



The development of Chinese air express integrators

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ABSTRACT

Despite the significance of the China e-commerce economy and the rapidly increasing air express service, there are few publications on the development of Chinese integrators that are significant contributors to the e-commerce boom. This research explores the network development of China's three integrators, namely, SF Express, TYO Express and China Post, and assesses the evolution of the networks during the pandemic period with the assistance of the complex network theory. It has been found that their networks underwent great development one year after the COVID-19 pandemic outbreak. Their domestic networks are compared with the networks of the world-class integrators in the EU. It appears that the Chinese integrators operate networks with both hub-and-spoke and point-to-point features at their principal hubs (Hangzhou and Shenzhen of SF express, and Nanjing of China Post). SF Express' network in the Chinese domestic market demonstrates different topological features from the ones of its Chinese counterparts and the foreign integrators in Europe, with fewer one-way flights and at a higher density.

1. Introduction

In the air cargo industry, integrators are defined as market players which provide an end-to-end air express service with time guaranteed with the flight and land transport, including goods collection and delivery for end-customers, for example, FedEx, UPS, and DHL, which are global leading integrators (Bowen Jr., 2012; Kupfer et al., 2017; Malighetti et al., 2019b). The rapid development in the e-commerce markets drives the demand of the air express service industry (Van Asch et al., 2020; Park, Choi & Zhang, 2009). In 2020 after the COVID-19 pandemic outbreak, because of the forced isolation, the sales of online shopping gained unrivaled growth in categories, such as medical, baby products, food, and drink items (Bombelli, 2020). The COVID-19 pandemic has accelerated the growing importance of e-commerce on the air cargo market, especially in the air express segment. By the end of September of 2020, integrators achieved a traffic increase of 14% (Boeing, 2020). It is expected that the air freight operated by integrators would take the significant lead in the competition under the current market environment, even though the development of air freight remains uncertain in the post-pandemic era (Suau-Sanchez, Voltes-Dorta & Cugueró-Escofet, 2020).

Currently, China is the largest e-commerce market with US\$1.5 trillion in revenue in 2019 (Boeing, 2020). In 2019 China's express

industry delivered 63.52 billion orders, worth a value of RMB749.78 billion (State Post Bureau, 2020). There is no doubt that e-commerce is the primary driver for the increase in China's air cargo volume and revenue. How the air cargo industry meets the e-commerce boom has been in the spotlight and has aroused interest and attention in academia. For example, Xiao (2011) applies a SWOT framework to analyse Post Express Service with private and foreign air express firms in China and points out the main service problems of the state-owned express company. Farooq et al. (2019) state that customer retention and loyalty can create a massive profit. A strong brand reputation has a positive effect on customer retention. Also, proper management is positively related to service delivery quality. Liu & Kang (2015) conduct a case study of Chinese leading integrator SF Express with an in-depth analysis of its operational model. In their interpretation SF Express achieves competitive strength through distinct delivery service with promptness and mature network coverage. These studies offer an overview of Chinese express industry and feature of delivery service performance. However, studies on the Chinese integrators' network remain rare, when compared with that for other integrators in the world.

Malighetti et al. (2019a) and Bowen Jr (2012) highlight the key positions of Chinese airports as the Asian gateways for global integrators. Some research has conducted network analyses with topological measures for global and regional air cargo markets with a focus

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on the global integrators (Bombelli, Santos & Tavasszy, 2020; Malighetti et al., 2019a; Bowen Jr., 2012). However, there is a lack of research on China's integrators and their network development. To fill the gap, this study will use the complex network theory (CNT) to examine the scheduled freighter network of China's integrators. The development progress and business strategies of individual integrators will be discussed.

This paper is structured as follows. The Literature on integrated carriers and background of China's integrators is reviewed in Section 2. The methodology is presented in Section 3. Section 4 analyses the networks of Chinese three integrators. Section 5 offers further topological measures and changes during the pandemic period. The comparison with peers in European market is in Sections 6. Section 7 contains discussion and concluding remarks.

2. Literature on integrated carriers and the development of China's integrators

2.1. Literature on integrators

Doganis (2019) and Morrell and Klein (2018) are the two authoritative books in air transport management that give a good description of the features of the integrators: door-to-door services, fast, reliable and guaranteed delivery, and tracking systems. These authors noticed that both airlines and freight forwarders are integrators' competitors, as integrators tend to own their own aircraft fleet, but there is also cooperation: they can use other airlines' spare capacity to carry their shipments. The three world leading integrators include DHL (known as a virtual airline owning or holding shares in many airlines), UPS (the largest package delivery company) and FedEx (famous for its hub/feed model).

In the air cargo industry, carriers can be classified into two primary groups: integrators and non-integrated service providers. The non-integrated service providers, including all-cargo carriers, combination carriers, and forwarders, operate differently from integrators. While integrators handle the entire transportation process independently, non-integrated service providers collaborate with one another to ensure the successful delivery of shipments, with each party responsible for a specific segment of the transport from the shipper to the consignee (Ong-hena, Meersman & Van de Voorde, 2014; Kupfer et al., 2017). While previous researchers have dedicated their focus to specific carrier types, such as all-cargo and forwarders (Kupfer et al., 2016; Balliauw et al., 2018; Li, Bookbinder & Elhedhli, 2012), the field of integrators has also received significant attention and has been the subject of numerous studies.

Bombelli (2020) provides a summary of the literature on integrators, which primarily focuses on two key aspects. The first branch explores the business and cost models adopted by integrators, while the second branch investigates the network configuration and characteristics of integrators. It is argued that these two categories are closely interconnected and mutually impact each other. Therefore, when conducting network analyses of integrators, it is imperative not to overlook the significance of their business and cost models.

When examining the network evolution of FedEx Express and UPS Airlines, Bowen Jr (2012) utilises graph theory measures to analyse network concentration and nodal accessibility. Additionally, the author explores the formation of hub-spoke patterns, taking into consideration factors such as high-traffic centers and intermediate geographic location, land-based transportation infrastructure, and fleet characteristics. Bowen Jr (2012) contends that integrator hubs are strategically positioned in areas where there is significant traffic flow and with intermediate points along routes that connect important markets.

The analysis of integrators' networks reveals a possible distortion that can arise when network indicators neglect to consider the directionality of connections (Bombelli 2020). Integrators' networks, in contrast to passenger airline networks with symmetrical demand,

display a significant imbalance characterised by numerous unidirectional or 'triangular' routes. These triangular routes stem from the unique routing patterns and specific requirements of cargo traffic, distinct from passenger traffic (Zhang and Zhang, 2020). Budd and Ison (2017) discuss the contrasting characteristics between passenger and cargo business, including cost structures, operational practices, and the geographical features of freight flows. Unlike passenger services, which commonly involve bidirectional demand, the transportation of goods often leads to unpaired and imbalanced freight flows. To tackle the lack of bidirectionality, commonly known as the 'backhaul problem', freighter aircraft are deliberately scheduled on triangular or multi-sector routes that span across numerous destinations, including global shipments, to mitigate the occurrence of empty or low-loaded sectors.

