A Research on the Optimization of Xinjiang Air Route Network from the Perspective of Spatial Interaction Intensity

Guodong Li[1], Lingli Tan[2*], Hongyu Yuan[2], Qingqing Duan[2], Yiming Wang[2], Xinyu Wang[2], Shubo Gao[2], Xinying Zhang[3*], Asim Khan[4]

[1] College of Economics and Management, Civil Aviation University of China /Civil Aviation of China Research Center for High Quality Development, Tianjin, China

[2]College of Transportation Science and Engineering, Civil Aviation University of China, Tianjin, China

[3]Management College, Ocean University of China, Qingdao, China

[4]Department of Basic Sciences and Humanities, National University of Sciences and Technology, Islamabad, Pakistan; masim.maths@gmail.com

*Corresponding Authors: 2679268409@qq.com; la2017zxy@163.com

DOI: https://doi.org/10.30212/JITI.202402.006

ABSTRACT

The scholarly examination of spatial interactions between Xinjiang and world-class airport clusters, based on aviation transportation, is essential for harnessing the region's role as a pivotal contributor to high-quality economic development and fostering regional coordinated development, thereby optimizing Xinjiang's air route network. This study employs an enhanced gravity model, utilizing flight frequencies, to quantitatively evaluate the spatial interactions between Xinjiang's airport regions and cities within China's world-class airport clusters from 2015 to 2019, thus facilitating the scientific design of their air route networks. The findings reveal several key points: (1)The overall strength of spatial interactions between Xinjiang and the cities hosting four world-class airport clusters demonstrates a trend of "steady longitudinal increase with lateral polarization."(2)Urumqi's spatial interaction strength with international aviation hub cities and regional aviation hub cities in the Beijing-Tianjin-Hebei, Chengdu-Chongqing, Yangtze River Delta, and Guangdong-Hong Kong-Macao Greater Bay Area displays a "hierarchical differentiation pattern". (3)The total strength of spatial interactions between Xinjiang's branch airports and the four major world-class airport clusters demonstrates a "weak overall longitudinal growth with lateral polarization" trend. A comprehensive analysis of the spatial interaction between Xinjiang and world-class airport hub cities suggests that Xinjiang should fully leverage the aviation transport industry to strengthen economic ties with the four major world-class airport hub cities. It is recommended to deepen aviation transport connections with the Yangtze River Delta Airport Cluster and the Guangdong-Hong Kong-Macao Greater Bay Area Airport Cluster, and to sustainably consolidate aviation market cooperation with the Beijing-Tianjin-Hebei Airport Cluster and the Chengdu-Chongqing Airport Cluster.

Keywords: Xinjiang, World-class airport cluster, Spatial interaction, Air transportation

1. Introduction

The regional coordinated development strategy is a crucial approach to tackle the significant challenges of imbalance and inadequacy in China's development [1]. The Central Committee of the Communist Party of China has consistently emphasized the importance of regional coordinated development. Since the 18th National Congress, a series of pivotal decisions have been made concerning regional coordinated development [2]. However, there still exist development disparities among China's eastern, central, and western regions, particularly regarding infrastructure and public service facilities in ethnic and border areas, which remain underdeveloped [3]. Specifically, substantial disparities persist in the gross domestic product (GDP) of western China compared to other regions [4]. Hence, expediting the implementation of the regional coordinated development strategy, enhancing inter-regional assistance mechanisms, and ensuring that these regions, together with the entire nation, achieve the goal of building a moderately prosperous society in all aspects is essential, thus fostering the coordinated development of all regions [5].

Enhancing external connectivity is pivotal for achieving coordinated development between Xinjiang and regions beyond its borders. Positioned at China's northwest border, Xinjiang exhibits a lower level of economic development, with per capita GDP and urbanization rates significantly lagging behind the national average [6]. Moreover, expanding the network of connections between Xinjiang and external regions can efficiently surmount geographical constraints, bolster inter-regional communication and collaboration [7], and markedly diminish transaction costs associated with factors like information, capital, and talent. This fosters the effective allocation of economic resources across regions, thereby establishing conducive conditions for regional coordinated development [8].

The aviation transportation network plays a crucial role in promoting coordinated development between Xinjiang and regions beyond its borders. Strengthening aviation transportation links with the four major world-class airport clusters emerges as a pivotal pathway for realizing Xinjiang's economic and social development. Xinjiang, characterized by complex terrain and a sparse road network, experiences a generally low level of accessibility [9]. However, aviation transportation, with its speed and adaptability, stands out as a key means to enhance Xinjiang's accessibility [10]. Scholars argue that optimizing inter-regional transportation speed can effectively reduce spatiotemporal distances between cities, leading to a "space compression effect" [11]. Aviation transportation serves as a rapid linkage channel for long-distance and high-level core cities [12]. World-class airport clusters serve as the core of the airport network, acting as a "power source" for the country's high-quality development and serving as major gateways for world-class city clusters to connect globally [13]. Therefore, the scientific design of Xinjiang's air route network with these major clusters has become a significant focus for the region's economic development.

