Spatial Connectivity Level Differences Between China and Belt and Road Countries: Analysis of Causes (Postprint)

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Abstract

Transportation infrastructure connectivity constitutes an important component of the "Five Connects" of the Belt and Road Initiative. Given the complex geographical characteristics between China and its neighboring countries, railway and highway construction entails high costs and long cycles; therefore, in establishing spatial connectivity among Belt and Road countries, priority should be given to enhancing aviation transport connectivity between China and Belt and Road nations. By examining the current state of aviation transport connectivity between China and Belt and Road countries in 2019 and incorporating its intrinsic characteristics, an evaluation index system for aviation transport connectivity levels was constructed. Requisite data were collected from the Civil Aviation Administration of China, Variflight, and "Civil Aviation from Statistics", and factor analysis was employed to calculate comprehensive scores for aviation transport connectivity between China and each Belt and Road country. Furthermore, the K-means clustering algorithm was utilized to classify the comprehensive aviation connectivity index of Belt and Road countries into five levels according to the natural breaks method: high connectivity, relatively high connectivity, basic connectivity, relatively low connectivity, and almost no connectivity. The results indicate: (1) Significant disparities exist in aviation transport connectivity levels between China and different Belt and Road countries, exhibiting a pyramid-shaped unbalanced development characteristic. (2) Aviation policies, aviation networks, regional geographical features, and regional economic levels constitute the primary causes of the unbalanced development of aviation transport connectivity among Belt and Road countries. This study provides a theoretical foundation for enhancing spatial connectivity levels between China and Belt and Road nations, aiming to promote regional economic development in countries and regions along the Silk Road Economic Belt through the development of the Belt and Road international aviation transport market, and

to facilitate the establishment, smooth operation, and prosperity of the "Air Silk Road".

Full Text

Abstract

Transport infrastructure connectivity constitutes a crucial component of the Belt and Road Initiative's five connectivity pillars. Given the complex geographical features between China and its neighboring countries, coupled with the high costs and long construction cycles of railway and highway projects, prioritizing the enhancement of air transport connectivity between China and Belt and Road countries is essential when establishing spatial linkages along the routes. This study examines the current status of air transport connectivity between China and Belt and Road countries in 2019, constructing an evaluation index system based on the conceptual characteristics of aviation connectivity. Data were collected from the Civil Aviation Administration of China (CAAC), VariFlight, and *Civil Aviation from a Statistical Perspective*. Factor analysis was employed to calculate comprehensive scores for aviation connectivity between China and each Belt and Road country, while K-means clustering algorithm categorized the connectivity levels into five natural grades using the natural breaks method: high connectivity, relatively high connectivity, basic connectivity, relatively low connectivity, and almost no connectivity. The results reveal: (1) Significant disparities exist in air transport connectivity levels among Belt and Road countries, exhibiting a "pyramid-shaped" pattern of unbalanced development. (2) Aviation policies, airline networks, regional geographical characteristics, and regional economic levels are the primary factors causing this imbalance. This paper provides a theoretical foundation for improving spatial connectivity between China and Belt and Road countries, aiming to promote regional economic development along the Silk Road Economic Belt through the development of the international air transport market and to facilitate the construction, smooth operation, and prosperity of the "Air Silk Road."

Keywords: Belt and Road; spatial connectivity; aviation connectivity; China

1 Introduction

1.1 Aviation Connectivity

The concept of connectivity originally referred to the physical connection between telecommunications networks—the physical links between operators' networks and external facilities and equipment [1]. Since the Asian Development Bank applied the connectivity concept to infrastructure projects in 2005, it has subsequently appeared in policies such as the *Master Plan on ASEAN Connectivity* and the *APEC Connectivity Blueprint* [2]. In 2014, President Xi Jinping chaired the Strengthening Connectivity Partnership Dialogue and elevated the meaning of connectivity, defining it as encompassing five dimensions: policy,

infrastructure, trade, finance, and people-to-people bonds [3].

