.8	6328	
Xicheng	3	S51	Highway	0.87	113	0.8	6328	29.96
	4	S12	Highway	0.75	113	0.8	6328	
Chaoyang	5	S12	Highway	0.5	75	1	6328	17.27
	6	S51	Highway	0.67	75	0.8	6328	
Fengtai	7	S12	Highway	0.92	150	1	6328	11.67
	8	S51	Highway	0.97	150	0.8	6328	
Shijingshan	9	S12	Highway	0.83	175	0.5	6328	14.61
	10	S32	Highway	0.85	175	0.5	6328	
Haidian	11	S12	Highway	0.67	113	1	6328	20.65
	12	North Tianbei Road	Class I road	1.15	113	0.5	3472	
Tongzhou	13	S51	Highway	0.6	64	0.8	6328	10.07
	14	S32	Highway	0.5	64	1	6328	
	15	PEK East	Class I road	0.6	64	0.5	3472	
Daxing	16	G4501	Highway	1	190	1	6328	14.54
	17	S51	Highway	1.13	190	1	6328	
Fangshan	18	S12	Highway	1.2	175	0.8	6328	9.97
	19	S32	Highway	1.37	250	1	6328	

Mentougou	20	S12	Highway	1	150	0.8	6328	10.27
	21	S32	Highway	1.33	213	1	6328	
Changping	22	S32	Highway	0.83	169	1	6328	9.60
	23	G4501	Highway	0.88	169	0.8	6328	
	24	S28	Highway	0.95	169	1	6328	
Pinggu	25	S32	Highway	0.83	163	1	6328	10.18
	26	PEK East	Class I road	1.5	163	0.5	3472	
Miyun	27	S32	Highway	1	188	1	6328	10.28
	28	PEK East	Class I road	1.45	188	0.5	3472	
Huairou	29	S32	Highway	0.8	125	1	6328	11.57
	30	PEK East	Class I road	1	125	0.5	3472	
Yanqing	31	S32	Highway	1.5	363	1	6328	9.89
	32	S11	Highway	1.58	363	0.9	6328	

Table 3-Economic Indicators between PEK and Other Regions, 2020

Nodes	**GDP/billion yuan**	**Transportation output/billion yuan**	**Secondary sector output/billion yuan**	**Tertiary industry output/billion yuan**
Dongcheng District	2954.70	16.41	72.98	2881.75
Xicheng District	5061.10	65.07	252.83	4808.23
Chaoyang District	7037.90	95.48	484.09	6551.11
Fengtai District	1854.20	68.03	285.07	1568.42
Shijingshan District	855.50	2.91	138.23	717.30
Haidian District	8504.60	96.81	679.96	7823.00
Tongzhou District	1103.00	9.83	410.49	679.45
Daxing District	2978.20	61.66	1610.87	1353.81
Fangshan District	759.90	3.06	285.30	460.56
Mentougou District	251.00	1.84	66.82	181.95
Changping District	1147.50	6.60	358.50	781.21
Pinggu District	284.10	8.04	71.29	199.99
Miyun District	338.60	6.00	85.23	240.69
Huairou District	396.60	5.64	159.03	233.19
Yanqing District	194.50	1.68	44.17	144.12
Shunyi District	1873.70	425.54	514.41	1343.58

For data processing, road comfort is only influenced by road class, and fuel consumption and highway tolls in travel costs are calculated using Baidu map data. The parameter values of the three models of generalized integrated travel impedance, road capacity, and node development gradient can be calculated for each node using Eqs. (4)–(7); Table 4 shows the results.

Table 4-Calculation Results for the Model Parameters Related to Each Node, 2020

Nodes	C_i	V_i	G_i
Dongcheng District	134.15	1.01	0.42
Xicheng District	170.96	1.01	0.39
Chaoyang District	95.93	1.01	0.37
Fengtai District	181.19	1.01	0.26
Shijingshan District	374.54	1.01	0.28
Haidian District	199.42	0.68	0.35
Tongzhou District	98.54	1.01	0.26
Daxing District	205.49	1.01	0.43
Fangshan District	248.68	1.01	0.27
Mentougou District	213.25	1.01	0.22

Changping District	192.03	1.51	0.23
Pinggu District	263.25	0.78	0.20
Miyun District	301.30	1.13	0.21
Huairou District	203.70	0.78	0.28
Yanqing District	398.73	1.01	0.22

Based on the results shown in Table 4, we can calculate the accessibility between PEK and other regions using Eq. (8). Then, the ground transportation accessibility of PEK can be obtained. As shown in Table 5, the ground transportation accessibility of PEK in 2020 is 6.35.