The COVID-19 pandemic has brought about significant changes to the air cargo industry, presenting both challenges and opportunities. Notably, Deng, Zhang and Wang (2022) conducted a study examining the impact of the pandemic on air cargo demand, specifically focusing on the Chinese scheduled freighter network (CSFN). Their study suggests that the CSFN actually experienced positive improvements during the pandemic. Importantly, contrary to expectations, their findings indicated that the enhanced performance of the CSFN was not solely due to the substitution effect resulting from reduced belly-hold capacity on passenger aircraft. Rather, it was driven by the increased demand for air cargo and airlines' recognition of the strategic importance of freighter operations in China. Overall, the COVID-19 pandemic has reshaped the air cargo industry, leading to a 'new normal' with unique opportunities. The industry has demonstrated its resilience by adapting to the changing demands of global supply chains. Simultaneously, the vital role of air transport in promptly delivering essential medical supplies and personal protective equipment has gained widespread recognition. The surge in online retail has fueled the demand for efficient and rapid delivery services, providing a substantial growth opportunity for the air cargo sector (Merkert, 2023). In fact, the boom in e-commerce resulted the expansion of integrators' network in the last two decades in the pre-COVID-19 period. DHL, FedEx and UPS set their feet in Asia around 2003 and 2004 and subsequently set their operating bases (Malighetti et al., 2019a). These integrators have a particular interest in China given it being the world's largest manufacturing center in the last 20 years. For example, UPS has established its major hubs in Shanghai and Shenzhen and also operated flights to other business centers including Chengdu, Hangzhou and Qingdao.

Despite the significance of integrators, there is a lack of studies examining the recent network development progress and business strategies of individual Chinese integrators in the post-COVID-19 period, particularly in the context of the strong growth of the international express market in China. This notable contrast is particularly evident when we compare it to the global integrators, whose network configurations have been thoroughly studied through network analyses with topological measures in the context of global and regional air cargo markets.

2.2. The development of China's integrators

Running their own air freight and the land transport in their parcels' delivery service, three express companies (Table 1) in China fulfill the definition of integrators discussed above. China Post is wholly state-owned, while SF Express and YTO Express are private companies. When online retailers emerged in China, most online orders were delivered by Chinese private express enterprises. These local logistics operators developed from inter-city highway express freight companies which included a 'door-to-door' service (Wang & Xiao, 2015). In terms of delivery orders of parcels, the private express delivery companies play a significant role by occupying over 80% market share of the Chinese parcel delivery business in 2019 (State Post Bureau, 2020). The fast-expanding market encouraged two local express companies, SF Express and YTO Express, to invest in self-owned air cargo fleets and

Table 1
Three Chinese integrators.

Integrators	Name of the Carriers	Year established	Fleet	Hub
SF Express	SF Airlines	2009	61 (B737, B747, B757, B767)	Shenzhen, Hangzhou
YTO Express	YTO Cargo Airlines	2015	12 (B737, B757)	Hangzhou
China Post Group Corporation	China Postal Airlines	1996	28 (B737, B757)	Nanjing

Source: Civil Aviation Administration of China (CAAC) reports, the company financial reports and publications.

operate scheduled freighter flights. (Li, 2020). In 2005 the civil aviation sector was opened to private capital, and private airlines started to develop (Wang et al., 2016; Ma et al., 2020a; Ma et al., 2020b). In 2009 SF Express established its cargo airline for the expanding local market. More recently, YTO Express initiated its self-run air cargo flights service in 2015.

By the end of 2020, these three integrators operated scheduled all-cargo flights in China, under the brand of China Postal Airlines, SF Airlines and YTO Cargo Airlines, respectively. Table 1 provides the fleet and hub information of the integrators.

2.2.1. SF Express

SF Express is China's number one logistics company with an annual revenue of RMB112.19 billion in 2019, which was much higher than any other express logistic company in China. What distinguishes SF Express from its domestic peers is that it offers an express professional service with a promised delivery time (PDT) to customers,¹ which brings a higher brand premium (SF Holding, 2019). According to the 2019 annual report of SF Holding (2020), the PDT service contributed RMB56.521 billion, contributed over 50% annual revenue of SF Express.

As the leading domestic integrator, SF Express has been developing its subsidiary, SF Airlines, rapidly. Although its size is not comparable to the state-owned 'Big Three' passenger airline backed cargo airlines or international peers such as UPS or FedEx, SF Airlines has the most potential to be the largest integrated carrier in China's air cargo market. After ten years of aggressive fleet development (Fig. 1), SF Airlines owned 61 all-cargo freighters at the end of 2020. With this in-house air freight support, SF Express achieves 'next day arrival' for major cities in mainland China. With placing its Airport Operation Centre in Shenzhen Airport, SF Airlines has built a nationwide 'dual-core' transportation network with Shenzhen and Hangzhou as its main hubs (Chen, 2017).

2.2.2. YTO Express

YTO Express was founded in 1999. Its annual revenue reached RMB31.15 billion in 2019 (State Post Bureau, 2020). To survive the fierce competition in the express delivery sector, it not only applied the franchise business model like other local express companies to capture market share rapidly, but it also cooperated with an e-commerce platform to ensure parcel order quantity. Meanwhile, Taobao.com, which is

¹ SF Express provides different categories of PDT services, including 'SF the Same Day Delivery' and 'SF Next Morning Delivery', based on the delivery destination and pickup time. In the 'Same Day Delivery' commitment, within the designated destinations and pickup time, the delivery will be completed by 8 p.m. on the same day. The committed timeline for 'SF Next Morning Delivery' is the next morning before noon. These PDT services are guaranteed with full refunds or other monetary compensation to customers if delivery is not fulfilled on time. PDT has been regarded as an advanced service offering in the air freight business, which can give the parcel express firm a competitive advantage (Niu, Dai & Zhuo, 2019).

the online Business-to-Business (B2B) and Business-to-Customer (B2C) platform developed by the Chinese e-commerce giant Alibaba Group, handled any unsatisfied performance on order fulfilment service. In 2005 YTO Express was the first express company to sign an official cooperation agreement with the Alibaba Group, and it then became the recommended logistics service provider for all e-sellers on Taobao.com (Wang & Xiao, 2015). Afterwards, YTO Express was on the fast track of development with Alibaba's e-commerce platform. The Alibaba Group invested in YTO Express in 2015 and 2019, becoming its second largest shareholder with a 22.5% stake. YTO Cargo Airlines, the wholly owned subsidiary of YTO Express, has Hangzhou Xiaoshan International Airport as its administrative headquarters and main operation base. At present, there are ten domestic destinations for YTO Cargo Airlines' regular domestic flights. By the end of 2019 the carrier maintained its own fleet of twelve all-cargo freighters – five B757-200s and seven B737-300s.

