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FedEx and UPS Network Structure and Accessibility Analysis Based on Complex Network Theory

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With the expansion of the global air cargo transport system, the operating structure of air cargo has become increasingly separate from passenger counterpart, forming an independent organization model. Despite the Chinese air cargo capacity has grown exponentially in the past, its network is still in its infancy. FedEx and UPS have well-established air cargo networks and have operated effectively on both international and domestic scale; thus, understanding the structure and evolution of their air cargo networks is of a high reference value. In conjunction with the division of US regions from the United States Geological Survey (USGS), this paper refers to FedEx and UPS as FEPS and analyzes its topological structure, complexity properties, and air cargo accessibility by using social network analysis (SNA) and accessibility evaluation methods. The results suggest that (1) the structure of the FEPS air cargo network is in the highly developed states and has the typical "small-world" and "scale-free" network characteristics; (2) the degree centrality values for the nodes in the FEPS network suggest that the network complexity has increased; (3) airports in Memphis (MEM), Louisville (SDF), Indianapolis (IDN), and Ontario (ONT) are the major hubs with both high centrality values and air cargo accessibility; and (4) the FEPS network presents a unique hub-and-spoke structure compared with the passenger counterpart.

1. Introduction

Air transport has a pivotal role in global and regional economic development. Air cargo transfers 35% of international trade value through only 1% of the total trade volume [1]. Additionally, with the booming of e-commerce, major air cargo carriers such as Amazon, Jingdong, and Alibaba rely heavily on the express delivery services, leading to an increase in air transport infrastructure development.

Additionally, flying air cargo naturally involves cargo handling, ground transportation, and different routing strategies, which are not present in passenger networks, and therefore, it is of high reference value to study the unique properties of the hub-and-spoke air cargo network and their rationale for the formation. For air cargo carriers operating on a similar scale, such as Chinese air cargo carriers Shunfeng Express and Yuantong Express who are still planning their dedicated airline routes for their air cargo transport network, comprehending the network property provides significant valuable insights for their network design.

Regardless of its importance, the air cargo industry is not regarded as important as the air passenger counterpart. Additionally, a tremendous amount of case studies and literature focuses on the structural characteristics of air passenger transport over the past decades, and yet, for a long time, the air cargo industry has existed as an adjunct to passenger transport. The rapid growth of the air cargo industry leads to the increasing structural separation of air passenger and cargo network, and the differences between networks are becoming increasingly evident. Air cargo hubs and route organizations display different network characteristics and properties from passenger transport. The U.S. air cargo development has been leading the world, with

FedEx and UPS are the two most important air cargo integrators together accounting for more than 75% of the U.S. air cargo market in 2018 (as shown in Table 1). Studying the air cargo network jointly formed by the two companies can clarify the basic characteristics of the U.S. air cargo network pattern and discover the unique features of the cargo network that differ from air passenger transportation, which is of academic significance, and can provide an empirical reference for other countries in building new air cargo networks with application value.

Our contribution is (i) to fill the gap in the literature of comprehending the air cargo network structure from an enterprise perspective, (ii) to analyze the complex network properties and the correlation between centrality measures, and (iii) to provide an index to measure air cargo accessibility from a complex network theory perspective. The rest of the paper is structured as follows. Section 2 summarizes the literature concerning air cargo transportation from a geological economic perspective. Section 3 briefly describes the history of FedEx and UPS, also the data used in this research. Section 4 and 5 focus on the complex network measures and air cargo accessibility index. Section 6 concludes this study and discusses some further research possibilities.

2. Literature Review

The existing literature on the air cargo network addresses their geographic characteristics, accessibility, robustness, and the economic benefits of the air cargo network structure. From an economic development perspective, the authors of [2] suggested that the air transport network fosters economic growth in China and the Chinese air transport network centered in Beijing, Shanghai, Guangzhou, and Shenzhen, covering the Pearl River Delta (PRD), Yangtze River Delta (YRD), Bohai Sea Economic Zone, and Chengdu-Chongqing Economic Zones. The authors of [3–6] discovered that there are overlaps between the Chinese air passenger network structure and economic development zones by analyzing the Chinese air passenger enterprises. The authors of [7] used gravity models to access the Chinese air cargo network and concluded that the Chinese air cargo market is still emerging and is still depends heavily upon passenger networks. The authors of [8] further analyzed the Chinese air cargo network and identified the international trade drivers using the augmented gravity model, considering cultural influence as socio-economic factors that affect the cargo demand. The authors also concluded that the domestic air-freight network in China is primarily composed of point-to-point, and the leading airports are yet to become cargo gateway hubs, and the composition of the economy is more important than the size of the economy. The authors of [9–11] compared the different air transport network structures and concluded that the structure of the air passenger networks is subject to the local socio-economic factors. The authors of [12] put forward the idea that air transport hubs have become the engine of the economy and conceptualized a new urban form centered on airports, namely, Aerotropolis. The authors of [13] confirmed that air transport infrastructure boosts the local economy.

Scholars have extensively depicted the structure of the air transport network using complex network theory and graph theory. The authors of [14, 15] provided a preliminary analysis of the world-wide airline network (WAN) through complex network theory and proposed a new model with geopolitical constraints. The author of [16] described the FedEx and UPS networks by their numbers of nodes and edges in an undirected network. The authors of [17] analyzed the city of Harbin and proposed to re-evaluate the unique geographic value of gateway airports. The authors of [18, 19] explored weighted networks using the example of the airport network (WAN) and the scientist collaboration network (SCN). The authors of [20] discovered the travel time between airport pairs in the European air passenger network, while the authors of [21] discussed the multilayer structure of the European ATN. The authors of [22, 23] analyzed the Chinese air transport network and its multilayered features. The authors of [24] suggested a strong relationship between air cargo and trade volume, noting that the oil price has a critical impact on the air cargo network. Malighetti et al. [25] discovered that FedEx, UPS, and DHL operated extensively through a multihub structure, and all of them focus on the flexibility and robustness of their networks. The authors of [26] analyzed the global air transport network and concluded that the air cargo network has a different structure than the passenger network, and bridging airports are more valuable.