Table 5-2020 PEK Ground Transportation Accessibility Calculation Results

Nodes	**Accessibility**	**Normalization**
Dongcheng District	0.0032	0.83
Xicheng District	0.0023	0.60
Chaoyang District	0.0038	1.00
Fengtai District	0.0014	0.38
Shijingshan District	0.0007	0.20
Haidian District	0.0012	0.31
Tongzhou District	0.0027	0.69
Daxing District	0.0021	0.55
Fangshan District	0.0011	0.28
Mentougou District	0.0010	0.27
Changping District	0.0018	0.47
Pinggu District	0.0006	0.15
Miyun District	0.0008	0.21
Huairou District	0.0011	0.28
Yanqing District	0.0006	0.15
Shunyi District		6.35

Similarly, the ground transportation accessibility of PEK for 2001–2019 can be obtained. Figure 2 shows the values and trend directions.

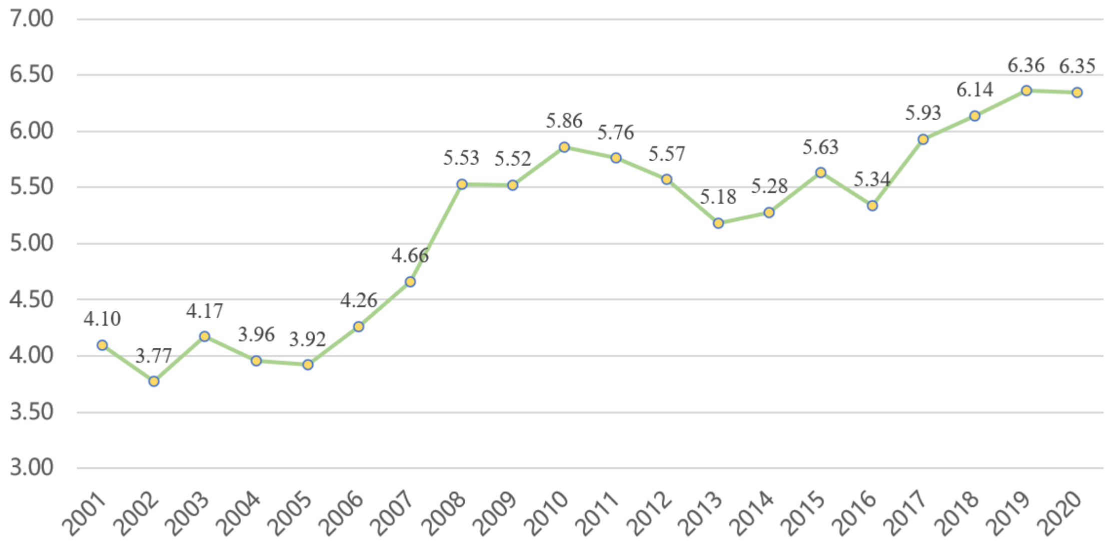

Figure 2-Trends in Ground Transportation Accessibility at PEK, 2001–2020

Figure 2 shows that before 2008, PEK's ground transportation accessibility was stable below 5, with an overall slow increase. In 2008, however, there was a significant increase, and then it continued to show an upward trend.

3) PEK Information Coverage Accessibility

Table 6 shows the annual investment in information technology construction for PEK during 2009–2020. The years 2009–2020 are the actual values, and 2001–2008 are the projected supplementary values. The amount of investment in informatization increased by about 20% year by year from 2009 to 2011 and then dropped to about 61% from 2011 to 2012. From 2013 to 2014, investment increased slightly and was relatively stable. Thereafter, except for 2014 and 2018, which were relatively flat, the increase was incremental each year, fluctuating between

16% and 66%, with the highest fluctuation occurring in 2017. Regarding annual investment in informatization from 2001 to 2008, the average annual growth rate is about 20%, with 2005–2007 reflecting the construction of Beijing Outward Bound. Thus, the calculation is based on growth rates of about 40%, 50%, and 60%.