Both domestic and international scholars have conducted numerous studies on spatial interactions. Ullman (1957) proposed the theory of spatial interaction, suggesting that cities and their adjacent regions are symbiotic [14]. Taffe (1962) investigated the air transportation network between cities in the United States, revealing a positive correlation between the strength of economic connections and the population size of cities, and an inverse relationship with the square of the distance between cities. This finding further confirmed the dominant position of central cities in urban networks [15]. Domestic scholars have primarily utilized gravity models to explore city interactions, spatial patterns [16], economic linkages between cities [17], and spatial layout analysis of central towns in regions [18]. As element flows between cities become increasingly diverse and complex, scholars have adapted the gravity model by considering factors such as city quality [19], intercity distances [20], and gravity coefficients [21]. However, there has been limited application of the gravity model based on flight frequencies. Currently, there is relatively limited literature focusing on research in the Xinjiang region, with only a small number of studies exploring Xinjiang's aviation transportation. Among these studies, there is even less literature addressing the spatial interaction intensity between Xinjiang and world-class airport hub cities.

Therefore, this study quantitatively calculates the spatial interactions between Xinjiang and 42 cities in China's four major world-class airport clusters from 2015 to 2019 using an improved gravity model based on flight frequencies. Subsequently, it optimizes the air route network to enhance regional economic layout, promote regional coordinated development, and lay the groundwork for future air route network optimizations.

2. Research Design

2.1 Selection of Research Objects and Data Sources

Given the significant impact of the COVID-19 outbreak on China's aviation transportation industry in early 2020, this study focuses on the period from 2015 to 2019. Data on flight routes and frequencies are extracted from the "China Civil Aviation Statistical Yearbook" spanning from 2016 to 2020, while regional gross domestic product (GDP) and population size are sourced from corresponding years of the "China Urban Statistical Yearbook." In 2019, Xinjiang operated 21 civil aviation transportation airports, including Urumqi Diwopu International Airport. Additionally, referring to policy documents such as the "14th Five-Year Plan for Civil Aviation Development," China's four major world-class airport clusters are identified as the Beijing-Tianjin-Hebei Airport Cluster, Chengdu-Chongqing Airport Cluster, Yangtze River Delta Airport Cluster, and Guangdong-

Hong Kong-Macao Greater Bay Area Airport Cluster. Note that due to differences in civil aviation management rules for Hong Kong, Macao, and other special administrative regions, this study excludes research on the aviation transportation market of these two special administrative regions. Altogether, the study encompasses a total of 42 cities and 47 airports.

2.2 Measurement of The Strength of Spatial Interactions

2.2.1 Gravitational modeling and modifications

Spatial interaction is a complex and crucial concept involving the exchange and linkage of material, energy, people, funds, and information among cities, regions, and nations [22]. Research on spatial interaction mainly focuses on two aspects: interaction intensity and interaction direction [23]. Gravity models, as one of the models describing spatial interaction, have been widely applied in the fields of regional economics, economic geography, and international trade [24]. In this study, we employ a gravity model and draw on the research findings of previous scholars [25], using two indicators, namely Gross Domestic Product (GDP) and end-of-year population (POP), which best reflect the comprehensive strength of cities, to determine urban quality. Recognizing that flight frequency metrics in aviation transportation can offer a more scientifically accurate depiction of spatial interaction between two points, this study develops an "Enhanced Gravity Model based on Flight Frequencies." The formula is outlined below:

$$R_i = \sum_{i=1}^{n-1} R_{ij} \quad \text{[Formular 1]}$$

$$R_{ij} = N_{ij} * \frac{\sqrt{P_i} * \sqrt{P_j}}{T_{ij} * T_{ij}} \quad \text{[Formular 2]}$$

$$P_j = \sqrt{GDP_j * POP_j} \quad \text{[Formular 3]}$$

R_i: the total spatial interaction intensity of airport city i within Xinjiang, where a larger R_i indicates a stronger spatial interaction between city i and cities in the world-class airport cluster.

R_{ij}: the spatial interaction strength between airport city i in Xinjiang (i=1,2,3,4......21) and city j in the world-class airport cluster (j=1,2,3.......42). A larger R_{ij} indicates a higher economic linkage intensity between city i and city j.

N_{ij}: the sum of flight frequencies for departures, transfers, and arrivals between airport city i in Xinjiang and city j in the world-class airport cluster each year. If there are no direct or connecting flights between two cities, the flight frequency is assigned a value of 1.

P_j: the quality of city j in the world-class city cluster, reflecting the economic radiance and attractiveness of city j. This study selects regional gross domestic product (GDP, in billion yuan) and population size (POP, in ten thousand people) as quality data.

T_{ij}: the shortest air travel time (in minutes) from airport city i in Xinjiang to city j in the four major world-class airport clusters: (1) If it belongs to a direct or connecting flight, the Great Circle Mapper is used to find the air route distance between airports, and the shortest travel time is calculated using the design cruising speed of the Boeing 747 as the airspeed (according to civil aviation standards, the transfer time for connecting flights is 45 minutes). (2) If there are no direct flights, MATLAB software is used to program and calculate the required shortest flight time.