2.2.3. China Post

China Post, China's state-owned official postal service, launched its Express Mail Service in 1985 and was the exclusive express service operation for more than a decade (Wang & Xiao, 2015). The integrators in China initially provided express delivery services for business documents and mail such as contracts, invoices, customs report cards and even design samples for manufacturers and purchasing agents. China Postal Airlines was established in 1995. It officially commenced cargo operations in February 1997. It was the first domestic specialised cargo airline in express mail and cargo transportation. The carrier is wholly owned by China Post and mainly handles air freight for it. Nanjing Lukou International Airport serves as its hub airport. This cargo airline has formed a mature scheduled all-cargo network with 27 key aviation cities around the country being connected.

3. Methodology

3.1. Complex network theory (CNT)

To address the problem of understanding Chinese integrators local freight network capacity, we apply the CNT approach to analyse the scheduled air freight network. The CNT can evaluate the structural properties of the networks by describing them in nodes and edges, which are the basic data elements, and so define the overall classification (regular, random, small-world and scale-free). The network characteristics are outlined with indices, which can be used to diagnose the inefficient connections and identify the importance or roles of nodes. The knowledge achieved can support further improvement of the networks (Hossain & Alam, 2017).

The CNT indices allow comparisons between the networks at different locations or the status of networks at different points in their timeline (Ducruet & Rodrigue, 2013). Even more importantly, the method assists the understanding of the spatial structure of the logistics networks, the importance of location and the real traffic flows (Wang et al., 2011). On international routes the Chinese passenger carriers are considered deficient in competitiveness when compared with foreign airlines (Cao et al., 2011; Fang et al., 2009). It would be interesting to determine the characteristics or indicators illustrating the domestic network efficiency gap between Chinese integrators and their counterparts such as DHL, UPS and FedEx in comparable domestic markets, such as North America and Europe.

Following Malighetti et al. (2019b), we model each integrator's network as a directed graph $G = (V, E)$, where V is the set of nodes (cities) and E is the set of directed edges. As each edge represents the route between city i and city j , each edge has forward and backward two directional edges and all connected city pairs with one or two links have both outward and inward directions (Malighetti et al., 2019b). As the existing studies discovered, the air cargo industry usually operates flights in circle routes in response to the imbalances of cargo traffic.

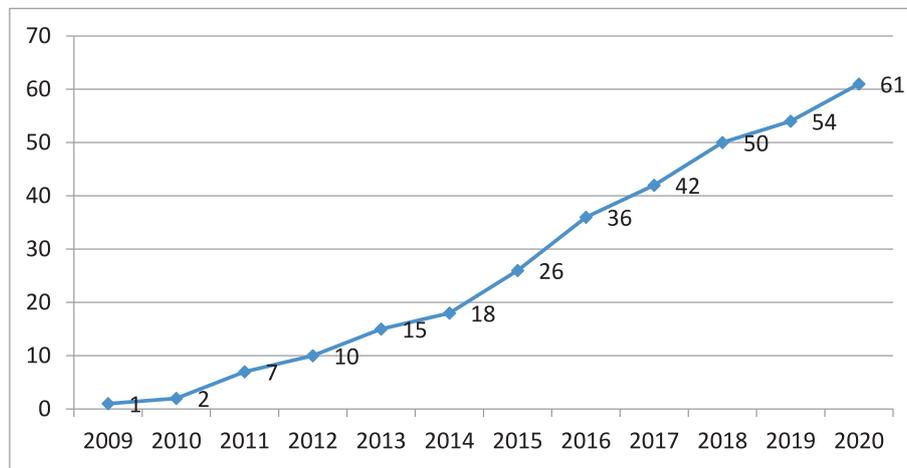


Fig. 1. SF Airlines fleet development, 2009–20.

Thus, the directed graph more aligns with actual circumstances than the undirected one.

For each Chinese integrator, the indices used to measure the network include degree distribution, the average path length and the clustering coefficient. The topological indices such as μ , α , γ and β are also applied to evaluate the network structure to find the changes of topological properties during the COVID-19 pandemic and compare their domestic network with the foreign integrators' network in Europe. Table 2 lists all the network variables and the indices.

- Degree of node i : k_i .

Degree is the number of directed (in and out) connections of a node bond with others. Degree k_i is defined as the number of these connections.

- Average degree of the network.

If there are n nodes, the average degree of all nodes $\langle k \rangle$ can be calculated as:

$$\langle k \rangle = \frac{1}{n} \sum_{i=1}^N k_i \quad (1)$$

- Average path length.

The distance between node i and j in a network is defined as the

number of connections passed from node i to j . There are some possible paths including direct or indirect between them. The distance d_{ij} is the shortest path with the minimum number of edges between node i and j . The average path length (L) represents the mean distance of any two nodes of a network, which can be expressed as:

$$L = \frac{1}{\frac{1}{2}n(n-1)} \sum_{i>j} d_{ij} \quad (2)$$

- The diameter of a network: D .

The diameter D is defined as the maximum value of all possible the shortest distance of node pairs in a network.

- Clustering coefficient: C .

C_i represents the clustering coefficient of node i . It is the rate of the connected edges (E_i) with all its neighbours to the number of all possible edges. The clustering coefficient of a network (C) is the mean value of all the single nodes, which is expressed as:

$$C = \frac{1}{n} \sum_{v_i \in V} \frac{E_i}{k_i(k_i-1)/2} \quad (3)$$

This index reflects the clustering degree of all nodes in the network (Wu et al., 2020). With the larger the value of clustering coefficient, the nodes cohere with each other by paths with fewer edges (Wang et al., 2011).

- Number of disconnected subgraphs: g

A graph is disconnected if two nodes are not connected by a path. The number of disconnected sub-graphs is denoted as g .

- Number of cycles in a network: μ

$$\mu = \frac{m}{2} - n + g \quad (4)$$

It reflects the complex rate and the maturity of the network.

- Alpha index: the ratio of the number of cycles in a network to the maximal feasible number or

$$\alpha = \mu / (2n - 5) \quad (5)$$

A higher alpha index indicates that there are more options for the user to travel from one place to another.

Table 2
List of network indices.

Index	Description
k_i	degree of node i
$\langle k \rangle$	average degree of the network
d_{ij}	shortest distance between nodes i to j
D	diameter of a network; the longest shortest path in the graph
L	average shortest path length or characteristic path length
C_i	clustering coefficient of node i
C	clustering coefficient of the network
n	number of nodes (cities)
m	number of edges (routes)
μ	number of cycles in a network
α	ratio of the number of cycles in a network to the maximum number of cycles in the network
γ	the ratio of the number of actual routes to the maximal feasible number of routes
β	average air routes of each node
g	number of disconnected subgraphs

- Gamma Index: the ratio of actual routes to the maximal feasible number of routes Following Bombelli's (2020), the maximal feasible number of edges is $(n*(n-1))$.

$$\gamma = m/[n(n-1)] \tag{6}$$

This index represents the concentration degree of a network.

- Beta Index: the average routes of each node.

$$\beta = m/n \tag{7}$$

Overall, larger values of α , γ , or β indicate a better connectivity.

3.2. The data

The data were obtained from the 2020 flight timetables published by CAAC. The CAAC issues two timetables a year – the summer/autumn timetable (from late March to late October) and the winter/spring timetable (from late October to late March of the next year) (Wu et. al., 2020). Due to the COVID-19 outbreak, the summer/autumn timetable was revised in May 2020. The study considers the three integrators' networks for a period from October 2019 to March 2021. In our study, a node represents a navigable city instead of an airport. The data are combined for cities with two airports such as Beijing and Shanghai.