Hansen [27] defined accessibility as the convenience of reaching a destination from a given location. In the past, the study of airport accessibility primarily focuses on reachability from either land or air location. Additionally, the competitiveness of passenger airports is severely affected by service quality [28]. The authors of [4] investigated the Chinese air passenger network accessibility from 2001 to 2013 and discovered that Beijing, Shanghai, Guangzhou, and Shenzhen have high passenger accessibility. Meanwhile, airport air-side accessibility increased in the southwest region, whereas the northeast gradually decreased. However, research on cargo accessibility is scarce despite the value created by the air cargo sector.

Other studies focus on the robustness of the air transport network using a variety of attacking strategies on the air transport network [29–32] though none of these studies discussed the implications for air cargo enterprises and their network structures.

3. Scope of the Study

Airports have become important nodes in the transportation economy, and the structure of the air cargo network not only reflects the connections between the local economy but also affects regional economic development. In recent years, the Chinese aviation industry has grown exponentially in terms of both size of the network and the cargo volume. Airports such as PEK, PVG, HKG, and CAN in Beijing, Shanghai, Hong Kong, and Guangzhou have already surpassed the top U.S. air cargo hubs such as MEM and SDF in Memphis and Louisville. However, the Chinese air cargo network still operates under the framework of its passenger counterpart

TABLE 1: FEPS domestic market share 2008–2018.

Year	FedEx market share (%)	UPS market share (%)	FEPS market share (%)
2008	47.69	30.24	77.93
2009	53.91	29.80	83.71
2010	54.23	29.34	83.57
2011	54.78	29.82	84.60
2012	55.43	29.57	85.00
2013	55.86	29.43	85.29
2014	54.84	30.01	84.85
2015	54.08	29.07	83.15
2016	52.58	28.63	81.21
2017	49.44	28.29	77.73
2018	48.98	26.79	75.77

and soon would be challenged by the increasing international trade and domestic market demand. Given the long history and depth of involvement of FedEx and UPS, the US Department of Transportation (US DOT) distinguishes FedEx and UPS as the only two air cargo carriers in GROUP III, which have operating revenue over a billion USD, and therefore, it is meaningful to study their network topological structure, complex network characteristics, and cargo accessibility.

Air cargo network has become an increasingly important part of the transportation economy, and its structure reflects not only the connectivity of the local economy but also serves as an indicator for regional economic development. In recent years, the Chinese aviation industry has grown exponentially in both size of the network and the cargo volume.

3.1. Brief History of FedEx and UPS. Founded in 1965, FedEx moved its headquarters from Little Rock, Arkansas, to Memphis, Tennessee, in 1973. FedEx was founded on the idea of creating an efficient air transport system for time-sensitive goods such as pharmaceuticals and chipsets, independent of the passenger network. In the late 1970s and early 1980s, FedEx actively participated in aviation policy reforms, expanding its operating area to Canada and establishing its aviation hub base at Memphis International Airport. At the beginning of the 21st century, FedEx created a multimodal transport network covering multiple regions of the world and logistics-related industrial chains through the acquisition of many logistics companies in other countries and regions.

United Parcel Service (UPS) was established in Seattle in 1907. In 1909, it cooperated with the U.S. Postal Service. In the 1930s, UPS was able to provide transportation services that covered the entire West Coast of the United States, becoming the first U.S. carrier to offer air cargo services. During World War II, the company expanded to the East Coast. In the 1950s, UPS began to build private roads, combined with its ground transportation, and full-air-freight-service was introduced. With the relaxation of U.S. aviation policy in the 1980s, UPS began to develop its fleet and obtained permission from the Federal Aviation Administration to set up UPS Aviation. In 1989, UPS expanded its business overseas for the first time and

expanded to the rest of the world, forming the global air cargo network landscape.

3.2. Data Selecting and Processing. The data for this study consist of eleven years of air cargo and freight data from the US DOT Bureau of Transportation Statistics (BTS) T-100 market data, which contains the OD pair of airports with cargo and passenger volume and flight distance between origin and destination. This study focuses on the domestic air cargo network, and therefore, international routes are excluded.

(1) Considering that the production and transport of goods are closely related to the development of the local economy, we consider the FEPS network as a directed graph. We break down the stopover flights A-B-C to A-B and B-C, and the direction of the flights is distinguished.

(2) The O-D network is built with the airport as a node and route as edges, and the cargo volume Freight Ton Kilometers (FTK) of the airport nodes is used as a weight to analyze the topological structure, complex network properties, and cargo accessibility.

(3) The United States Geological Survey divides the United States territory into the Pacific, Rocky Mountains, Southwest, Northeast, Southeast, Midwest, Alaska, and Hawaii. We describe the topology in conjunction with the USGS division.

4. Methodology

4.1. Complex Network Indices

4.1.1. Degree and Degree Distribution. One of the key properties of nodes in the network is the degree of a node. The degree k_i of a node refers to the number of links it has to other nodes. The average degree of all nodes in the network becomes the average degree of the network, denoted as k. The degree distribution of nodes in the network is represented by the probability distribution function $p(k)$ and the cumulative probability distribution function $P(k)$. When $p(k)$ and $P(k)$ are power functions, the structure is said to have a "scale-free" property expressed as follows:

$$P(k) = \sum_{k_I=k}^{\infty} p(k). \tag{1}$$

Previous studies have shown that $p(k)$ of a random network has a similar Poisson distribution. Many studies have attributed the topology of real networks to conform to power-law distribution characteristics $P(k) \propto k^{-\lambda} (2 \leq \lambda \leq 3)$ of "scale-free" network [33].

4.1.2. Average Path Length (L). The average path length L of the network is defined as the average distance between any two nodes, which can reflect the strength of network accessibility, and it can be used to present the mean distance of any two nodes of a network written as follows:

$$L = \frac{1}{n(n-1)} \sum_{i \neq j} d(v_i, v_j). \tag{2}$$

4.1.3. Cluster Coefficient (C_i). Clustering coefficient measures how closely a node is connected to its neighbor, defining as the ratio of the connected edges E_i with all its neighbors to the maximum number of possible links. The clustering coefficient (C) is the mean value of all the single nodes, as the ratio of the number of edges between a node and the maximum number of edges may be connected to all nodes connected to it. For nodes, v_i, its adjacent node collection, the number of actual variables in N_i is as follows:

$$E_i = \frac{1}{N} \sum_{v_i \in V} e_{jk}. \tag{3}$$

For nodes in a directed network, the clustering coefficient of v_i is expressed as

$$C_i = \frac{E_i}{k_i(k_i - 1)}. \tag{4}$$

The higher the C_i is, the closer the nodes are connected. Average clustering coefficient C is defined as the average of all node cluster coefficients. High C indicates stronger connections within the network.