3. Empirical Results and Analysis

3.1 Evaluation Results and Analysis of Spatial Interaction Intensity between Xinjiang and Cities in Four Major World-Class Airport Clusters

Table 1 presents the evaluation results of spatial interaction intensity between Xinjiang and cities in the four major world-class airport clusters.

Table 1. presents the evaluation results of spatial interaction intensity between Xinjiang and cities in the four major world-class airport clusters from 2015 to 2019

World-class airport cluster/year	2015	2016	2017	2018	2019
Beijing-Tianjin-Hebei airport cluster	296.60	317.06	352.81	418.77	465.56
Chengdu-Chongqing airport cluster	255.40	273.25	285.88	351.01	394.12
Guangdong-Hong Kong-Macao	172.70	195.65	235.09	285.01	345.28
Guangdong-Hong Kong-Macao Greater Bay Area airport cluster	59.52	68.42	90.01	112.60	110.38
Total	784.22	854.38	963.79	1167.39	1315.34

Source: By authors.

Referring to Table 1, it is evident that the spatial interaction intensity between Xinjiang and cities in the four major world-class airport clusters follows a pattern of "vertical enhancement with horizontal polarization." Specifically:

(1) The spatial interaction intensity between Xinjiang and the four major world-class airport clusters demonstrates a trend of "steady vertical growth".

The spatial interaction intensity between Xinjiang and the Beijing-Tianjin-Hebei Airport Cluster, Chengdu-Chongqing Airport Cluster, Yangtze River Delta Airport Cluster, and Guangdong-Hong Kong-Macao Greater Bay Area Airport Cluster increased from 296.60, 255.45, 172.70, and 59.52 in 2015 to 465.56, 394.12, 345.28, and 110.38 respectively in 2019. This indicates the significant role of the aviation transportation industry in enhancing intercity interaction and altering regional spatial structures. It also demonstrates that economically robust regions like the Beijing-Tianjin-Hebei area can effectively utilize aviation transportation to stimulate economic development in regions like Xinjiang, thereby facilitating the implementation of national strategies for regional coordinated development.

(2) The overall spatial interaction intensity between Xinjiang and the four major world-class airport clusters demonstrates a trend of "horizontal polarization."

The spatial interaction intensity between Xinjiang and the four major world-class airport clusters exhibits significant disparities, indicating pronounced differentiation. In 2015, the spatial interaction intensity between Xinjiang and the Beijing-Tianjin-Hebei Airport Cluster was 1.16 times that of the Chengdu-Chongqing Airport Cluster, 1.72 times that of the Yangtze River Delta Airport Cluster, and 4.98 times that of the Guangdong-Hong Kong-Macao Greater Bay Area Airport Cluster. By 2019, these ratios had changed to 1.18, 1.35, and 4.22 respectively, illustrating a marked "polarization pattern" in the utilization of aviation transportation to stimulate overall economic development in Xinjiang by the Beijing-Tianjin-Hebei region, the Chengdu-Chongqing region, the Yangtze River Delta region, and the Guangdong-Hong Kong-Macao Greater Bay Area region. This also suggests that the significant differences in spatial distances between the four major world-class airport clusters and Xinjiang create objective realities, leading to notable disparities in the role of aviation transportation in promoting the spatial interaction intensity between the airport clusters and Xinjiang.

3.2 Evaluation and Analysis of Spatial Interaction Intensity between Urumqi and Four Major World-Class Airport Hub Cities

According to Table 2, the results of the evaluation of spatial interaction strength between Urumqi and the four world-class airport cluster cities can be seen.

Table 2. Evaluation results of spatial interaction strength between Urumqi and four world-class airport cluster cities from 2015 to 2019

World-class airport cluster/year	2015	2016	2017	2018	2019
Beijing-Tianjin-Hebei airport cluster	280.25	298.11	329.70	388.69	415.17
Chengdu-Chongqing airport cluster	249.51	266.53	278.70	336.15	360.73
Guangdong-Hong Kong-Macao	165.67	187.81	225.71	276.83	321.60
Guangdong-Hong Kong-Macao Greater Bay Area airport cluster	56.48	64.93	85.66	107.42	103.29

Source: By authors.

(1) The overall spatial interaction intensity between Urumqi and the four major world-class airport cluster cities exhibits a trend of "steady vertical growth."

The spatial interaction intensity between Urumqi and the cities in the Beijing-Tianjin-Hebei Airport Cluster, Chengdu-Chongqing Airport Cluster, Yangtze River Delta Airport Cluster, and Guangdong-Hong Kong-Macao Greater Bay Area Airport Cluster increased from 280.25, 249.51, 165.67, and 56.48 in 2015 to 415.17, 360.73, 321.60, and 103.29 respectively in 2019. This underscores the growing significance of aviation transportation in bolstering economic interconnections between Urumqi and cities in the world airport clusters, thus fostering economic interactions. Furthermore, it highlights Urumqi's capacity to effectively leverage the radiating effect of economically robust regions such as the Beijing-Tianjin-Hebei area through aviation transportation to promote local economic development, thereby facilitating the implementation of the national strategy for regional coordinated development.

