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## Article

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## Original Article

Analysis of weighted network centrality for cold chain commodities in international air cargo under the COVID-19 pandemic<sup>☆</sup>Youngwoong Park, Seung Bum Ahn<sup>\*</sup>, Jae Chul Sohn

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## ABSTRACT

Air Cargo plays a key role under the global supply chain crisis brought about by COVID-19 pandemic. This study aims to analyze empirically the transport patterns and correlations of key commodities of cold chain in air cargo. We analyzed air cargo O-D data by weight for key commodities including pharmaceutical and coolchain products for top 100 airports in the last 10 years. We analyzed weighted centralities for key cold chain commodities traffic using social network analysis methodology. Whereas previous studies focused on unweighted centrality metrics, this study covered weighted centrality metrics, which represent more accurate empirical situation. The international air cargo networks for cold chain are significantly improved after COVID-19. Comparative analysis of cold chain traffic trends for top 10 international air cargo airports was also performed. The role of top 10 airports in the performance of air cargo transportation was found to be more important, especially in COVID-19 period.

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## 1. Introduction

In international trade, transportation industry consists of an important part of the global economy, and active inter-continent transportation has intensified dependence on shipping and aviation. In the past, freight transportation in international trade was mainly done by sea or land, and only some special items were subject to air transport. However, due to the introduction of wide-body aircraft, containerization of air cargo, automation of ground operation, downsizing of the manufacturing sector, increased demand for transportation of high-value-added cargo, and inventory management policies, air cargo has become an important mode of transportation in international trade. Air cargo has characteristics such as high speed, high-quality maintenance, high fares, and small-volume transportation, and is mainly transported centering on IT, fresh cargo, medicine, and high-value-added items. Recently, air freight transportation has been on the rise due to the expansion of the IT product and e-commerce market. As of 2019, 48% of global air cargo transportation items consist of high-tech products such as

semiconductors, computers, electronics, and parts. Next, 26% are special goods and chemicals such as art, luxuries, and dangerous goods, and the remaining 26% consists of various other items, such as machinery, transportation equipment, clothing, fresh, refrigerated food, and other cool chain products (Accenture, 2022).

Air cargo accounts for less than 1% of world trade in terms of transport weight, but transports more than \$6 trillion of goods annually, accounting for more than 35% of world trade in terms of item value and is expected to grow by an annual average of 4.0% per tonnage from 2020 to 2039 (Boeing, 2020). In particular, after COVID-19, air cargo is expected to increase greatly by 13% compared to 2019 (IATA, 2020).

Factors affecting air cargo growth are complex and sometimes changes are severely affected. The volume of air cargo on a particular route varies with sudden and inexplicable changes in circumstances. Unlike air passengers who tend to return to their origin, air cargo shows a more complex pattern, since it has no particular patterns of direction. Extensive analysis of the types of air cargo commodities is required because they include a directional imbalance of air cargo transport and a variety of goods that require special handling.

As COVID-19 has caused a shortage of essential machines and medical supplies around the world, establishing a stable supply chain for medicines including vaccines is emerging as a key policy task in each country. There are increasing concerns in countries with

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**Table 1**  
Airport code list.