$$C = \frac{1}{n} \sum_{i=1}^{n} C_i. \tag{5}$$

4.1.4. Degree Centrality (DC). Degree centrality is measured by the degree of the given airport in the network. It reflects the size of the node's direct contact with other nodes in the network. The node centrality indicates the likelihood of contact with other nodes, the larger the value, the greater probability of connections with other nodes, and it is defined as follows:

$$DC_i = \frac{1}{n-1} k_i. \tag{6}$$

4.1.5. Closeness Centrality (CC). Closeness centrality is measured by the sum of the shortest distances from a given node to all nodes, reflecting the relative accessibility of the node in the network.

$$CC_i = \left[\frac{1}{n-1} \sum_{j=1, j \neq 1} d_{ij} \right]^{-1}. \tag{7}$$

4.1.6. Betweenness Centrality (BC). The betweenness centrality is measured with the number of shortest paths, between any couple of nodes in the graph that passes through the target node, reflecting the node's transit and bridging capabilities in the network.

$$BC_k = \frac{2}{n^2 - 3n + 2} \sum_{i=1, j \neq k}^{n} \sum_{j \neq k}^{n} \frac{\delta_{ij}^k}{\delta_{ij}}, \tag{8}$$

where δ_{ij} represents the total number of shortest paths between node v_i to v_j. The larger the BC_k is, the stronger the hub-and-spoke effect of the network has.

4.2. Air Cargo Accessibility (ACA) Index. Referring to the Reynolds [34] method of measuring passenger accessibility from Ireland to other airports in Europe by the number of seats between routes, air cargo accessibility in this study is measured by the weighting of freight and centrality between airports as follows:

$$Ai = \sum_{i=1}^{n} FTK_{ij} \times W_{DC_i}, \quad i = 1, 2, 3, \dots, n, \tag{9}$$

where A_i represents airport cargo accessibility, n for the total number of airports, AFT_{ij} (Freight Ton Kilometer) represents the air cargo volume from airport i to j, and W_{DC_j} represents the sum of in-degree and out-degree of airport j; equation (9) indicates that the A_i airport's accessibility is equal to the weighted sum of the annual cargo volume and connectivity of the airport's arrival at the other airports.

$$AI_i = \frac{A_i}{(1/n) \sum_{i=1}^{n} A_i} \quad i = 1, 2, 3, \dots, n. \tag{10}$$

According to equation (10), the accessibility of FEPS airports from 2008 to 2018 is calculated, and the change of airport node canary is analyzed according to the average of the reachability, the standard deviation, and other statistical parameters. The ratio of airport i to the average reachability $AI_i > 1$ indicates that airport i has accessibility above or equal to the average accessibility of all airports.

5. Findings

5.1. FEPS Network Topology Characteristics. As seen in Figure 1, airports in the Midwest and Southeast regions have better connectivity. We divided the airports in the FEPS network into five hierarchical groups based on their cargo volume. The size of the FEPS network is reflected by the number of nodes and edges, which has not drastically changed from 2008 to 2018.

Between 2008 and 2014, US domestic air cargo volume increased as the US economy (and the world) recovered from the global financial crisis. However, the air cargo growth rate slowed between 2015 and 2018. The number of FedEx airports increases as FedEx finished acquiring TNT in 2016. In 2017, both FedEx and UPS shifted their focus to multimodal transportation by closing their nonhub, low cargo capacity airports. Meanwhile, the complexity of the network has increased. By the end of 2018, the average degree in the network increased by 6% from 8.374 in 2008 to 8.925 in 2018, which indicates stronger network connectivity (as seen in Table 2). Meanwhile, the average clustering coefficient increased from 0.419 to 0.572, indicating connections amongst nodes are stronger. 281 FEPS airports scattered across the country with 62 airports in the Midwest, 54 in the Southeast, 53 in the Pacific, 33 in the Northeast, 29 in the Rocky Mountains, 27 in Southeast, and 23 in noncontiguous regions. However, the hub establishment of the FEPS network is not aligned with the fast economic development regions. According to the US Bureau of Economic Analysis, major economic growth took place in a part of the Rocky Mountain, Pacific, and Southeast region, where the FEPS hubs are not located, indicating the different requirement for the hub establishment for the air cargo network.

Compared with the passenger hub locations such as Chicago, New York, Atlanta, and San Francisco, air cargo hub selection considers neither the needs for round trip flights nor the convenience to go more tourist destination. Instead, air cargo hubs focus more on places with higher geographic accessibility. For instance, MEM and SDF in Memphis and Louisville have flights that can reach any city in the nation within 4 hours.

5.2. Complex Network Properties. The probability of the cumulative degree of the FEPS network in 2008, 2011, 2016, and 2018 is calculated (as shown in Figure 2). All of which follows a power-law distribution with a long tail on the right, $R^2 > 0.85$, indicating that a large number of nodes are connected through a small number of hubs via multiple edges, portraying a typical hub-and-spoke network structure, where most of the nodes are connected through a few hub nodes.

Figure 3 displays the geographic distribution of nodes centrality values. The overall centrality values (DC, CC, and BC) have increased, specifically, DC and CC increased in the Rocky Mountains and Southwest regions; however, there is no significant increase in the BC, indicating that the nodes with strong transshipment capability have not increased drastically, while an increasing number of nodes have more direct connections.

Tables 3–6 summarize the change in the rankings of complex measures, which reflects the complexity of the

network and its structural characteristics, especially the hub nodes. The change of the centrality values suggests the routing strategies in the FEPS network are constantly adjusting over time, resulting in shifts of complexity in the network. Only MEM and SDF ranked highest by all three indices, which implies these two nodes as the core hubs. Other airports have rather volatile changes in their centrality measures. For instance, Philadelphia (PHL) in 2008 (Table 3) has a degree of 100 (ranked 8th) and dropped to 84 in 2011 (Table 4) and further 82 in 2016 (Table 5) and eventually raised to 89 (Table 6) in 2018 (ranked 6th), and the closeness centrality (CC) dropped from 0.459 (ranked 4th) to 0.448 (ranked 13th).