(2) The overall spatial interaction intensity between Urumqi and the cities in the four major world-class airport clusters demonstrates a trend of "horizontal polarization."

In 2015, the spatial interaction intensity between Urumqi and the cities in the Beijing-Tianjin-Hebei airport cluster was respectively 1.12 times, 1.69 times, and 4.96 times that of the Chengdu-Chongqing airport cluster, the Yangtze River Delta airport cluster, and the Guangdong-Hong Kong-Macao Greater Bay Area airport cluster. By 2019, these ratios had changed to 1.15 times, 1.29 times, and 4.01 times respectively. This indicates a significant "polarization pattern" in Urumqi's utilization of the radiating effect of the Beijing-Tianjin-Hebei region, the Chengdu-Chongqing region, the Yangtze River Delta region, and the Guangdong-Hong Kong-Macao Greater Bay Area through aviation transportation to drive economic development. It also demonstrates that due to the necessity for aviation transportation to operate within a certain spatial distance, the objective reality of the spatial distance difference between Urumqi and the four major world-class airport cluster cities is a significant factor contributing to the notable differences in the intensity of spatial interaction between Urumqi and the airport clusters.

3.3 The Evaluation Results and Analysis of Spatial Interaction Intensity between Urumqi and the Four Major World-Class Airport Hub Cities

According to Table 3, the evaluation results of spatial interaction intensity between Urumqi and the four major world-class airport hub cities are presented.

Table 3. Evaluation results of spatial interaction strength between Urumqi and hub cities of four world-class airport clusters from 2015 to 2019

World-class airport cluster/year		2015	2016	2017	2018	2019
Beijing-Tianjin-Hebei airport cluster	Beijing	242.96	251.56	279.58	318.16	355.01
	Tianjin	29.85	38.56	39.36	50.12	39.48
	Shijiazhuang	7.42	7.98	10.75	20.40	20.67
Chengdu-Chongqing airport cluster	Chendu	101.47	112.15	118.40	174.21	185.24
	Chongqing	146.43	150.85	157.48	156.33	167.65
Guangdong-Hong Kong-Macao	Shanghai	106.31	113.75	139.60	147.29	167.39
	Hangzhou	29.27	35.85	41.78	57.27	77.99
	Nanjing	20.99	25.51	31.24	38.95	37.76

	Wenzhou	3.98	4.24	3.95	5.09	5.63
	Ningbo	0.34	1.87	2.24	6.28	6.65
	Hefei	3.47	4.21	3.59	13.42	14.77
Guangdong-Hong Kong-Macao Greater Bay Area airport cluster	Guangzhou	34.50	43.39	58.25	72.19	63.88
	Shenzhen	21.97	21.25	26.90	33.98	37.88

Note: In view of the polarization of spatial interaction degree between Urumqi and the cities of the world-class airport clusters, this study only presents the results of spatial interaction intensity between Urumqi and the cities of international hub airports and regional hub airports in the four world-class airport clusters (the same below).

(1) The spatial interaction intensity between Urumqi and the aviation hub cities in the Beijing-Tianjin-Hebei region as a whole exhibits a trend of "vertical overall enhancement, with one core and two secondary hubs".

The spatial interaction intensity between Urumqi and the Beijing-Tianjin-Hebei airport cluster exhibits a steadily increasing trend. Specifically, the spatial interaction intensity between Urumqi and Beijing, Tianjin, and Shijiazhuang increased from 242.96, 29.85, and 7.42 in 2015 to 355.01, 39.48, and 20.67 respectively in 2019. In comparison, Beijing demonstrates the highest spatial interaction intensity among the international and regional aviation hub cities within the Beijing-Tianjin-Hebei airport cluster, significantly surpassing other cities. It emerges as the "core city" with the strongest ability to leverage aviation transport to drive the economy of Urumqi within the Beijing-Tianjin-Hebei airport cluster.

(2) The spatial interaction intensity between Urumqi and the aviation hub cities within the Chengdu-Chongqing airport cluster demonstrates an overall trend of "vertical overall enhancement, with dual cores predominating".

The spatial interaction intensity between Urumqi and the aviation hub cities within the Chengdu-Chongqing airport cluster demonstrates a steady upward trend. Specifically, the spatial interaction intensity between Urumqi and Chengdu increased from 101.47 in 2015 to 185.24 in 2019, while the interaction intensity with Chongqing increased from 146.43 in 2015 to 167.65 in 2019. Analysis reveals a consistent increase in intercity interaction between Urumqi and Chengdu, Chongqing from 2015 to 2019, while the interaction intensity with other cities in the Chengdu-Chongqing region remains low.

(3) The spatial interaction intensity between Urumqi and the aviation hub cities within the Yangtze River Delta airport cluster demonstrates an overall trend of "vertical enhancement, with one core, two sub-centers, and multiple scattered points".