Building upon this definition, this study conceptualizes international aviation connectivity as the interconnection of civil aviation transport systems across different countries and regions based on mutual respect for territorial sovereignty. It involves strengthening aviation transport infrastructure construction and linkages, improving the smooth implementation of aviation transport policies and institutions, and ultimately enhancing the flow of people and goods. Through aviation connectivity, international economic and trade exchanges are realized, promoting interregional economic cooperation and regional integration.

Aviation connectivity is defined within the framework of air transport, which utilizes aircraft to transport passengers, cargo, and mail. Air transport can be categorized into civil aviation and military aviation based on the user. Civil aviation comprises public air transport and general aviation [4]. Within the connectivity framework, public air transport is applicable to passenger, cargo, and mail transportation. With its speed and mobility advantages, public air transport has become a crucial mode for international trade cooperation and exchange. Therefore, this paper defines aviation connectivity as the connectivity of international civil public air transport.

Economic globalization has intensified global economic exchanges, with over 35% of trade value currently realized through air transport [5]. Scholars and aviation industry experts contend that promoting aviation connectivity requires: (1) advancing aviation infrastructure construction to provide a platform for international air transport development; (2) improving aviation operational standards to develop the international air transport market and create competitive air transport products; and (3) continuously optimizing the international air transport network to strengthen cooperation with Belt and Road countries. Aviation transport connectivity serves as a vital means to promote modern international economic and trade cooperation, simultaneously reducing spatial distances and enhancing cultural exchanges between nations, thereby facilitating capital flow, trade smoothness, and people-to-people bonds [6].

1.2 Belt and Road Countries

Following President Xi Jinping's visits to East and Southeast Asia in 2013, the "Silk Road Economic Belt" and "21st Century Maritime Silk Road" cooperation initiatives were proposed. These initiatives aim to build a community of shared interests, destiny, and responsibility based on political trust, economic integration, and cultural inclusiveness through the joint efforts of all countries along the routes. By 2022, China had signed Belt and Road cooperation documents with 147 countries and 32 international organizations [7].

Considering the geographical factors of these countries, this study focuses on 147 countries that have signed Belt and Road agreements with China, divided into ten regions: Africa, East Asia, Southeast Asia, South Asia, West Asia, Central Asia, Europe, Oceania, South America, and North America (Table 1).

Using these ten regions as the study scope, this paper analyzes the aviation transport connectivity levels between China and these countries.

2 Data and Methods

2.1 Indicator Selection

The Belt and Road Initiative aims to promote five connectivities, providing an important platform for factor exchanges among participating countries. Theoretically, factor exchanges can be summarized as the movement of people and goods. Therefore, the frequency of such exchanges serves as a key indicator of the importance of air transport. The connectivity level between China and Belt and Road countries can be measured using flight exchange frequency.

Aviation policy connectivity holds paramount strategic importance as the foremost component of the five connectivities vision. According to the CAAC website, China's aviation policy exchanges with Belt and Road countries primarily include bilateral air transport agreements and airworthiness agreements. Therefore, the "aviation policy connectivity" dimension analyzes: (1) whether agreements have been signed with China, and (2) the degree of air traffic rights openness with contracting parties.

Aviation network connectivity is a critical condition for civil aviation transport. Generally, regions with superior infrastructure conditions exhibit more active civil aviation development and higher aviation network connectivity. This paper analyzes aviation infrastructure primarily through civil aviation facility accessibility, measured by four indicators: number of connected airports, connected cities, connected routes, and connected countries/regions [8].

The frequency of factor exchanges serves as an important metric for aviation transport connectivity. Therefore, this dimension examines the number of operating airlines and round-trip flights (excluding Hong Kong, Macron, and Taiwan) between China and each country.