This suggests that there is no trend in the alteration of the centrality measures for any single node in the network, and more importantly, some nodes gained more transit capability or ground handling support, which might have moved up in the rankings and serve as the local or regional warehouse. Interestingly, the gateway airports such as ATL, LAX SEA, and ORD do not exhibit strong rankings in all three centrality values; though those airports serve as international mega-hubs for passenger network, it has a very limited impact on the air cargo network, which further suggests separation of the cargo and passenger network structure and their unique structural properties.

Figure 4 further illustrates the relations between degree centrality (DC), betweenness centrality (BC), and closeness centrality (CC). As seen in Figure 4, the correlation between DC and BC increased from 0.859 to 0.871, and the correlation between DC and CC decreased from 0.714 to 0.612 while the correlation between CC and BC dropped from 0.836 to 0.527.

This indicates three scenarios regarding the network complexity properties.

(1) The probability of nodes having numerous direct connections (DC) and having high transit capability (BC) increased, meaning that the hub airports in the network have stronger transshipment capability at the same time they have more directions to other nodes in the network, indicating hub-and-spoke effects increase.

(2) The probability of nodes having both numerous direct connections (DC) and a large sum of shortest paths (CC) from other nodes reduces. In other words, many nodes are becoming terminal nodes, in which case, increase the total number of directions; at the same time, these nodes do not serve as the transit nodes.

(3) The probability of nodes has both a large sum of shortest paths (CC), and strong capability of transit (BC) decreased, meaning that the bridging nodes in the networks are distancing from other smaller nodes.
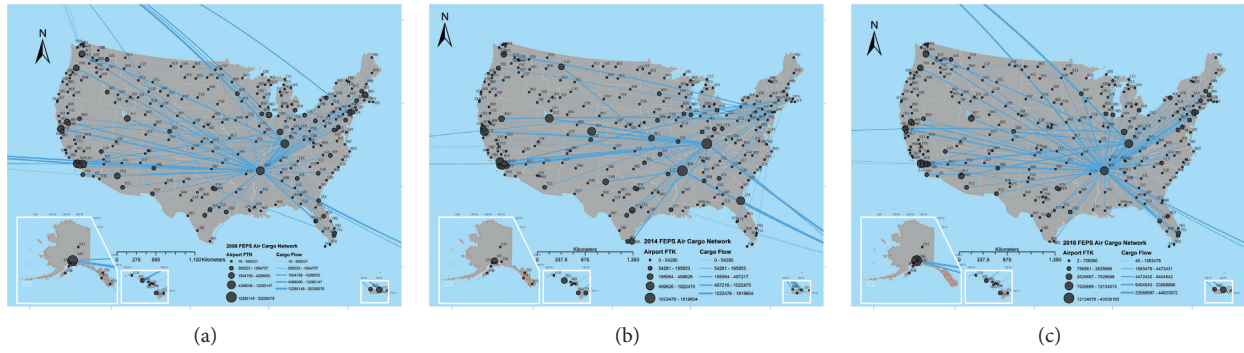
Figure 1: FEPS air cargo network topology in 2008, 2014, and 2018.

Table 2: FEPS network complex network characteristics from 2008 to 2018.

FEPS air cargo network characteristics							Random network indices	
Year	Nodes	Routes	Diameter	Average degree	Average clustering coefficient	Average path length	Average path length (L_{rand})	Clustering coefficient (C_{rand})
2008	280	2221	6	8.347	0.419	2.93	2.62	0.031
2011	284	2401	6	8.458	0.505	2.954	2.672	0.031
2015	279	2522	6	9.362	0.562	2.422	2.372	0.045
2016	280	2540	6	8.411	0.576	2.981	2.774	0.028
2018	281	2508	6	8.925	0.572	2.931	2.566	0.032

$y = 4.4246x^{-1.083}$
$R^2 = 0.8647$

08p(k)
08P(k)

(a)

$y = 5.4668x^{-1.14}$
$R^2 = 0.8722$

11p(k)
11P(k)

(b)

(c)

(d)
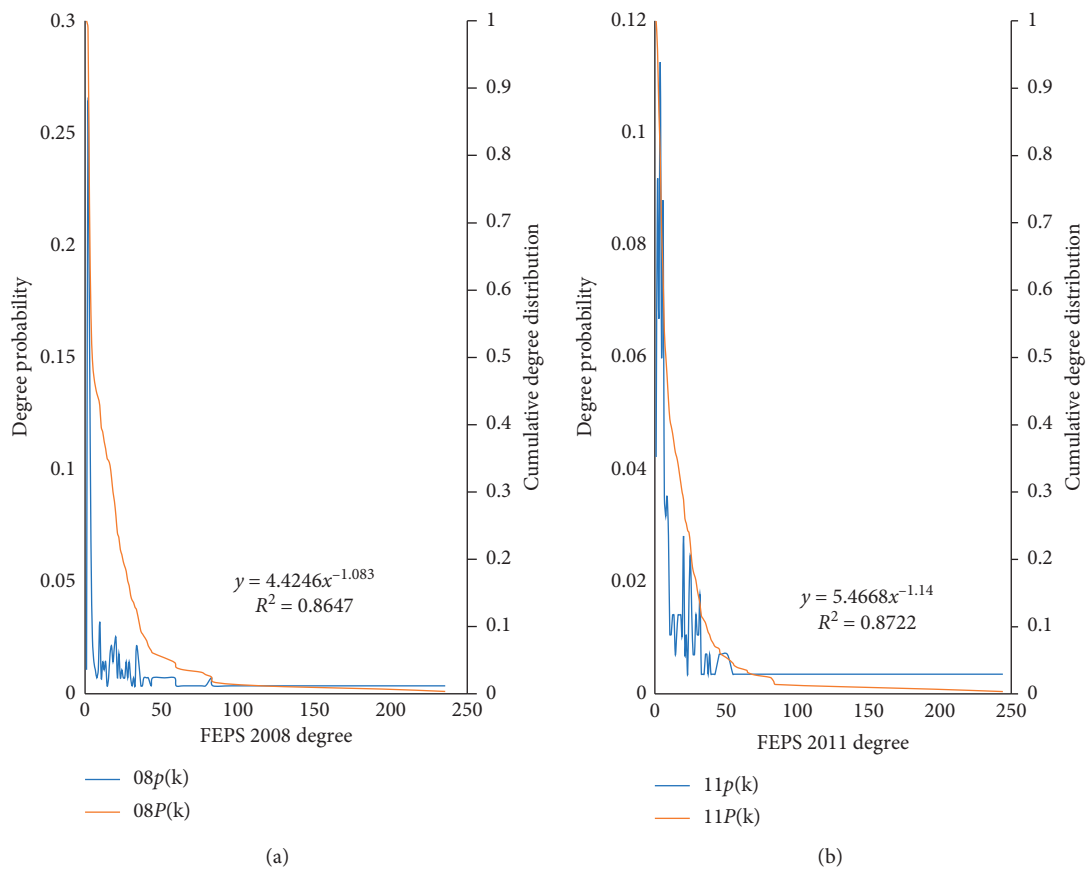
FIGURE 2: Cumulative degree distribution of the FEPS network in 2008, 2011, 2016, and 2018.