The spatial interaction intensity between Urumqi and the aviation hub cities within the Yangtze River Delta cluster exhibits a steady increase. Specifically, the spatial interaction intensity between Urumqi and Shanghai, Hangzhou, Nanjing, Wenzhou, Ningbo, and Hefei increased from 106.31, 29.27, 20.99, 3.98, 0.34, 3.47 in 2015 to 167.39, 77.99, 37.76, 5.63, 6.65, 14.77 in 2019, respectively.

Upon comparison, Shanghai emerges with the highest spatial interaction intensity among the international aviation hub cities and regional aviation hub cities in the Yangtze River Delta cluster, significantly surpassing other cities. It becomes the "core city" with the strongest economic driving force for Urumqi through aviation transport. The designation of "two sub-centers" applies to Hangzhou and Nanjing, with the interaction value of Urumqi being 2.05 times higher with Hangzhou compared to Nanjing, yet both are markedly lower than Shanghai. The category of "multiple scattered points" encompasses Wenzhou, Ningbo, and Hefei, where the interaction intensity with Urumqi is relatively low, showing minimal differences among them.

(4) The spatial interaction intensity between Urumqi and the aviation hub cities of the Guangdong-Hong Kong-Macao Greater Bay Area demonstrates an overall trend of "vertical enhancement with one core and one main center".

The spatial interaction intensity between Urumqi and the aviation hub cities within the Guangdong-Hong Kong-Macao Greater Bay Area has exhibited a steady increase. Specifically, the spatial interaction intensity between Urumqi and Guangzhou and Shenzhen rose from 34.5 and 21.97 in 2015 to 63.88 and 37.88 in 2019, respectively. Upon analysis, it becomes apparent that the average spatial interaction intensity between Urumqi and Guangzhou and Shenzhen stands at 41.42. Notably, Urumqi demonstrates the highest intercity interaction intensity with Guangzhou among the cities within the Greater Bay Area aviation hub, with an intercity interaction intensity of 72.19 in 2018, significantly surpassing other cities. Furthermore, the intercity interaction intensity between Urumqi and Shenzhen ranks second among the cities in the Greater Bay Area aviation hub, with an intercity interaction intensity of 37.88 in 2019.

3.4 The Evaluation Results and Analysis of Spatial Interaction Intensity between Xinjiang Feeder Airports and China's Four Major World-Class Airport Clusters

Table 4 presents the evaluation results of spatial interaction intensity between the Xinjiang feeder airports area and the four major world-class airport clusters in China.

Table 4. Evaluation results of spatial interaction strength between Xinjiang regional feeder airports and four world-class airport clusters from 2015 to 2019

	World-class airport cluster/year	2015	2016	2017	2018	2019		2015	2016	2017	2018	2019
Kashgar	Beijing-Tianjin-Hebei airport cluster	0.01	0.01	0.01	0.01	6.82	Ili	5.65	7.61	6.54	7.00	10.83
	Chengdu-Chongqing airport cluster	5.65	5.84	5.83	10.05	15.38		0.01	0.01	0.01	0.02	3.28
	Guangdong-Hong	4.29	4.53	5.22	5.63	9.43		0.02	0.02	0.02	0.02	10.09

	Kong-Macao											
	Guangdong-Hong Kong-Macao Greater Bay Area airport cluster	2.95	3.45	4.02	4.36	4.78		0.01	0.01	0.01	0.01	0.01
	Total	12.9	13.83	15.08	20.05	36.41		5.69	7.65	6.58	7.05	24.21
Bazhou	Beijing-Tianjin-Hebei airport cluster	5.60	3.00	5.34	8.81	12.80	Aksu	1.61	1.82	1.63	3.51	8.44
	Chengdu-Chongqing airport cluster	0.02	0.02	0.02	0.02	0.03		0.01	0.02	0.02	0.02	2.80
	Guangdong-Hong Kong-Macao	0.02	0.02	0.01	0.02	0.02		2.15	2.23	1.62	0.24	0.37
	Guangdong-Hong Kong-Macao Greater Bay Area airport cluster	0.01	0.01	0.01	0.01	0.01		0.01	0.01	0.01	0.01	0.01
	Total	5.65	3.05	5.38	8.86	12.86		3.78	4.08	3.28	3.78	11.62
Hami	Beijing-Tianjin-Hebei airport cluster	1.81	2.58	3.77	4.23	3.44	Hotan	0.54	1.20	1.93	2.94	3.41
	Chengdu-Chongqing airport cluster	0.00	0.00	0.22	1.81	2.22		0.00	0.00	0.00	0.78	4.62
	Guangdong-Hong Kong-Macao	0.12	0.01	0.58	0.63	0.73		0.41	0.52	0.63	0.17	1.18
	Guangdong-Hong Kong-Macao Greater Bay Area airport cluster	0.06	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.35
	Total	1.99	2.59	4.57	6.67	6.39		0.95	1.72	2.56	3.89	9.56
Karamay	Beijing-Tianjin-Hebei airport cluster	1.07	1.69	2.13	2.56	3.07	Turpan	0.06	0.79	1.14	0.28	1.12
	Chengdu-Chongqing airport cluster	0.16	0.80	0.55	0.01	1.42		0.00	0.00	0.00	0.21	2.16
	Guangdong-Hong Kong-Macao	0.01	0.22	0.61	1.09	1.02		0.01	0.27	0.67	0.27	0.80
	Guangdong-Hong	0.00	0.00	0.16	0.52	0.92		0.00	0.00	0.13	0.06	0.63