IATA code	Airport name	Country	IATA code	Airport name	Country
AMS	Amsterdam	Netherlands	LGG	Liege	Belgium
ARN	Stockholm	Sweden	LHR	London	United Kingdom
ATH	Athens	Greece	LIS	Lisbon	Portugal
ATL	Atlanta GA	United States	LOS	Lagos	Nigeria
AUH	Abu Dhabi	United Arab Emirates	LUX	Luxembourg	Luxembourg
BCN	Barcelona	Spain	MAA	Madras	India
BKK	Bangkok	Thailand	MAD	Madrid	Spain
BLR	Bangalore	India	MCT	Muscat	Oman
BNE	Brisbane	Australia	MEM	Memphis TN	United States
BOG	Bogota	Colombia	MEX	Mexico City	Mexico
BOM	Mumbai	India	MIA	Miami FL	United States
BOS	Boston MA	United States	MNL	Manila	Philippines
BRU	Brussels	Belgium	MUC	Munich	Germany
BUD	Budapest	Hungary	MXP	Milan	Italy
CAI	Cairo	Egypt	NBO	Nairobi	Kenya
CAN	Guangzhou	China	NGO	Nagoya	Japan
CDG	Paris	France	NKG	Nanjing	China
CGK	Jakarta	Indonesia	NRT	Tokyo	Japan
CGN	Cologne	Germany	OAK	Oakland CA	United States
CKG	Chongqing	China	ORD	Chicago IL	United States
CTU	Chengdu	China	PDX	Portland OR	United States
DEL	New Delhi	India	PEK	Beijing	China
DEN	Denver CO	United States	PEN	Penang	Malaysia
DOH	Doha	Qatar	PHL	Philadelphia PA	United States
DUB	Dublin	Ireland	PHX	Phoenix AZ	United States
DXB	Dubai	United Arab Emirates	PTY	Panama City	Panama
EMA	East Midlands	United Kingdom	PVG	Shanghai	China
EZE	Buenos Aires	Argentina	RUH	Riyadh	Saudi Arabia
FCO	Rome	Italy	SCL	Santiago	Chile
FRA	Frankfurt	Germany	SDF	Louisville KY	United States
GDL	Guadalajara	Mexico	SDQ	Santo Domingo	Dominican Republic
GRU	Sao Paulo	Brazil	SEA	Seattle WA	United States
HAN	Ha Noi	Viet Nam	SFO	San Francisco CA	United States
HGH	Hangzhou	China	SGN	Ho Chi Minh City	Viet Nam
HKG	Hong Kong SAR	China	SHJ	Sharjah	United Arab Emirates
HNL	Honolulu HI	United States	SIN	Singapore	Singapore
HYD	Hyderabad	India	SJO	San Jose	Costa Rica
IAD	Washington DC	United States	SVO	Moscow	Russian Federation
IAH	Houston TX	United States	SYD	Sydney	Australia
ICN	Incheon	Republic of Korea	SZX	Shenzhen	China
IND	Indianapolis IN	United States	TAO	Qing Dao	China
ISL	Istanbul	Turkey	TLV	Tel-Aviv	Israel
JFK	New York NY	United States	TPE	Taipei	Taipei
KHN	Nanchang	China	TSN	Tianjin	China
KIX	Osaka	Japan	WAW	Warsaw	Poland
KMG	Kunming	China	XIY	Xi An	China
KUL	Kuala Lumpur	Malaysia	XMN	Xiamen	China
LAX	Los Angeles CA	United States	YVR	Vancouver BC	Canada
LCK	Columbus OH	United States	YYC	Calgary AB	Canada
LEJ	Leipzig	Germany	YYZ	Toronto ON	Canada

high dependence on overseas drug supply and demand as major drug and raw material producers temporarily restrict exports or disrupt production due to the vaccine-producing country's domestic priority policy. Air cargo is a key in vaccine distribution through temperature-sensitive distribution systems using state-of-the-art technologies and procedures and has proven to be a very important means of transport for fast and efficient transport of COVID-19 vaccines. Thorough planning by all sectors of the entire cargo supply chain is needed to ensure complete readiness when the COVID-19 vaccine is approved and ready for distribution. To ensure the quality of the vaccine, the handling and transportation of the vaccines must comply with international regulations and manufacturer's requirements and requires temperature controls without any delays. In this study, global trade data (Accenture, 2022) is used to track changes in centrality before and after COVID using Social Network Analysis to compare and analyze the network of pharmaceuticals and fresh food, which are representative items of air transport O-D transportation and cold chain. In addition, it was intended to understand the

change in centrality and the air transport pattern of cold chain commodities.

## 2. Social network analysis in the aviation sector

Social Network Analysis (SNA) study analyzed the spatial and geographical features and development of the network by analyzing the 20 years of U.S. airlines' flight schedules from 1990 to 2010 (Lin & Ban, 2014), and a comparative study of the transition process of hub and spoke networks of major airlines was conducted by analyzing the Social Network of flight schedule data in Europe from 1994 to 2004 for large European Full Service Carriers (FSC) and Low-Cost Carriers. (LCC) (Alderighi et al., 2007). In addition, the centrality ranking of airports was measured through network centrality analysis on air schedules for the top 20 airports selected based on 2011 annual passenger processing performance, suggesting that if two or more airports have the same efficiency value, it is useful to