(a)

(b)

(c)

(d)

(e)   (f)

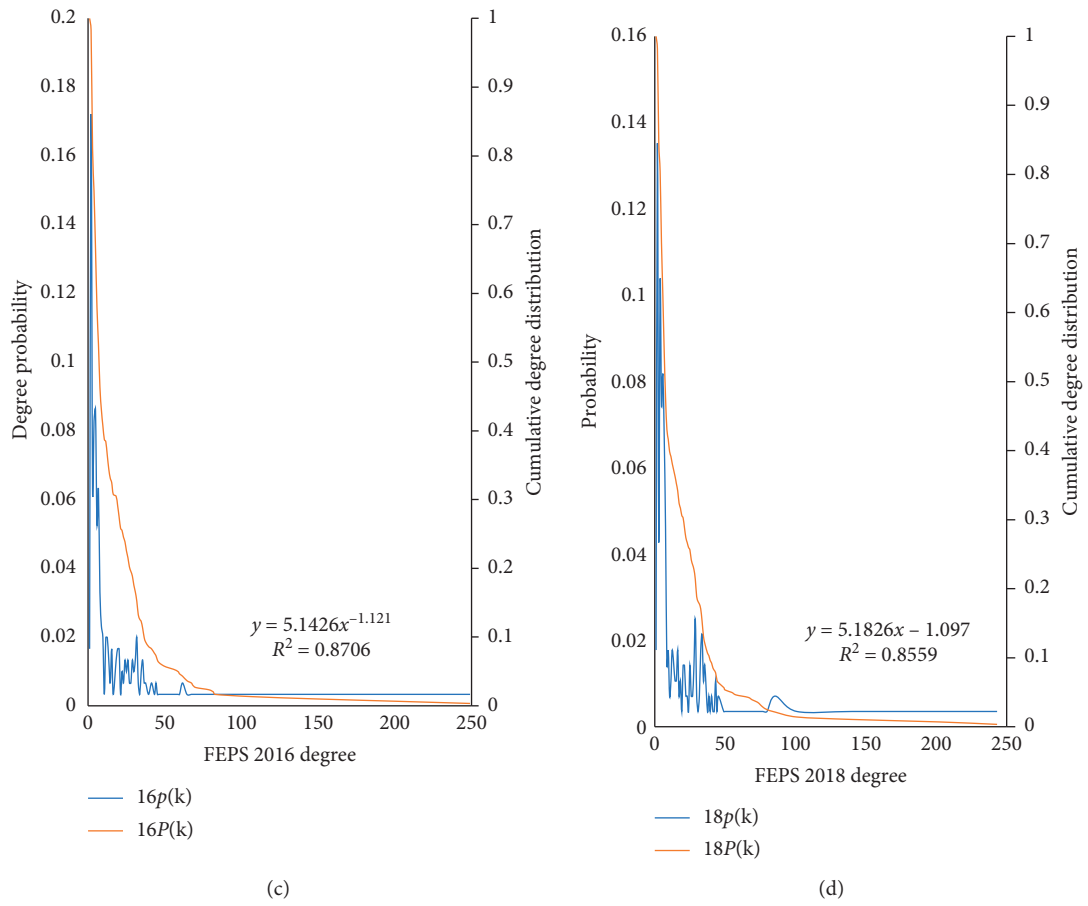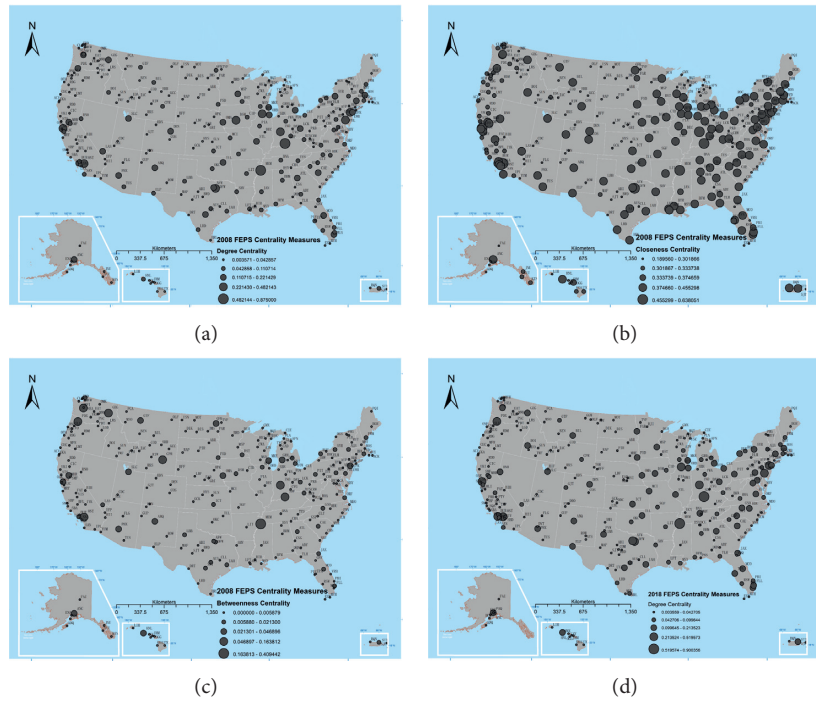Figure 3: Spatial distribution of degree centrality, closeness centrality, and betweenness centrality of FEPS air cargo network in 2008 and 2018.