The available freight tonnes (AFT) are applied to estimate and to compare air freight capacity between integrators and airports (Malighetti et al., 2019b; Bombelli, 2020; Bombelli, Santos & Tavasszy,2020). The AFT of a flight is equal to the maximum payload of the related operating freighter. In unit time frame, mostly weekly, the AFT is the flight frequencies within the period multiplied by a flight's AFT.

In their seasonal flight plans the integrators report the proposed aircraft type in the approved scheduled routes. On some routes there would be a change to another size of freighter according to the actual transportation volume. Usually, the listed type of aircraft on the schedule is the minimum size of the aircraft that the cargo airline can operate. We list aircraft types with the payload tonnes in Table 3, according to the technical specifications obtained from Boeing's website (Boeing, 2021). The cargo fleets of China's airlines for the domestic market are dominated by Boeing freighters.

4. China's integrators' freighter networks

Table 4 reports the indices showing the structure characteristics of each Chinese integrator network. SF Express has the biggest network with 125 routes, which is almost double the routes of China Post. It also has larger average degree, smaller average path and diameter. All these indices together reflect better connectivity compared to other domestic competitors. But SF Express' network has less cohesiveness than the one of China Post according to its lower clustering coefficient value. YTO Express' network is small in scale in regards of the numbers of nodes and edges. Therefore, it is not surprising that this network with the lower clustering coefficient has less cohesiveness than the other integrators.

Figs. 2–4 show the structure and size of the individual integrators through the number of connections to a city and the weekly AFT of a route of pair cities. The proportional colour circles represent different

ranges of the connections (routes) number to a city in the figures. The wide colour lines correspond to the different scales of routes' weekly AFT. For visual clarity, lines representing edges are undirected. Therefore, the corresponding circles and lines in the figures represent the same scale of the connection number and weekly AFT to enable an easier comparison of the carriers.

Stable and massive express delivery and other air freight volume support SF Express' scheduled freighter network. At the end of 2020, for the sake of SF Express' premium delivery service, especially PDT business, 39 cities were covered in SF Express' network. Its network is based on a hub-and-spoke model to optimise the speed of delivery from any local area to all parts of the country (SF Airlines, 2017). In practice, with two main national hub airports in Hangzhou and Shenzhen, SF Airlines' network combines point-to-point and hub-and-spoke structures (Fig. 2). Most of its navigable cities connect with these two hubs: 17 cities have a sole connection with Hangzhou or Shenzhen, and four cities connect with both hubs. The two separate systems function independently, or they can work as one through the Hangzhou–Shenzhen route. As the two national hubs play the critical role in SF Airlines' network, the Hangzhou–Shenzhen route is shown in all the charts in Fig. 3.

The network of China Post has a similar feature to that of SF Airlines. Although most of its flights originate from and end at Nanjing, its main hub, this integrator also operates direct flights linking Beijing, Hangzhou and Guangzhou (Fig. 3). Circle routes are operated within the network, for example, Nanjing–Shenyang–Dalian–Weifang–Nanjing, Nanjing–Fuzhou–Xiamen–Nanjing and Nanjing–Fuzhou–Wenzhou–Xiamen–Nanjing. Some airports are in-transit airports between Nanjing and the far north and southwest cities. For example, Taiyuan, Nanchang and Changsha are intermediate airports connecting Hohhot, Nanning and Chongqing, respectively, in the network.

Although the network of YTO Express is small in scale, it covers the most economically developed areas in China. It operates with a basic functional structure that is less dependent on the mega-cities of Beijing, Shanghai and Guangzhou (Fig. 4). YTO Express' regular domestic flights service ten domestic destinations: provincial capitals, the economically developed coastal city of Wuxi and peripheral cities in central and western China such as Yulin in Shanxi Province. The network hierarchy has Hangzhou as a main hub and Xi'an, Shijiazhuang and Shenzhen as secondary regional hubs. Xi'an acts as an intermediate node to connect remote cities such as Yulin and Yinchuan accordingly. There are also connections between regional hubs such as Xi'an–Shijiazhuang and Shijiazhuang–Shenzhen. As an integrator, its coverage and capacity are insignificant.

As the analysis above shows, to achieve national coverage Chinese integrators have developed routes between Beijing, Shanghai, Guangzhou, Chengdu and cities around them to cover the most economically developed areas of China. Few carriers developed flights to cities in the northeast, Xinjiang and Inner Mongolia. In the networks of SF Express and China Post, most cities in the peripheral areas or with lower cargo demand connect directly to their main national hubs rather than secondary regional ones. Based on their different strategies and backgrounds, small-scale carriers will focus on density areas rather than national coverage. Regional airports play crucial roles in those networks. The choice of nodes for small integrators depends on their development strategies and the level of cooperation with the local authorities.

5. Topological measures and changes during the COVID-19 period

Examining the results of the topological measures in Table 5, we can see that the structures of the individual air express carriers in the Chinese domestic market underwent various adjustments during the pandemic. SF Express, China Post and YTO Express expanded their networks to more cities with significant route developments. Mainly operating in the private sector, SF Express increased the number of

Table 3
Cargo tonnage by aircraft type.

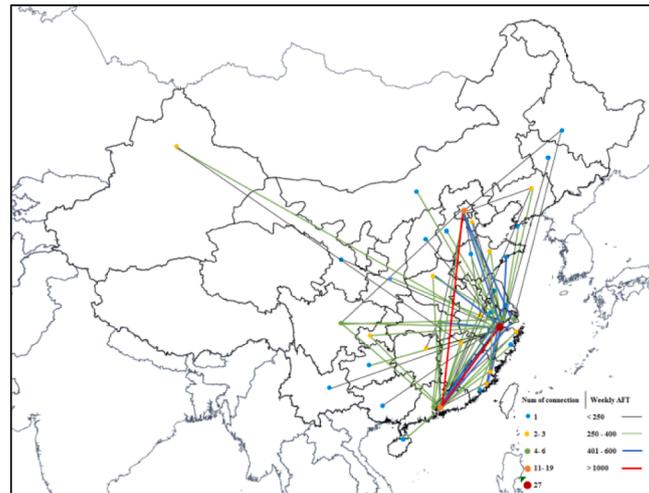
Freighter Type	Payload (tonnes)
B747-400F	112.00
B777F	102.00
B767-300F	52.48
B757-200F	35.00
B737-400F	20.50

Source: <https://www.boeing.com/commercial/freighters/>, accessed 22/12/2021.