	Kong-Macao Greater Bay Area airport cluster											
	Total	1.24	2.71	3.45	4.18	6.43		0.07	1.06	1.94	0.82	4.71
Shihezi	Beijing-Tianjin-Hebei airport cluster	——	0.23	0.62	0.72	0.45	Altay	0.00	0.00	0.00	0.00	0.00
	Chengdu-Chongqing airport cluster	——	0.00	0.50	0.98	0.27		0.00	0.00	0.00	0.94	1.09
	Guangdong-Hong Kong-Macao	——	0.00	0.00	0.01	0.01		0.00	0.00	0.00	0.08	0.01
	Guangdong-Hong Kong-Macao Greater Bay Area airport cluster	——	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.19	0.36
	Total	——	0.23	1.12	1.71	0.73		0.00	0.00	0.00	1.21	1.46
Tacheng	Beijing-Tianjin-Hebei airport cluster	0.01	0.01	0.01	0.01	0.01	Bozhou	0.00	0.00	0.00	0.00	0.00
	Chengdu-Chongqing airport cluster	0.01	0.01	0.00	0.01	0.01		0.00	0.00	0.00	0.00	0.00
	Guangdong-Hong Kong-Macao	0.01	0.01	0.01	0.01	0.01		0.00	0.00	0.00	0.00	0.01
	Guangdong-Hong Kong-Macao Greater Bay Area airport cluster	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00
	Total	0.03	0.03	0.02	0.03	0.03		0.00	0.00	0.00	0.00	0.01
Tumxuk	Beijing-Tianjin-Hebei airport cluster	——	——	——	——	0.00						
	Chengdu-Chongqing airport cluster	——	——	——	——	0.00						
	Guangdong-Hong Kong-Macao	——	——	——	——	0.00						
	Guangdong-Hong Kong-Macao Greater Bay Area	——	——	——	——	0.00						

	airport cluster					
	Total	——	——	——	——	0.00

Source: By authors.

(1) The overall spatial interaction intensity between the Xinjiang feeder airport area and the four major world-class airport clusters shows a trend of "slow longitudinal growth".

From the perspective of spatial interaction intensity between the Xinjiang feeder airport area and the four major world-class airport clusters, distinct regional differentiation is evident. The Xinjiang feeder airport area can be categorized based on their total interaction intensity. Firstly, mature feeder airport areas like Kashgar, Ili, Bazhou, and Aksu have exhibited growth in spatial interaction intensity with the four major world-class airport clusters from 2015 to 2019, increasing respectively from 12.9, 5.69, 5.65, and 3.78 to 36.41, 24.21, 12.86, and 11.62. Although these feeder airport areas have seen gradual economic radiation effects driven by the four major world-class airport clusters through aviation transportation, the overall growth rate is relatively modest. Secondly, feeder airport areas represented by Hami, Hotan, Karamay, Turpan, Altay, Tacheng, and Bortala also experienced a slight increase in spatial interaction intensity with the four major world-class airport clusters during the same period, rising from 1.99, 0.95, 1.24, 0.07, 0, 0.03, and 0 to 6.39, 9.56, 6.43, 4.71, 1.46, 0.03, and 0.01 respectively, indicating minimal growth. Lastly, areas like Shihezi (where Shihezi Huayuan Airport opened on December 26, 2015) and Tumxuk (where Tumxuk Tangwangcheng Airport opened on December 26, 2018) serve the Xinjiang Production and Construction Corps and have relatively recent opening times. The spatial interaction intensity between Shihezi and the four major world-class airport cluster cities shows minimal growth, while there is no interaction between Tumxuk and the four major world-class airport cluster cities due to the absence of scheduled flights between them.

(2) The spatial interaction intensity between the feeder airport areas in Xinjiang and the four major world-class airport clusters demonstrates a pattern of "horizontal bi-level differentiation".

The interaction intensity between the feeder airport areas in Xinjiang and the four major world-class airport clusters reveals a distinct pattern of "horizontal bipolarization." Regions such as Kashgar, Ili, Bazhou, and Aksu demonstrate a notable polarization in spatial interaction intensity with the cities within these airport clusters. For instance, Bazhou showcases a stark contrast in interaction intensity between the Beijing-Tianjin-Hebei airport cluster, registering at 12.80 in 2019, and the Guangdong-Hong Kong-Macao cluster, which was merely 0.01. This discrepancy underscores a significant divide, emphasizing the pronounced bipolarization.