Table 6-Raw Data for Indicators Related to the Accessibility of Information Coverage

Year	**Annual investment (million yuan)**	**Years**	**Annual investment (million yuan)**
2001	708.50	2011	7698.93
2002	850.20	2012	3640.26
2003	1020.24	2013	5770.40
2004	1224.29	2014	5269.45
2005	1469.15	2015	6630.10
2006	2056.81	2016	8282.22
2007	3085.21	2017	4903.97
2008	4936.34	2018	16170.19
2009	5923.61	2019	19109.65
2010	6627.53	2020	6212.53

Figure 3 shows the trend of information coverage accessibility in PEK.

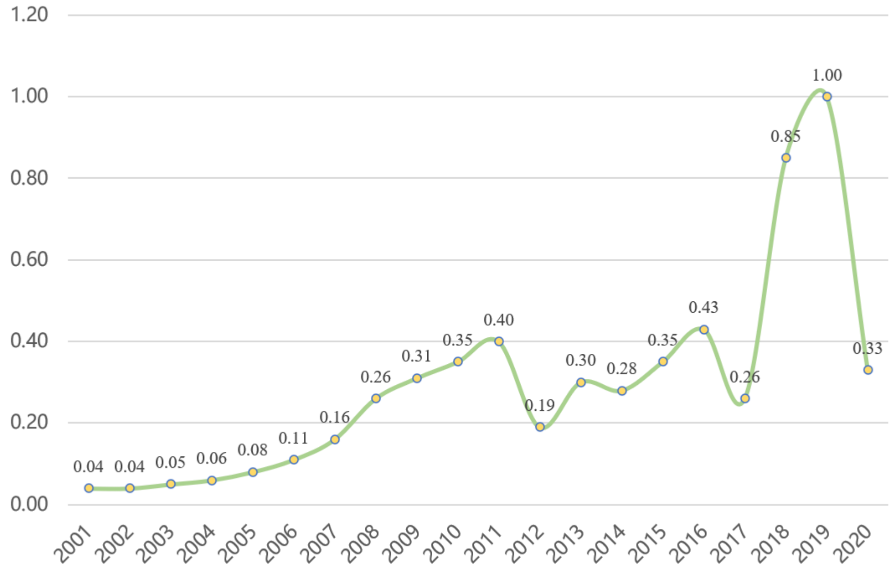

Figure 3-Trend of PEK's information Coverage Accessibility, 2001–2020

As we can see in Figure 3, the information coverage accessibility of PEK fluctuates greatly overall, with especially obvious fluctuations from 2016 to 2020.

4) Contribution of Each PEK Accessibility Type

When standardizing the raw data, the data for 2001–2020 are used as the evaluation object (i.e., $n = 20$ in Eq. (12)). The standardized indicator data are then obtained. We condensed the information using PCA to analyze the applicability of the research data. Table 7 shows the results.

Table 7-KMO Values and Bartlett's Test

KMO value		0.734
Bartlett Sphericity Check	Approximate chi-square	40.552
	df	3
	p -value	0.000

We can see in Table 7 that the KMO value is 0.734, which is greater than 0.6 and meets the requirement for PCA. The data also pass Bartlett's test of sphericity (p<0.05), indicating that the data are suitable for PCA [26]. Table 8 shows the results after PCA.

Table 8-Linear Combination Coefficients and Weighting Results

Name	**Principal component 1**	**Composite score coefficients**	**Weights**
Characteristic root	2.585	-	-
Variance explained rate	86.18%	-	-
Airline network accessibility	0.5843	0.5843	33.74%

Ground transportation accessibility	0.5902	0.5902	34.08%
Information coverage accessibility	0.5571	0.5571	32.17%

Finally, the values of β_1, β_2, and β_3 are determined to be 0.5843, 0.5902, and 0.5571, respectively.

C. Analysis of Integrated Accessibility Results

The integrated accessibility of PEK AIC can be expressed as follows:

$$A = 0.584Ac^{Air} + 0.590Ac^{Land} + 0.557Ac^{Information}. \quad (18)$$

Substituting the data for 2001–2020, we calculate the comprehensive AIC integrated accessibility of PEK. Figure 4 shows the change trend.