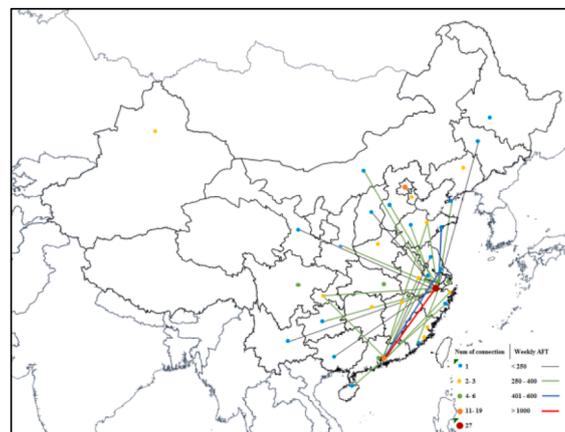
Table 4
 Characteristics of integrators' network structures.

Integrators	No. nodes (n)	No. edges (m)	Average degree $\langle K \rangle$	Average path length (L)	Diameter (D)	Clustering coefficient C
SF Express	39	125	6.41	2.20	4	0.307
China Post	27	66	4.89	2.45	5	0.383
YTO Express	10	20	4	1.97	4	0.192

(a) The overall network



(b) Hub-and-spoke structure



(c) Point-to-point structure

Fig. 2. SF Express' network.

routes by 30% to 125, while YTO Express doubled the size of its network. SF Express expanded its air cargo network to Huai'an, Xiamen and Taiyuan. The connection to these cities with a similar degree and closeness value helped SF Express to enhance its network coverage. As a new airport in Beijing, Daxing, commenced operation, SF Express developed new routes to connect Beijing with Hefei and the hub cities of Shenzhen, Chengdu and Wuhan. These cities and new routes increased SF Express' connectivity in 2020. YTO Express developed routes to the peripheral nodes of Shijiazhuang, Kunming and Yulin and to Nanchang on the east coast. The new routes enhanced the hub function of Xi'an. The isolated Guangzhou–Tianjin route was removed. Consequently, all cities in its network are now connected in one graph, and connectivity is optimised. At the same time, China Post improved its network by adding one node and revising the route between Dalian and Qingdao.

Overall, the integrators have developed their networks significantly

in the pandemic period. Private integrators have played the main role in driving the whole nation's scheduled freighter network optimisation. The index μ column in Table 5 suggests that SF Express operates the most developed networks in the country. The α ratios of SF Express and YTO Express increased. The γ values of YTO Express and China Post fell from 2019 to 2020 when the cohesiveness of these carriers decreased slightly. These developments reflect the situation whereby the integrators' networks are developing with nodes increasing faster than route developments, and so the density of the network becomes lower. According to the β column, SF Express maintains the best connectivity with the biggest network scale. With the lowest γ of 0.084, and considering the much larger scale of the network than other Chinese integrators, the network's density is still relatively scattered, and the level of centralisation is the highest.

In terms of weekly cargo AFT, all integrators enlarged their capacity

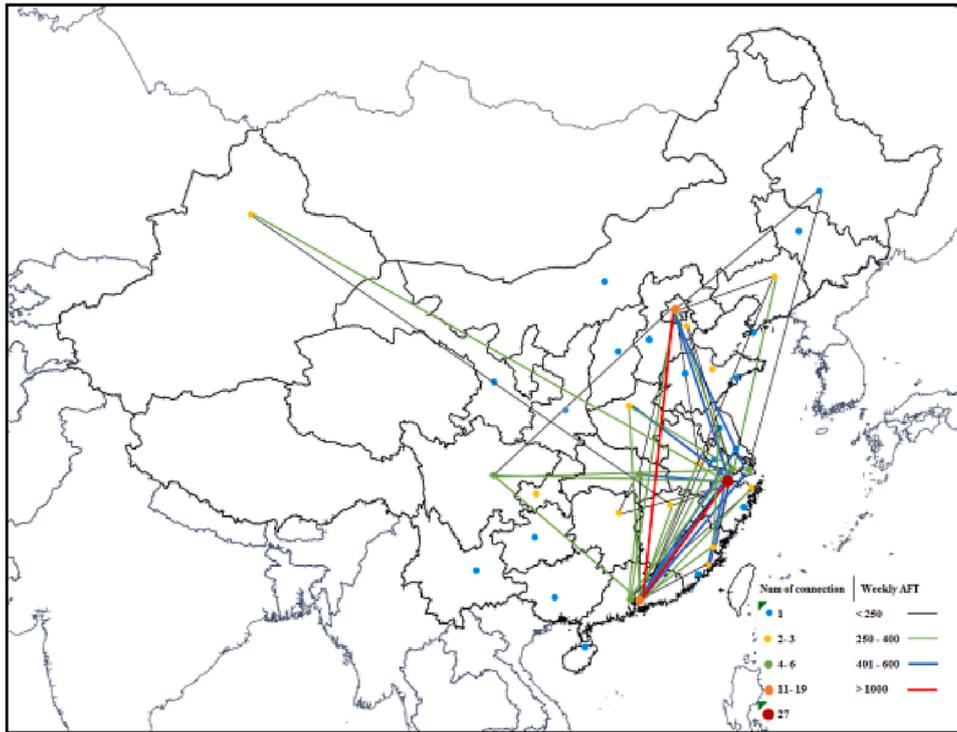


Fig. 2. (continued).

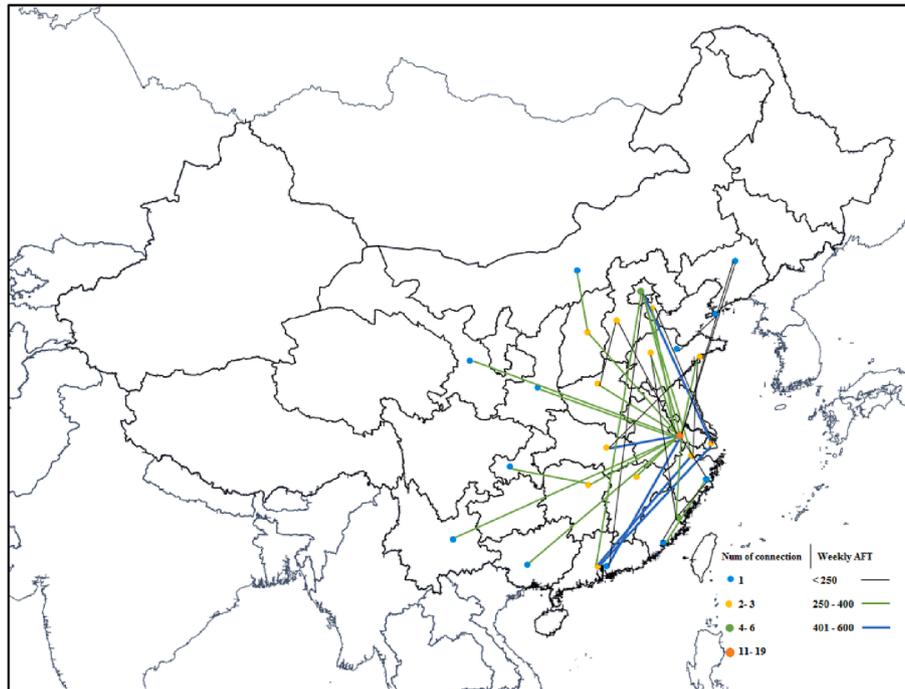


Fig. 3. China Post's Network.

in the first year after the pandemic outbreak. After network restructuring from remote cities in the southwest region to the central and east coast areas, and with more routes operating in the 2020 winter/spring timetable, YTO Express doubled its weekly AFT to 5412t. With support from air express volume, SF Express and China Post enhanced their weekly capacity by 28.4% and 3.1%, respectively.