These properties suggest that many existing bridging hubs are evolving into major hubs, which have long distances to the remote nodes. Additionally, the number of nodes with degree value less and equal to 2 increased from 38 (13% of total nodes) to 44 (15% of total nodes), indicating that there are more nodes in the network emerging as the terminal destination. Also, the proportion of airports with zero betweenness centrality reduced from 45.5% to 33%, indicating an increase in the number of relay airports within the FEPS network. According to the division of USGS, the airport hubs mainly concentrated in the southeastern, followed by the Midwest Region, Pacific, Northeast and Southwest, and the Rocky Mountains regions.

5.3. The FEPS Air Cargo Accessibility Index (ACA). The success of the economy depends on the well-performing air cargo transportation system; measuring approaches are needed to access and track this performance in terms of the system's ability to provide access to the market. This paper employs the standard deviation coefficient to measure the change in air cargo accessibility. The results indicate that the average air cargo accessibility of FEPS airports increased by 27% in 2008–2018. During 2008–2014, the accessibility grows from 38.52 (million ton-kilometers) to 44.22 (million ton-kilometers), an increase of 14%. Growth rates slowed from 2015 to 2018, with the average accessibility rate increasing by 11%. Cargo accessibility increased to 49.2 (million ton-kilometers) in 2018. The number of airports in FEPS with accessibility coefficients greater than 1 increases from 20 to 30 during 2008–2018, increasing from 7% to 10%, which indicates that the majority of airports have below the average accessibility. The number of airports with cargo accessibility coefficients greater than 1 in the FEPS network increased from 20 to 30 in 2008–2018, increased from 7% to 10%, indicating that 90% of airports in the network have below-average air cargo accessibility, and therefore only a few airports in the FEPS network serve as hub airports. The air cargo accessibility standard deviation increased by 22% and the standard deviation coefficient decreased by 4%, indicating an increase in the

absolute difference in accessibility between airports but decreased as the average airport accessibility increased. The number of airports with more than 1 million ton-kilometers increased from 114 in 2008 to 119 in 2018, increased by 4%. Most of the hub airports are in mid-size cities, with high GPD growth; also, these hub airports have both strong demand and transit capability. The characteristics of FEPS air network airport cargo accessibility are as follows (see Table 7):

(1) The high cargo accessibility of the hub airports represented by MEM, SDF, ANC, ONT, IND, OAK, EWR, and LAX indicates that these airports have a significant position as hubs in the network. From a regional perspective, FEPS airport cargo accesses are higher in the Southeast, Midwest, and Pacific and lower in the Rocky Mountains, Southwest, and Southeast.

(2) FEPS airport cargo accessibility and its growth rate are not proportional. The top 20 airports in FEPS experienced negative annual average cargo accessibility, including SDF, ORD, BOS, SEA, DFW, and SLC, with negative growth rates of −4.01%, −8.3%, −9.83%, −11.9%, −26.91%, −39.75%, and −42.71%. The negative growth in SDF, however, does not affect the hub and top-ranking status of the FEPS hub. O'Hare, DFW, SEA, and BOS are the main passenger hub airports, which have reduced cargo accessibility, indicating a growing gap between FEPS air cargo networks and passenger networks. However, Los Angeles, as a larger passenger hub airport, had the highest growth rate of 137.78%, followed by Phoenix 95.04%, Portland 84.04%, Fort Worth 60.78%, Oakland 59.18%, Salt Lake City 55.34%, Memphis 44.13%, Indianapolis 35.32%, Ontario 31.01%, Anchorage 25.9%, Newark 18.37%, and Philadelphia 13.44%. Among them, Los Angeles airport cargo accessibility exhibits a stronger increase which is mainly due to the rapid development of e-commerce, as well as the cargo passengers brought through the LA international gateway.

Table 3: Top 20 ranking airports by centrality measures (DC, BC, and CC) in 2008.

Rank	Airport code	Degree	Airport code	Betweenness centrality	Airport code	Closeness centrality	Rank	Airport code	Degree	Airport code	Betweenness centrality	Airport code	Closeness centrality
1	MEM	245	MEM	0.409	MEM	0.638	11	CAE	62	GFK	0.039	PDX	0.441
2	SDF	202	SDF	0.164	SDF	0.561	12	LAX	61	MKE	0.034	LAX	0.441
3	IND	135	IND	0.083	IND	0.509	13	ATL	61	EWR	0.033	BIL	0.437
4	PHL	100	PDX	0.065	ONT	0.481	14	PDX	54	SMF	0.032	AFW	0.435
5	EWR	87	ONT	0.063	OAK	0.469	15	AFW	54	SLC	0.031	SEA	0.434
6	ONT	86	GEG	0.058	EWR	0.462	16	ORD	46	OMA	0.029	CAE	0.432
7	OAK	86	CPR	0.057	DFW	0.461	17	MCO	46	GRR	0.028	GEG	0.429
8	RFD	82	SEA	0.056	PHL	0.459	18	DEN	45	GTF	0.027	SLC	0.429
9	DFW	79	OAK	0.047	RFD	0.455	19	GEG	43	ANC	0.026	MSP	0.428
10	DSM	67	HNL	0.041	DSM	0.451	20	LCK	43	PHX	0.026	DEN	0.428

Table 4: Top 20 ranking airports by centrality measures (DC, BC, and CC) in 2011.

Rank	Airport code	Degree	Airport code	Betweenness centrality	Airport code	Closeness centrality	Rank	Airport code	Degree	Airport code	Betweenness centrality	Airport code	Closeness centrality
1	MEM	254	MEM	0.403	MEM	0.641	11	DEN	61	HNL	0.036	AFW	0.45
2	SDF	204	SDF	0.154	SDF	0.569	12	PDX	58	CPR	0.034	DFW	0.449
3	IND	140	SEA	0.075	IND	0.501	13	LAX	57	SLC	0.033	SEA	0.44
4	ONT	88	PDX	0.071	ONT	0.478	14	PHX	53	MKE	0.029	SLC	0.439
5	EWR	87	ONT	0.064	OAK	0.47	15	LCK	53	OMA	0.029	RFD	0.439
6	OAK	86	IND	0.059	EWR	0.464	16	SLC	48	PHX	0.026	GEG	0.438
7	PHL	84	OAK	0.055	DEN	0.457	17	ATL	48	ANC	0.026	BIL	0.438
8	DFW	73	GEG	0.052	PHL	0.454	18	SEA	47	SMF	0.025	DSM	0.432
9	AFW	68	GTF	0.041	LAX	0.453	19	DSM	47	EWR	0.025	MSP	0.427
10	RFD	67	GFK	0.039	PDX	0.451	20	MSP	44	FSD	0.025	ABQ	0.427

TABLE 5: Top 20 ranking airports by centrality measures (DC, BC, and CC) in 2016.