4. Results and Discussion

This study utilizes data from 2015 to 2019 to analyze the interaction between Xinjiang's airport cities and China's four major world-class airport clusters. An improved gravity model based on flight frequency is employed to calculate the spatial interaction intensity between them. The empirical results show that: (1) the spatial interaction intensity between Xinjiang and the four world-class airport clusters shows the characteristics of a "steady increase in the vertical direction and polarization in the horizontal direction". (2) The spatial interaction intensity between Urumqi and the cities of the four world-class airport clusters as a whole shows "steady growth in the vertical direction and polarization in the horizontal direction". (3) The spatial interaction intensity between Urumqi and the cities in China's four world-class airport clusters shows a "gradient differentiation pattern", i.e., the spatial interaction intensity between Urumqi and the cities in the Beijing-Tianjin-Hebei Airport Cluster, the Chengdu-Chongqing Airport Cluster, the Yangtze River Delta Airport Cluster, the Guangdong-Hong Kong-Macao Bay Area Airport Cluster and the cities in the Beijing-Tianjin-Hebei Airport Cluster respectively shows the following pattern "a core and two vice", "dual core is the main", "a core and two vice multi-scattered points", "a core and a main" situation. (4) The spatial interaction between Xinjiang's feeder airport cities and China's four world-class airport clusters shows "weak overall growth vertically and polarization horizontally".

Drawing from empirical research and data analysis, and considering the evolving trends in China's economic and social high-quality development, as well as the specific challenges faced by Xinjiang's economic growth, the following policy recommendations are proposed to better harness the comparative advantages of air transportation for driving economic development in regions experiencing high-quality economic growth and to optimize Xinjiang's air route network to promote high-quality economic development:

Maximizing Aviation Industry Leverage: Xinjiang should capitalize on the aviation industry to bolster economic connections with the four major world-class airport cluster cities and fully exploit the synergistic effects of regions like Beijing-Tianjin-Hebei. Given that civil aviation serves as a vital conduit for Xinjiang's integration with leading economic regions like Beijing-Tianjin-Hebei, efforts should focus on strengthening aviation market links with these clusters, deepening aviation transport connections with the Yangtze River Delta and the Guangdong-Hong Kong-Macao Greater Bay Area, while also reinforcing aviation market cooperation with the Beijing-Tianjin-Hebei and Chengdu-Chongqing airport clusters.

Developing Differentiated Aviation Transport Networks: Urumqi should develop a tailored aviation transport network with the four major world-class airport clusters. Leveraging its geographical advantages, Urumqi should establish an aviation express network featuring an "intranet network within Xinjiang and a fan-shaped network from east to west." This entails intensifying aviation transport links with key markets such as Beijing, Tianjin, Shanghai, Nanjing, Hangzhou, Guangzhou, Shenzhen, Chengdu, and Chongqing, positioning Urumqi as a platform to empower Xinjiang's economic high-quality development with the leading cities of the four major airport clusters.

Promoting Centralized and Unified Airport Management: Xinjiang should promote centralized and unified management of airports to achieve coordinated development between trunk and feeder airports. The development of the Urumqi hub is pivotal in driving the growth of all airports in Xinjiang. Thus, it should be considered integral to the overall civil aviation development in the region rather than operating as an independent hub. By fostering "trunk and feeder linkage" and promoting coordinated development, Xinjiang can accelerate its integration into the national modern economic system, ultimately achieving high-quality economic development.

Based on the differences in passenger flows at airports, this study innovatively constructs an "improved gravity model based on flight frequency" to explore the importance of air transport in promoting spatial interactions in a more objective way. Of course, there are some limitations in the selection of sample time span and the design of gravity model in this paper. In order to further improve the study, future research should broaden the sample time span for different research objects, introduce more analytical indicators, and deeply explore the relationship between the intensity of spatial interactions between regions. This will help to deepen the understanding of the mechanism of air transport's role in regional development and spatial connectivity.

Acknowledgments

We are grateful for the financial support from the National Natural Science Foundation of China (U2333206); the Major Project of Key Research Base of Humanities and Social Sciences of the Ministry of Education of China (22JJD630006); the Civil Aviation Safety Capacity Building Project of 2024 "Domestic Air Express Safety Supervision"; and the Major Project of Social Sciences of Tianjin Municipal Commission of Education (2018JWZD52).

References

[1] Xie, D. and Zhao, Y.N. Problem-oriented regional coordinated development strategy - evolutionary logic, innovative development, practical exploration. Industrial Technology and Economics, 2023, 42(05), 3-9.

[2] Mao, J., Tang, S. and Xiao, Z. Industrial policy intensity, technological productivity growth: Evidence. Research Policy, 2021. DOI:10.1016/j.respol.2021.104287.

[3] Chen, J. Research on Regional Coordinated Development under the Goal of Common Wealth in the New Development Stage. Journal of Yunnan University for Nationalities (Philosophy and Social Science Edition).