The current study focuses on the individual integrators' network development while Deng et al. (2022) examined the all-cargo network at an aggregate level during the pandemic period, without disclosing

individual integrator's network features and characteristics. However, these two studies complement each other. The findings of the current research provide further evidence that the enhanced performance of the CSFN was not solely attributed to the substitution effect resulting from the reduction of belly-hold capacity on passenger aircraft. Instead, it was most likely driven by the increased demand for air cargo, at a time when the pandemic amplified the significance of e-commerce (Deng, et al., 2022).

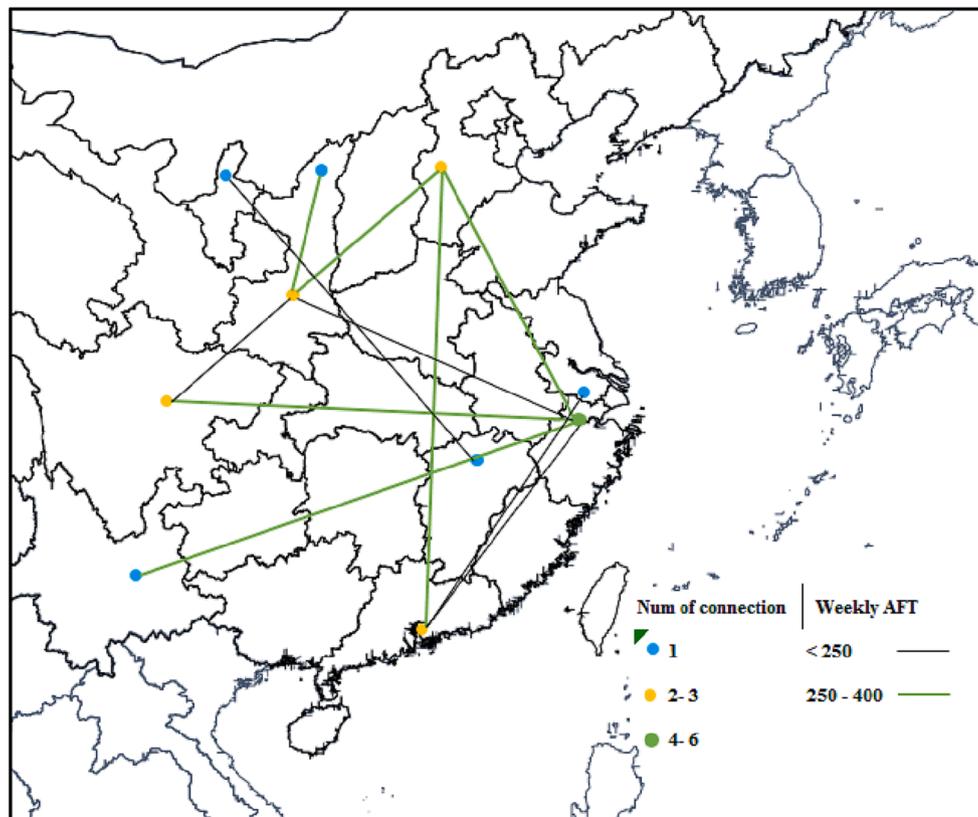


Fig. 4. YTO Express' Network.

Table 5
The network structure index by winter/spring schedules.

Airline	Year	<i>n</i>	<i>m</i>	μ	α	γ	β	Weekly AFT
SF Express	2019	36	96	13	0.194	0.076	2.667	30,586
	2020	39	125	24	0.329	0.084	3.205	39,278
China Post	2019	26	64	7	0.149	0.098	2.462	18,245
	2020	27	66	7	0.143	0.094	2.444	18,819
YTO Express	2019	8	10	0	0	0.357	1.25	2624
	2020	10	20	2	0.133	0.222	2.000	5412

6. Comparison with integrators in Europe

According to the World Bank (2020), in 2019 the European Union's gross domestic product reached USD15.626 trillion while mainland China's was USD14.28 trillion. These two markets have similar economic volumes and geographical areas. To understand the variations in network efficiency and capability between domestic and foreign carriers, we compare the topological indices and weekly AFT of carriers in these two markets. There are four dominating integrators – DHL, FedEx, TNT and UPS, in the European market (Malighetti et al., 2019b). In Table 6 navigable cities (*n*), edges (*m*), 'one-way flights percentage' and 'Weekly AFT' of four foreign carriers in the European market are collected and calculated by Malighetti et al. (2019b) from one-week scheduled flights in 2015.

In regard to the navigable cities (*n*) and links (*m*) in Table 6, the four European carriers have significant network size and coverage. SF Express and China Post are the two leading carriers in the Chinese domestic market with good-sized national networks. Unlike the European carriers' oligopolistic market position (Malighetti et al., 2019b), the Chinese air freight industry has fierce competition from numerous highway freight companies. In terms of weekly AFT, with a massive cargo demand SF Express and China Post together have more than 60% of the

Table 6
Comparing Chinese carriers' domestic networks with four European counterparts.

Carriers	<i>n</i>	<i>m</i>	β	γ	One-way flights %	Weekly AFT
DHL (in Europe)	87	265	3.05	0.035	48.0%	59,590
FedEx (in Europe)	40	85	2.13	0.054	43.0%	26,023
TNT (in Europe)	51	121	2.37	0.047	55.0%	13,250
UPS (in Europe)	35	74	2.11	0.062	20.0%	32,693
SF Express	39	125	3.21	0.084	9.0%	39,278
China Post	27	66	2.44	0.094	30.8%	18,819
YTO Express	10	20	2.00	0.222	18.2%	5412

market share in the scheduled air freighter flights. The other Chinese domestic carriers have small and fragmented portions only.

The β and γ indices can reflect the connectivity and centralisation of networks. In a network with a certain number of nodes, the maximal feasible number of links is determined. The higher the number of connections, the more paths are ready to connect nodes (Ducruet & Rodrigue, 2013). In this case, larger values of β and γ indicate better connectivity. Typically, however, airlines' networks with hub-and-spoke structures illustrate low β index and γ index values. In contrast, networks with point-to-point systems in the main have a larger value of these indices. Thus, networks inclined to centralisation have lower values of these indices (Malighetti et al., 2019b). Chinese integrators' β and γ are much higher than those of FedEx and UPS, which have a similar number of nodes. These facts reflect the higher degree of centralisation among the European carriers as compared to the Chinese ones.

SF Express' network shows the largest β with 3.21 in Table 6. It reflects a better connectivity with more direct routes between city pairs. First, SF Express has a lower percentage of one-way flights. Most city

pairs are connected with two direction links between them. Furthermore, SF Express with two national hubs has both hub-and-spoke and point-to-point structures. The result is a more complex and less centralised network. The values of the indices are according to the pattern shown in Fig. 3. The complexity increased in 2020 when SF Express' network increased by only three nodes but with 29 edges. Most of the new links are between Beijing, Shanghai, Guangzhou, Wuhan and Chengdu, which are the country's regional aviation centres.