Rank	Airport code	Degree	Airport code	Betweenness centrality	Airport code	Closeness centrality	Rank	Airport code	Degree	Airport code	Betweenness centrality	Airport code	Closeness centrality
1	MEM	259	MEM	0.367	MEM	0.624	11	PDX	67	MKE	0.035	BIL	0.447
2	SDF	207	SDF	0.164	SDF	0.577	12	PHX	64	GTF	0.034	PHL	0.443
3	IND	154	ONT	0.093	IND	0.52	13	DEN	64	HNL	0.034	SEA	0.442
4	ONT	111	IND	0.079	ONT	0.499	14	RFD	62	OMA	0.032	LAX	0.44
5	OAK	86	PDX	0.075	OAK	0.475	15	ATL	61	PHX	0.032	SLC	0.436
6	EWR	85	GEG	0.053	DEN	0.467	16	DSM	58	SLC	0.031	GEG	0.434
7	PHL	82	ANC	0.046	AFW	0.454	17	ORD	53	FSD	0.031	PHX	0.434
8	DFW	73	SMF	0.043	PDX	0.453	18	MSP	50	OAK	0.029	DSM	0.434
9	AFW	71	SEA	0.041	EWR	0.45	19	SLC	48	PIT	0.028	ORD	0.434
10	LAX	70	CPR	0.039	DFW	0.449	20	MCO	47	EWR	0.026	RFD	0.433

TABLE 6: Top 20 ranking airports by centrality measures (DC, BC, and CC) in 2018.

| Rank	Airport code	Degree	Airport code	Betweenness centrality	Airport code	Closeness centrality	Rank	Airport code	Degree	Airport code	Betweenness centrality	Airport code	Closeness centrality
1	MEM	253	MEM	0.357	MEM	0.640	11	LAX	72	HNL	0.039	AFW	0.456
2	SDF	210	SDF	0.176	SDF	0.583	12	PDX	69	OAK	0.038	RFD	0.449
3	IND	146	ONT	0.087	IND	0.522	13	DEN	60	SEA	0.036	PHL	0.448
4	ONT	105	IND	0.076	ONT	0.489	14	ORD	57	ANC	0.036	MSP	0.443
5	EWR	89	PDX	0.067	OAK	0.479	15	MSP	52	MKE	0.034	BIL	0.442
6	PHL	89	GEG	0.055	PDX	0.471	16	ATL	51	CPR	0.031	PHX	0.441
7	DFW	83	FAR	0.047	DEN	0.468	17	PHX	47	GTF	0.030	BOI	0.438
8	AFW	80	SLC	0.043	EWR	0.464	18	SLC	47	OMA	0.030	ORD	0.435
9	OAK	78	SMF	0.039	DFW	0.462	19	GEG	46	ICT	0.029	FAR	0.435
10	RFD	76	AFW	0.039	LAX	0.461	20	MCO	45	FSD	0.027	SLC	0.434

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

(i)
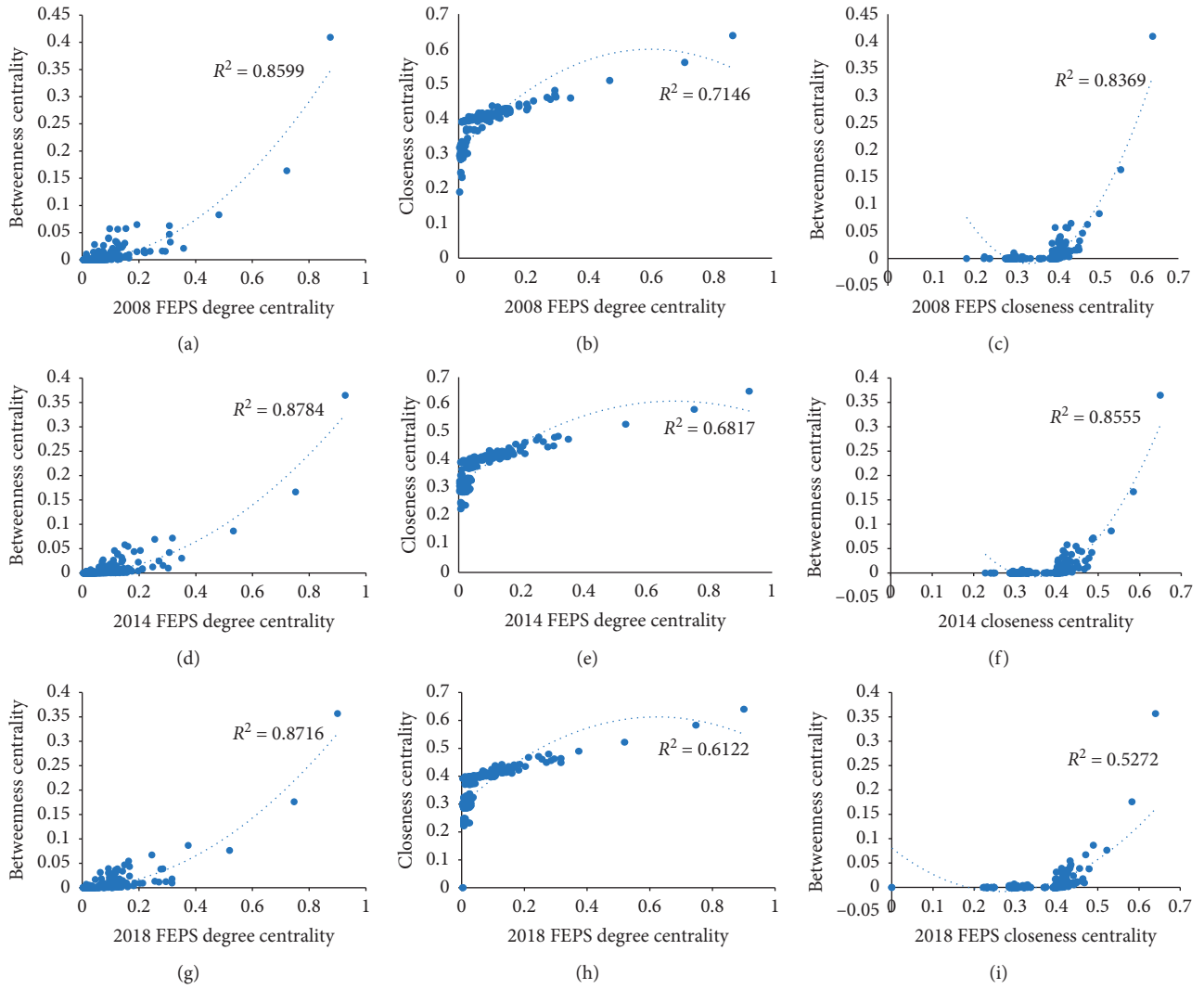
FIGURE 4: Correlation of degree centrality (DC), closeness centrality (CC), and betweenness centrality (BC) in 2008.