[4] Ding, Z.I. and Li, M.J. Cross-domain collaborative governance towards common wealth: A political economy interpretation of east-west collaboration. Exploration of Economic Issues, 2023, 01, 60-72.

[5] Jin, R. and Wang, X.Y. Governance Framework, Operational Mechanisms, and Action Models for Regional Collaboration in Promoting Common Prosperity - Exploratory Research Based on Mountain-Sea Collaboration in Fujian Province. Journal of Public Management, 2023, 20(04), 93-106+172-173.

[6] Wang, J.T. and Wang, H.R. Multidimensional Measurement of Chinese-style Regional Modernization Level:

Theoretical Logic, Spatial and Temporal Evolution, and Enhancement Paths. 20231030. Journal of Xi'an Jiaotong University (Social Sciences).

[7] Los B. and Verspagen B. R&D Spillovers and Productivity: Evidence from U. S. Manufacturing Microdata． Empirical Economics, 25(1), 127-148．

[8] Samaniego H . Uncovering the Socioeconomic Structure of Spatial and Social Interactions in Cities. Urban Science, 2023, 7. DOI:10.3390/urbansci7010015.

[9] Gao, Z.G. and Dai, X.M. An Honghong, et al. On the Transportation Construction in Xinjiang Against the Background of "Dual Cycle" New Development Pattern. Journal of Xinjiang University (Philosophy, Humanities & Social Science), 2021, 49(06), 1-9.

[10] Eric, T.N. Semeyutin, A. and Hubbard, N. Effects of enhanced air connectivity on the Kenyan tourism industry and their likely welfare implications. Tourism Management, 2020, 78, 104033. DOI:10.1016/j.tourman.2019.104033.

[11] Seo, W. and Nam, H.K. Trade-off Relationship between Public Transportation Accessibility and Household Economy: Analysis of Subway Access Values by Housing Size. Cities, 2019, 87(4), 247-258. DOI:10.1016/j.cities.2018.11.004.

[12] Sunny B. and Joy S. Network assessment of Tier-II Indian cities' airports in terms of type, accessibility, and connectivity. Transport Policy, 2022, 124, 221-232.

[13] Cui, H.M. Research on the Development of Aviation Industry Based on the Goal of World-class Urban Agglomeration. Nanjing University of Aeronautics and Astronautics, 2020.

[14] Ullman, E.L. American commodity Flow. Seattle: University of Washington Press.1957.

[15] Taaffe, E.J. The urban hierarchy: An air passenger definition. Economic Geography, 1962, 38 (1), 1-14.

[16] Li, Z.H. Spatial effect of port service coordination of Yangtze River Delta in China based on fuzzy clustering and gravitational model. Journal of Intelligent and Fuzzy Systems, 2021, 53, 1-9. DOI:10.3233/JIFS-189919.

[17] ÓPEZ E, GUTIÉＲＲEZ and GÓMEZ G. Measuring regional cohesion effects of large-scale transport infrastructure investments: An accessibility approach. European Planning Studies, 2008, 16(2), 277-301. DOI: 10.1080/09654310701814629.

[18] Xie, L.W., Gu, Z.P. and Tan, C.H. Research on the dynamics of urban spatial structure in Chenzhou city based on the gravity model[J]. Shanxi Architecture, 2021, 47(13), 7-10.

[19] He, J.H., Li, C. and Yu, Y, et al. Measuring Urban Spatial Interaction in Wuhan Urban Agglomeration， Central China: A Spatially Explicit Approach. Sustainable Cities and Society, 2017, 32, 569-583. DOI:10.1016/j.scs.2017.04.014.

[20] Yuan, X.M., Wei, F.l. and Zhang, X. Spatial correlation and influencing factors of high-quality development level of county economy in Hebei Province. Resource Development & Market, 2023, 39(01), 59-68+128.

[21] Jiang, J.D., Jiang, S.H. and Wang, X.B, et al. Construction of agricultural product logistics network in Jiangsu Province based on improved gravity model. Jiangsu Agricultural Science, 2022, 50(21), 240-248.

[22] Zhang, W.X., Ding, N. and Lu, G.W., et al. Study on the influence of high-speed railway on the consumption space of Yangtze River Delta cities. Economic Geography, 2012, 32(6), 1-6.

[23] Whitehead, J.C., Blomquist, G.C, Hoban, T.J, et al. Assessing the Validity and Reliability of Contingent Values：A

Comparison of On-Site Users, Off-Site Users, and Non-Users. Journal of Environmental Economics and Management, 1995, 29(2), 238-251.

[24] Chen, J.H., Chen, Y., and Che, M.M. China’s High-quality Economic Development Level, Regional Difference and Dynamic Evolution of Distribution[J]. Quantitative and Technical Economic Studies, 2020, 37(12), 108-126.DOI:10.13653/j.cnki.jqte.2020.12.006.

[25] Zhao, D.Y., Ye, X.H., and Qin, Z.Y.A. Research on Measurement of Economic Linkages among Cities in Anhui Province Based on the Gravity Model. Journal of Henan College of Finance & Taxation, 2023, 37(05), 73-81.