Based on the conceptual characteristics of aviation connectivity and principles of comprehensiveness, comparability, data availability, and representativeness, this study establishes a three-dimensional evaluation index system comprising aviation policy connectivity, aviation network connectivity, and aviation transport connectivity (Table 2).

2.2 Data Sources and Preprocessing

The COVID-19 pandemic in 2020 caused tremendous shocks to global civil aviation, with severe restrictions on international routes and numerous flight cancellations. Therefore, this study uses 2019 aviation transport data to analyze connectivity levels, examining differences in aviation connectivity between China and Belt and Road countries. Data were sourced from the Civil Aviation Administration of China, VariFlight, and *Civil Aviation from a Statistical Perspective*.

2.3 Data Standardization

Due to different measurement units and value ranges across indicators, raw data were standardized to eliminate dimensional effects:

$$Z_{ij} = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)}$$

where Z_{ij} represents the standardized value of indicator j for country i, X_{ij} is the original data, $\min(X_j)$ is the minimum value of indicator j, and $\max(X_j)$ is the maximum value.

2.4 Applicability Analysis

To verify the suitability of factor analysis, Bartlett's sphericity test and KMO (Kaiser-Meyer-Olkin) test were conducted. The results (Table 3) show a KMO value of 0.796 (>0.7) and a significance probability of 0.000 (<0.001), indicating that the sample data are appropriate for factor analysis.

3 Results

3.1 Factor Extraction and Score Calculation

Principal component analysis was used to obtain eigenvalues and variance contribution rates. In 2019, the cumulative variance contribution rate reached 82.089%, indicating that two common factors (Y_1 and Y_2) could represent 82.089% of the information and adequately explain the original data (Table 4).

Using regression analysis, the component score coefficient matrix was obtained. With x_i representing each indicator, the factor scores were calculated as:

$$Y_1 = 0.195x_1 + 0.196x_5 + 0.212x_6 + 0.010x_2 + 0.075x_3 + 0.213x_4 + 0.186x_7 + 0.467x_8 + 0.470x_9$$

$$Y_2 = -0.010x_1 + 0.062x_5 + 0.075x_6 + 0.212x_2 + 0.213x_3 + 0.186x_4 + 0.467x_7 + 0.062x_8 + 0.075x_9$$

To accurately analyze each country's aviation connectivity capacity, weighted calculations were performed to obtain a comprehensive scoring model:

$$Y = 0.61986Y_1 + 0.20103Y_2$$

Based on this model, comprehensive factor scores for each country were calculated. Table 5 lists countries with scores greater than 0.

3.2 Aviation Transport Connectivity Levels

Based on the comprehensive scores, connectivity levels were divided into five categories: high connectivity, relatively high connectivity, basic connectivity, relatively low connectivity, and almost no connectivity. Using the K-means clustering algorithm with five clusters, initial cluster centers were set at 1, 0.5, 0, -0.5, and -1. Through iterative optimization, the final classification results were obtained (Table 6).

4 Discussion

4.1 Highest Connectivity with Asian Belt and Road Countries

Overall, aviation transport connectivity between China and Asian countries is the highest, with Southeast Asian countries ranking first in Asia. Thailand exhibits the highest connectivity level with China among all Belt and Road countries, while South Korea and Vietnam demonstrate relatively high connectivity. Singapore, Malaysia, Myanmar, and others maintain basic connectivity levels. These findings align with previous research on South Asia [9] and Central Asia [10], suggesting three primary explanatory factors:

1. **Policy Facilitation**: China has opened fifth freedom traffic rights with ten Southeast Asian countries. According to CAAC's latest *International Air Freight Traffic Rights Allocation Rules*, round-trip all-cargo routes with these countries are classified as Category I, significantly reducing restrictions on air transport connectivity.

2. **Aviation Industry Development**: Thailand's well-developed aviation industry and rich tourism resources make air transport the primary mode for Chinese tourists entering Thailand, accounting for a large share of its international passenger market. Thailand operates 38 international airports with over 60 fixed routes to Chinese cities including Beijing, Shanghai, Guangzhou, Kunming, Chengdu, and Hong Kong. Following the commissioning of Bangkok's Suvarnabhumi Airport, Thailand has become a crucial transportation hub in Southeast Asia.