In terms of the β , compared with UPS and FedEx, China Post has a smaller number of nodes but a larger β . It suggests that China Post' network structure is similar to that of SF Express, a mix of hub-and-spoke and point-to-point features. The result is consistent with Fig. 4. Beijing, Shanghai, Guangzhou and Hangzhou are connected and form the point-to-point pattern. They also serve as spoke cities with Nanjing being the main hub. However, in terms of one-way flight percentages, the value of China Post is between UPS and FedEx. Given that evidence, its network shown is more like a conventional integrator's air cargo network. To avoid empty backhauling in an uneven demand pattern, especially in the dedicated cargo networks of the air express freight industry, substantial proportions of flights run in one direction on round paths to make capacity utilisation more efficient (Malighetti et al., 2019b; Bombelli et al., 2020).

7. Discussion and conclusion

The analysis in this paper has revealed the characteristics of Chinese integrators' network and compared their topological measures and AFT with their European counterparts. In general, their network pattern reflects the companies' business strategies and focus. It is found that SF Express is the key player in the domestic market and formed its air cargo network different to other competitors. To support its national premium express delivery service, the carrier's network covers most of the cities, which currently are running schedule freighter flights, with the most being bidirectional routes. This characteristic in China of bidirectional routes contrasts with the situation in Europe where there is a high proportion of one-direction flights. The unique symmetric network pattern of SF Express shows that its cargo operation is distinct from the rest of its domestic and global competitors.

As discussed, the air freight operations often present 'big circle' or 'triangular' routes around a few destinations. This asymmetry is the result of imbalances in cargo demand (Zhang and Zhang, 2020; Bombelli, Santos & Tavasszy, 2020). Traffic imbalance is a big challenge in the air freight industry, and it can only be resolved through adjusting 'import/export imbalances' with the implementation of some long-term economic policies (Zhang and Zhang, 2020). The scheduled air freighter network of SF Express shows almost symmetry with a relatively small one-way flight percentage shown in Table 6. SF Express enjoys the most significant annual revenue with its primary growth coming from the e-commerce industry. Therefore, it appears that with the increase in consumption and the boom in e-commerce, when parts and goods are dispatched from manufacturing sites to consignees, air cargo demand imbalance challenges could be mitigated or overcome through filling the return flights with consumer products.

E-commerce, especially B2C, has been widely accepted and has changed public shopping behaviours, which in turn drives the development of China's air cargo industry. Without any visit to physical stores, shopping online breaks the space and time barriers and offers customers more convenient access to products (Wang & Xiao, 2015). With the help of e-commerce, choices of several categories of products such as electronics and even fresh food are not limited to local production. Relying on air cargo services for safe and speedy delivery, those products can be sold cross-province and even cross-border. As reported by SF Airlines (2019) in 2019, within the annual shopping festival 'Double 11', SF Airlines achieved an almost 30 % year-on-year growth in freight volume, among which includes a large proportion of electronics products and fresh food products.

Unlike global competitors such as FedEx and UPS in the US, which developed and dominated their market share before the e-commerce era, Chinese freight express firms emerged and developed during the e-commerce boom from 2006 to 2013 when online commerce caused extraordinary growth in parcel delivery volumes (Wang & Xiao, 2015). SF Express is one of them and puts a lot of volume on its inhouse cargo airlines to support its PDT and fresh food delivery business. In the Chinese domestic market, air freight still depends highly on the belly capacity of passenger flights with which all-cargo flights face fierce competition. Only with adequate demand can the carriers develop dedicated cargo flight routes and networks (Gong et al., 2018). The operation of bidirectional routes may imply that the cargo demand and the flow of SF Express's scheduled all cargo flights have reached a good balance thanks to the boom in the e-commerce market.

In sum, the paper applies topological measures to analyse China's three integrators. Referring to carriers' business development strategies, the paper explains how the network patterns shaped the current main national hubs and the function of the chosen secondary or regional hubs. The Chinese integrators have undergone great development in their networks one year after the COVID-19 pandemic outbreak.² Private integrators investment was the main force in driving the whole nation's scheduled freighter network optimisation. By comparing their network indices values with the ones of world-leading integrators in the European market, we see that the European carriers with their preponderance of hub-and-spoke structure have a higher degree of centralisation. In contrast, China's integrators have both hub-and-spoke and point-to-point structures, which make the network less centralised and more complex. We also found that SF Express' scheduled air freighter network, with its fewer one-way flights at a higher density, demonstrates different topological features from its counterparts in the Chinese domestic market and the European market. With massive delivery volume from e-commerce orders, the air cargo demand and flow of SF Express reach a good balance in the network. In the post Covid-19 outbreak period, the influence of e-commerce on air cargo would become more significant. Integrators are the main operators positioned to gain from the growth of e-commerce.

It should be pointed out that among the three integrators studied in this research, two of them are privately owned, which implies that private cargo carriers can respond effectively to the consumers' needs and thus make a critical contribution to a nation's economy. This contribution is particularly prominent in the event of a crisis like Covid-19. Therefore, a country's transport policy should treat the private carriers equally as the public ones and create an environment to facilitate their growth. Although our focus is on China's domestic integrator market, with the boom in cross-border e-commerce and continuing growth in international trade, there is a need to keep a close watch on how international integrators respond and adapt to the even-changing consumption trend and develop appropriate regulation measures accordingly.

CRedit authorship contribution statement

Yu Deng: Writing – original draft, Methodology, Formal analysis.
Yahua Zhang: Supervision, Methodology, Writing – review & editing.
Frank Elston: Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

² These development trend and pattern remain two years after the outbreak of Covid-19 after we have checked the most recent data.