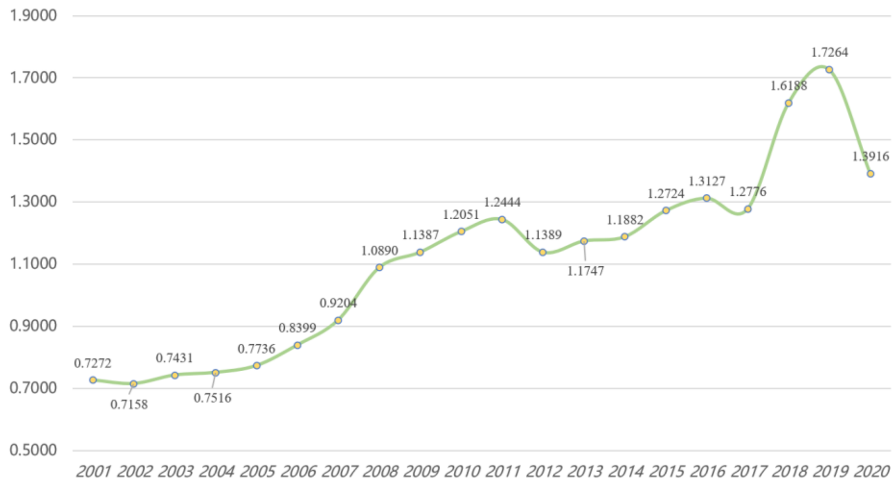

Figure 4-Trend of PEK's AIC Integrated Accessibility, 2001–2020

We can see in Figure 4 that AIC accessibility shows an overall upward trend. The overall fluctuation is obvious from 2017 to 2020 and reaches the maximum value in 2019, with 2012 as the demarcation line, showing a double life-cycle S-curve. Based on comprehensive AIC accessibility, the development of the Beijing Capital Airport Airside Economic Demonstration Zone can be divided into four stages, which is consistent with time sequence of the development of the Shunyi aerotropolis [27].

The period 1993–2001 is the embryonic stage (not reflected in Figure 4), mainly owing to the reform of the civil aviation system starting in 2002. This led to changes in the calibre of many statistics, making the data before and after less comparable; thus, the quantitative measurement of integrated accessibility in this stage is not very meaningful. In terms of practical development, however, we can find that in 1993, the airport's passenger throughput was 10 million, and the "Capital Airport Highway" was opened to traffic. At the same time, an airport industrial zone was planned on the west side of the capital airport, which started to rapidly develop the area's economy, marking the germination of airport–industry accessibility. However, the development level of the new Shunyi aerotropolis was still low, and overall AIC integrated accessibility was low.

The period 2002–2011 saw rapid development, and AIC integrated accessibility increased at a high rate, reaching 1.2444 in 2011. After 2002, the Second Airport Expressway, Beijing–Chengdu Expressway, and Beijing–Pingdu Expressway opened in succession, improving ground transportation accessibility. Also, investment in the informatization of the Capital Airport increased, and the overall accessibility of information coverage showed an upward trend. The "Beijing Urban Overall Planning (2004–2020)" defined the functional positioning of the Shunyi aerotropolis, leading to the improvement and development of the "city" aspect of the AIC. In 2006, the Shunyi Airport Economic Zone was identified by the "Beijing Eleventh Five-Year Plan for National Economic and Social Development" as one of the six high-end industrial functional zones that Beijing will focus on during the "Eleventh Five-Year Plan" period. AIC was further developed with the construction and commissioning of the T3 Terminal Building.

The period 2012–2019 is the stage of gradual moulding. In 2012, development entered a new cycle, and AIC integrated accessibility declined compared with the previous year. After that, however, AIC integrated accessibility rose year by year, reaching a peak in 2019. In 2014, the Beijing Airside Economic Core Zone was established, integrating the three functional zones of the former Logistics Base, Airport Development Zone, and Guomen Business Zone. A new strategy of creating a "core zone of international aviation centre with port–city integration" was put forward at the same time. Although investment in airport information technology decreased in 2017, it significantly increased in 2018 and 2019, resulting in a downward and then upward trend in AIC integrated accessibility. At this stage, the number of destination airports, flight density, and mileage of PEK was increasing, and the accessibility of the air route network improved. A transportation system supported by urban railways, highways, and expressways was formed in the vicinity of PEK, with a total of six expressways around the airport (i.e., Airport Expressway, Airport North Expressway, Beijing–Pingxiang Expressway, Second Expressway of the Airport, Sixth Ring Road, Beijing–Chengxiang Expressway), covering the downtown area of Beijing as well as the surrounding area. Thus, an AIC integrated development trend appeared.