TABLE 7: Top 20 Air Cargo Accessibility airports in the FEPS Networks (units: million ton- kilometers).

RANK	2008 ACA		2011 ACA		2014 ACA		2016 ACA		2018 ACA	
	Airport	FTK	Airport	FTK	Airport	FTK	Airport	FTK	Airport	FTK
1	SDF	2481.6	SDF	2572.2	MEM	2964.18	MEM	2843.51	MEM	3069.92
2	MEM	2129.9	MEM	2530.93	SDF	2515.72	SDF	2598.53	SDF	2382.14
3	ANC	1210.34	ANC	1293.82	ANC	1334.8	ANC	1553.56	IND	630.92
4	ONT	515.35	LAX	496.65	LAX	611.4	ONT	773.22	ONT	675.15
5	IND	466.25	ONT	483.23	ONT	573.58	LAX	743.01	EWR	376.95
6	OAK	368.77	IND	467.79	IND	466.62	IND	611.33	PHL	169.78
7	LAX	361.07	OAK	448.2	OAK	447.25	OAK	574.39	DFW	178.8
8	EWR	318.46	EWR	378.58	EWR	364.5	EWR	378.57	AFW	69.35
9	PHL	149.66	SEA	205.54	SEA	225.96	PDX	260.01	OAK	587
10	RFD	144.4	PDX	201.56	PDX	202.29	PHX	241.28	RFD	132.42
11	PDX	136.49	PHX	179.1	PHX	176.52	SEA	206.32	LAX	858.56
12	SEA	132.3	PHL	126.57	DFW	139.25	DFW	171.75	PDX	247.1
13	SMF	131.84	DFW	125.05	PHL	129.32	PHL	145.41	DEN	93.09
14	ORD	125.61	RFD	124.96	SLC	104.44	BFI	126.95	ORD	71.96
15	DFW	111.21	SLC	117.76	HNL	97.96	SMF	117.19	MSP	68.63
16	AFW	94.88	HNL	96.27	SMF	95.74	SLC	115.17	ATL	28.46
17	SLC	91.44	DEN	87.86	RFD	93.19	RFD	103.19	PHX	167.05
18	PHX	85.65	SMF	86.58	DEN	91.9	HNL	98.32	SLC	142.04
19	BOS	73.38	BOS	67.11	BOS	72.18	DEN	93.2	GEG	74.79
20	MIA	68.58	SJU	64.27	MIA	66.3	MSP	81.17	MCO	53.1

*Anchorage (ANC) is one of the airports in Alaska, which does not serve as a national hub in the domestic scale; but on international scale, it still serves a big role.

6. Conclusion and Discussion

This paper depicts and analyzes the FEPS network from a complex network theory perspective. The major findings are summarized and discussed.

The FEPS network presents a different hub-and-spoke structure compared with its passenger counterpart, yet the air cargo network has both small-world and scale-free network characteristics since it has a small average path length and large average clustering coefficient, and its degree conforms to a power-law distribution.

Besides, the centrality indices do not comprehensively reflect the importance of nodes in the FEPS network as the accessibility measures denote that the growth in cargo volumes is not proportional to the growth of centrality value during the study period. Additionally, the correlation of node centrality shows a decreasing trend; that is, the probability of nodes in the FEPS network having high centrality values (degree, betweenness, and closeness centrality) has reduced over the years.

The core hubs in the FEPS network include MEM, SDF, IND, and ONT. The market share decreased 2% from 2008 to 2018, partially due to FEPS restructured its aviation network after 2015, closing some nonhub airports and increasing the share of multimodal transportation. Geographically speaking, hub airports are concentrated in the Southeast, Midwest, Pacific, Northeast, and sparsely distributed in the Rocky Mountains and Southwest. Unlike air passenger networks, major hubs in the FEPS network are concentrated in small- and mid-size cities such as Memphis, Louisville, and Newark, all of which have strong capability of transshipment and cargo handling. Compared with Atlanta, Chicago, New York, and other passenger hubs, the air cargo network is separating from the passenger network. We believe that small- to mid-size cities usually have more political and economic incentives since air cargo businesses could support local and regional economic development.

The Chinese air cargo network is still in its infancy, with most of the cargo carried by passenger carriers, partially due to the development of the Chinese HSR (High-Speed-Rail). However, because of the increasing demand in international trade and domestic consumption, several private air cargo integrators have already begun taking the initiative to invest in their own dedicated air transport routes and fleets. Taking Shunfeng Express as an example, its newly built regional hub airport is located in the north part of Hubei province, which is outside the Pearl River Delta (PRD), Yangtze River Delta (YRD), Chengdu-Chongqing Economic Zone, and Bohai Sea Economic Zones, suggesting the adjustment of hub distribution and route planning, which are crucial to air cargo integrators as the market in China will continue to grow in the foreseeable future. Additionally, airport infrastructures can also bring employment opportunities, real estate development, and ultimately GDP growth. Consequently, more air transport enterprises in China have begun adjusting their network structures accordingly. Additionally, on a broader perspective, analyzing the air cargo network under different socioeconomic contexts has theoretical and application values, and therefore, future work should also take the market, corporate policy, government policy, and climate into consideration.

Data Availability

The data used to support the findings of this study are obtained from https://http://www.transtats.bts.gov/DL_SelectFields.asp?Table_ID=292 (US Department of Transportation Bureau of Transportation Statistics).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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