References

- Balliauw, M., Meersman, H., Onghena, E., Van de Voorde, E., 2018. US all-cargo carriers' cost structure and efficiency: A stochastic frontier analysis. *Transp. Res. A Policy Pract.* 112, 29–45.
- Boeing, 2020. World Air Cargo Forecast 2020–2039, Boeing Commercial Airplanes, Seattle, US, https://www.boeing.com/resources/boeingdotcom/market/assets/downloads/2020_WACF_PDF_Download.pdf, viewed 8 Jul 2020.
- Boeing, 2021. Boeing freighter family, Boeing Commercial Airplane. Seattle, US, <https://www.boeing.com/commercial/freighters/>, viewed 22/03/2021.
- Bombelli, A., 2020. Integrators' global networks: A topology analysis with insights into the effect of the COVID-19 pandemic. *J. Transp. Geogr.* 87, 102815.
- Bombelli, A., Santos, B.F., Tavasszy, L., 2020. Analysis of the air cargo transport network using a complex network theory perspective. *Transport. Res. Part E: Log. Transport. Rev.* 138, 101959.
- Bowen Jr, J.T., 2012. A spatial analysis of FedEx and UPS: hubs, spokes, and network structure. *J. Transp. Geogr.* 24, 419–431.
- Budd, L., Ison, S., 2017. The role of dedicated freighter aircraft in the provision of global airfreight services. *J. Air Transp. Manag.* 61, 34–40.
- Cao, Y., Zhang, L., Shen, D., Wang, C., 2011. Research On The International Competitiveness Of Cargo Airways: With The Sample Of Air China Cargo. IEEEPublishing 9781424472536.
- Chen, SS, 2017. An exploration into sf shenzhen 'command center.' Why can wang wei make express delivery faster and safer, Yicai, 25 February, Shanghai, China, <https://www.yicai.com/news/5233717.html>, viewed 4 Aug 2019.
- Deng, Y., Zhang, Y., Wang, K., 2022. An analysis of the Chinese scheduled freighter network during the first year of the COVID-19 pandemic. *J. Transp. Geogr.* 99, 103298.
- Doganis, R., 2019. *Flying off course: Airline economics and marketing*, 4th ed. Routledge.
- Ducruet, C. & Rodrigue, JP, 2013. Graph theory: Measures and indices. The geography of transport systems. <https://transportgeography.org/contents/methods/graph-theory-measures-indices>, viewed 8 Dec 2020.
- Fang, W., Wan, Y., Gao, Y., 2009. Analysis of mainland China's international air cargo network: status quo and challenges. In 9th International Conference on Electronic Business, Macau, November 30 - December 4, 2009 <http://iceb.johogo.com/proceedings/2009/838-845.pdf>, viewed 28 Oct 2020.
- Farooq, Q., Fu, P., Hao, Y., Jonathan, T., Zhang, Y., 2019. A review of management and importance of e-commerce implementation in service delivery of private express enterprises of China. *SAGE Open* 9 (1).
- Hossain, M.M., Alam, S., 2017. A complex network approach towards modeling and analysis of the Australian airport network. *J. Air Transp. Manag.* 60, 1–9.
- Kupfer, F., Kessels, R., Goos, P., van De Voorde, E., Verhetsel, A., 2016. The origin–destination airport choice for all-cargo aircraft operations in Europe. *Transport. Res. Part E: Log. Transport. Rev.* 87, 53–74.
- Kupfer, F., Meersman, H., Onghena, E., Van de Voorde, E., 2017. The underlying drivers and future development of air cargo. *J. Air Transp. Manag.* 61, 6–14.
- Li, T., 2020. A SWOT analysis of China's air cargo sector in the context of COVID-19 pandemic. *J. Air Transp. Manag.* 88, 101875.
- Li, Z., Bookbinder, J.H., Elhedhli, S., 2012. Optimal shipment decisions for an airfreight forwarder: Formulation and solution methods. *Transport. Res. Part C: Emerg. Technol.* 21 (1), 17–30.
- Liu, Y., Kang, T., 2015. Operational model of China's express services industry: A case study of SF-Express. *J. Internat. Trade Commerce* 11 (5), 43–58.
- Ma, W., Wang, Q., Yang, H., Zhang, Y., 2020a. Evaluating the price effects of two airline mergers in China. *Transport. Res. Part E: Log. Transport. Rev.* 141, 102030.
- Ma, W., Wang, Q., Yang, H., Zhang, Y., 2020b. Is multimarket contact an antitrust concern? A case of China's airline market. *Transp. Res. A Policy Pract.* 132, 515–526.
- Malighetti, P., Martini, G., Redondi, R., Scotti, D., 2019a. Air transport networks of global integrators in the more liberalised Asian air cargo industry. *Transp. Policy* 80, 12–23.
- Malighetti, P., Martini, G., Redondi, R., Scotti, D., 2019b. Integrators' air transport networks in Europe. *Netw. Spat. Econ.* 19 (2), 557–581.
- Merkert, R., 2023. Air cargo and supply chain management. In: Sarkis, J. (Ed.), *The Palgrave Handbook of Supply Chain Management*. Palgrave Macmillan Cham.
- Morrell, P.S., Klein, T., 2018. *Moving Boxes By Air: The Economics Of International Air Cargo*. Routledge.
- Onghena, E., Meersman, H., Van de Voorde, E., 2014. A translog cost function of the integrated air freight business: The case of FedEx and UPS. *Transp. Res. A Policy Pract.* 62, 81–97.
- Park, Y., Choi, J.K., Zhang, A., 2009. Evaluating competitiveness of air cargo express services. *Transport. Res. Part E: Log. Transport. Rev.* 45 (2), 321–334.
- SF Airlines 2017, About SF Airlines. SF Airlines, Shenzhen, China, http://www.sf-airlines.com/sfa/en/article_141.html, viewed 12 March 2019.
- SF Airlines, 2019, Meeting Head-on Logistics Peak, SF Airlines Sees Steady Increase of Freight Volume, SF Airlines, Shenzhen, China, http://www.sf-airlines.com/sfa/en/article_2729.html, viewed 1 Jun 2021.
- SF Holding 2019, Annual report 2018. SF holding, Shenzhen, China, <https://www.sf-express.com/cn/sc/download/20190316-2018-SF-Annual-Report.PDF>, viewed on 21 Apr 2019.
- SF Holding, 2020. Annual report 2019. SF Holding, Shenzhen, China, <https://www.sf-express.com/cn/sc/download/20200324-IR-RPT-1-2019.PDF>, viewed 19 Apr 2020.
- State Post Bureau, 2020. 2019 Express market supervision report. Beijing, China, <http://www.spb.gov.cn/zy/xxgg/202007/W020200901585557453012.pdf>, viewed 21 Nov 2020.
- Suau-Sanchez, P., Voltes-Dorta, A., Cugueró-Escofet, N., 2020. An early assessment of the impact of COVID-19 on air transport: Just another crisis or the end of aviation as we know it? *J. Transp. Geogr.* 86, 102749.
- Van Asch, T., Dewulf, W., Kupfer, F., Cárdenas, I., van de Voorde, E., 2020. Cross-border e-commerce logistics – Strategic success factors for airports. *Res. Transp. Econ.* 79, 100761 viewed 12 Feb 2021.
- Wang, J., Mo, H., Wang, F., Jin, F., 2011. Exploring the network structure and nodal centrality of China's air transport network: A complex network approach. *J. Transp. Geogr.* 19 (4), 712–721.
- Wang, J.J., Xiao, Z., 2015. Co-evolution between e-tailing and parcel express industry and its geographical imprints: The case of China. *J. Transp. Geogr.* 46, 20–34.
- Wu, C., Liao, M., Zhang, Y., Luo, M., Zhang, G., 2020. Network development of low-cost carriers in China's domestic market. *J. Transp. Geogr.* 84, 102670.
- Xiao, H., 2011, Study on e-commerce post express service in China. In 5th International Conference on Management and Service Science, Wuhan, China, pp.1–4.
- Zhang, A., Zhang, Y., 2020. 2002, Issues on liberalisation of air cargo services in international aviation. *J. Air Transp. Manag.* 8 (5), 275–287. [https://doi.org/10.1016/S0969-6997\(02\)00008-X](https://doi.org/10.1016/S0969-6997(02)00008-X), viewed 18 Apr.