3. **Economic Vitality**: Southeast Asia represents one of the world's most dynamic and promising economic regions, creating favorable opportunities for civil aviation enterprises. According to the World Bank's Ease of Doing Business Index, several Southeast Asian countries rank highly (Singapore: 2nd, Malaysia: 15th, Thailand: 21st), indicating a sound operational environment for aviation enterprises and driving aviation connectivity with China.

4.2 Relatively High Connectivity with European Belt and Road Countries

Aviation transport connectivity between China and European Belt and Road countries is relatively high, with Russia being the most closely connected European partner and ranking among the top Belt and Road countries overall. Three factors explain this:

1. **Strategic Importance**: Russia holds significant strategic status in Belt and Road construction, being the most actively cooperative and supportive partner. It plays a crucial role in regional connectivity. In 1996, China and Russia established a strategic partnership of coordination, which was strengthened in 2011 and elevated to a comprehensive strategic partnership of coordination for a new era in 2019, actively promoting the alignment between the Belt and Road Initiative and the Eurasian Economic Union.
2. **Policy Coordination**: The two countries established bilateral transport and airworthiness relations early on and subsequently signed multiple aviation transport agreements. With fifth freedom rights and Category I all-cargo routes, their aviation policy connectivity is high.
3. **Geographical Factors**: Russia's vast territory and sparse population make aviation transport the preferred transportation mode. With over 1,200 airports (ranking 5th globally), Russia maintains fixed routes with more than 20 Chinese cities including Beijing, Harbin, and Guangzhou.

4.3 Low or No Connectivity with Most African, Oceanian, and American Countries

In Africa, South Africa, Ethiopia, Kenya, and Egypt; in Oceania, New Zealand and Fiji maintain relatively low connectivity levels with China. All other countries in these regions exhibit low or no connectivity, with Africa having the most countries without aviation links. In the Americas, only Cuba operates direct flights to China (approximately 2 round-trip flights monthly), resulting in generally low or no connectivity.

According to Ma et al. [11], two primary factors explain this pattern:

1. **National Openness and Economic Development**: Oceania comprises 14 countries with significant development gaps. Only New Zealand is a developed country; most island nations are agricultural economies with underdeveloped comprehensive transport systems, focusing on rail and road transport with inadequate civil aviation infrastructure and few direct flights to China. New Zealand, with 7 international airports and fixed routes to China, serves as the region's aviation hub.
2. **Infrastructure Development**: Africa lacks a complete transport system, primarily relying on road transport. Only a few countries like South

Africa, Ethiopia, Kenya, and Egypt have better-developed aviation industries with direct flights to China, though flight frequencies remain low. Many African countries suffer from underdevelopment and transportation gaps, resulting in limited direct flights and overall low connectivity. Similarly, the Americas have well-developed road and rail networks with economic centers concentrated in the United States. Belt and Road countries in the region are all developing nations, leading to significant disparities in aviation development levels.

5 Conclusions

1. China has achieved preliminary success in promoting aviation connectivity with Belt and Road countries. However, influenced by aviation transport policies, airline networks, regional geographical characteristics, and regional economic levels, significant differences exist in aviation transport connectivity levels, characterized by a "pyramid-shaped" unbalanced development pattern.

2. Aviation policy, airline networks, regional geographical characteristics, and regional economic levels are the main causes of unbalanced development. It is recommended to select key node cities based on regional geographical characteristics, build air traffic corridors, and accelerate aviation connectivity construction to maximize political and economic benefits. Different construction plans should be proposed according to each country's economic environment and existing transport infrastructure, promoting comprehensive and coordinated development through multi-party collaboration.

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Note: Figure translations are in progress. See original paper for figures.