Beyond 2020 is the innovation stage of "seeking change in the midst of change." Because of COVID-19, AIC integrated accessibility was reduced after 2020. The opening of Beijing Daxing International Airport in October 2019 has furthered the establishment of an international transportation hub, driving the concentration of high-end airside industries through infrastructure construction and broadening the radius of the north and south of the Beijing aerotropolis. In this way, the well-connected route network, fast and convenient ground transportation, and comprehensive and efficient information coverage will boost Beijing's economic development and further enhance its international status and influence. Beijing's aerotropolis has now entered a new development cycle of "two ports, two cities, and one industrial belt."

The comprehensive AIC integrated accessibility measurement provides a quantitative basis for determining the development stages of aerotropolises. This provides support from an accessibility perspective for the high-quality development of these aerotropolises.

V. Conclusion

This study constructs an aerotropolis-focused AIC integrated accessibility measurement model based on external radiation, internal connection, and information interaction. Using big data from 2001–2020 of PEK, we perform empirical calculations to explore the relationship between aerotropolis construction and AIC integrated accessibility. Regarding traditional airport accessibility calculation, the comprehensive AIC integrated accessibility measurement introduces information coverage accessibility, highlighting accessibility in the information age. It also proved the feasibility of using big data for AIC integrated accessibility measurement.

The case analysis of PEK shows that under the combined effects of airport route accessibility, airport ground transportation accessibility, and airport information coverage accessibility, AIC development in PEK's airside economic demonstration zone can be classified—with 2002, 2012, and 2020 as the node points—into the stages of sprouting, rapid development, gradual formation, and innovation. Focusing on AIC integrated accessibility can help us to grasp the speed, process, and quality of the development of aerotropolises. Obviously, the AIC integrated accessibility can indeed guide the scientific development of an aerotropolis.

In this paper, the integrated accessibility measurement from the perspective of AIC system of aerotropolis fills the research gap in this part and can provide better support for the high-quality development of aerotropolis. The integrated accessibility measurement of AIC provides a new tool for the development stage of aerotropolis, and provides a key hand for the development of AIC system from the perspective of integrated accessibility. Based on the above research, this paper puts forward the following suggestions for improving the integrated accessibility of the capital airport:

1) *Enhance the Accessibility of the Airport'S Nodal Route Network:* strengthen cooperation with domestic and foreign airlines to increase the number and frequency of routes and flight density; introduce more international routes, especially those connecting major economies and tourist hotspots, so as to enhance the airport's international influence; optimize flight schedules, rationalize flight take-off and landing times, and reduce flight delays and waiting times; strengthen the connection with ground transportation; and provide convenient public transportation, such as subways and buses, to facilitate passengers' access to their destinations from the airport.

2) *Scientific Layout of Airside-Preferred Enterprises:* according to the resource endowment and industrial characteristics of the areas around airports, targeted introduction and development of airside-preferred enterprises, such as aviation maintenance, logistics and warehousing, and aviation foodstuffs, etc.; provision of preferential policies and facilitating conditions to attract enterprises to settle in the areas around airports to form the effect of industrial clusters; and enhancement of cooperation with enterprises, provision of customized services and support, and assistance to enterprises to enhance their competitiveness and innovation capacity.

3) *Optimize the Network Structure of the New Airport City Based on the Internet:* build a perfect information platform to provide real-time flight information, baggage tracking, parking lot inquiries and other services, so as to make it convenient for travellers to obtain the information they need; support the development of the digital

economy, cultivate and attract Internet enterprises to move into the new airport city, promote innovation and entrepreneurship and technology application, and enhance the city's economic competitiveness.

DATA AVAILABILITY

The data that has been used is confidential.

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NOTES ON CONTRIBUTOR(S)

SHEN Danyang: Supervision, Conceptualization, Methodology, Funding acquisition, Writing-Reviewing and Editing, LIU Ximeng: Data curation, Writing- Original draft preparation. LI Xiudi: Writing- Reviewing and Editing.

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