**Table 2**  
Top 50 airports ranked by weighted centrality scores (international air cargo).

Degree centrality				Closeness centrality				Betweenness centrality			
2019		2021		2019		2021		2019		2021	
HKG	1	1	–	HKG	4	1	+3	TPE	4	1	+3
TPE	3	2	+1	TPE	5	2	+3	DXB	2	2	–
NRT	4	3	+1	NRT	8	3	+5	HKG	1	3	–2
ICN	6	4	+2	PVG	6	4	+2	ISL	7	4	+3
PVG	2	5	–3	LAX	14	5	+9	NRT	9	5	+4
DXB	5	6	–1	ICN	11	6	+5	PVG	5	6	–1
ISL	9	7	+2	FRA	7	7	–	ICN	10	7	+3
FRA	7	8	–1	AMS	12	8	+4	FRA	6	8	–2
AMS	10	9	+1	DXB	10	9	+1	MIA	8	9	–1
LHR	8	10	–2	BKK	9	10	–1	AMS	11	10	+1
LAX	14	11	+3	ISL	17	11	+6	LAX	20	11	+9
ORD	17	12	+5	SIN	15	12	+3	LHR	3	12	–9
BKK	11	13	–2	ORD	18	13	+5	ORD	23	13	+10
CAN	15	14	+1	HAN	25	14	+11	ATL	24	14	+10
CDG	13	15	–2	CAN	22	15	+7	JFK	13	15	–2
JFK	16	16	–	KIX	16	16	–	SEA	25	16	+9
MIA	19	17	+2	LHR	13	17	–4	YYZ	26	17	+9
BOG	22	18	+4	SGN	26	18	+8	GRU	19	18	+1
HAN	27	19	+8	NBO	23	19	+4	MAD	15	19	–4
SIN	18	20	–2	JFK	21	20	+1	NBO	27	20	+7
KIX	20	21	–1	BOM	19	21	–2	LGG	28	21	+7
KUL	24	22	+2	CDG	28	22	+6	SZX	29	22	+7
GRU	21	23	–2	PEN	31	23	+8	PEK	22	23	–1
PEK	12	24	–12	MIA	33	24	+9	BOG	21	24	–3
CGK	33	25	+8	PEK	20	25	–5	DOH	30	25	5
SFO	34	26	+8	KUL	37	26	+11	CDG	14	26	–12
SGN	31	27	+4	SFO	44	27	+17	SIN	31	27	+4
SCL	23	28	–5	CGK	34	28	+6	LEJ	32	28	+4
ATL	40	29	+11	TSN	50	29	+21	CAN	33	29	+4
MAD	25	30	–5	BOG	36	30	+6	LUX	34	30	+4
BOM	26	31	–5	CKG	27	31	–4	BKK	12	31	–19
NBO	32	32	–	SZX	39	32	+7	CGN	35	32	+3
SZX	53	33	+20	BLR	38	33	+5	MEM	36	33	+3
SYD	30	34	–4	ATL	47	34	+13	KIX	37	34	+3
MEX	38	35	+3	MXP	46	35	+11	BOM	38	35	+3
DEL	28	36	–8	SCL	45	36	+9	SGN	39	36	+3
YYZ	35	37	–2	MAA	29	37	–8	OAK	40	37	+3
MNL	36	38	–2	DEL	32	38	–6	PHL	41	38	+3
MXP	39	39	–	GRU	42	39	+3	SDF	42	39	+3
IAH	42	40	+2	SYD	30	40	–10	SYD	43	40	+3
CKG	44	41	+3	MNL	24	41	–17	AUH	44	41	+3
XMN	46	42	+4	XMN	35	42	–7	MNL	45	42	+3
PEN	50	43	+7	MAD	49	43	+6	KUL	46	43	+3
EZE	37	44	–7	TAO	43	44	–1	CGK	47	44	+3
SEA	58	45	+13	MEX	58	45	+13	MXP	48	45	+3
CTU	56	46	+10	LUX	73	46	+27	BRU	49	46	+3
BRU	47	47	–	SEA	65	47	+18	HAN	50	47	+3
BLR	45	48	–3	CAI	41	48	–7	MEX	51	48	+3
MAA	43	49	–6	CTU	56	49	+7	DEL	16	49	–33
YVR	41	50	–9	HYD	48	50	–2	HNL	52	50	+2

determine a more reasonable ranking through centrality values (Choi et al., 2014).

A network study of 44 airports in the Asia-Pacific region emphasized the importance of Incheon International Airport in the integration of air transport markets in Korea, China, and Japan (Oh & Park, 2010). Through a comparative analysis of major airports in the world for 20 years from 1995 to 2015, the process of changing the international passenger transport network from hub-intensive to decentralized was suggested (Kim & Ahn, 2017a).

Network analysis of air cargo analyzed the centrality of international air cargo networks between continents using origin-destination transport data from the International Civil Aviation Organization, (ICAO) (Kim & Ahn, 2017b), and study on the process of cargo transfer was conducted through the analysis of the concentration of airports by dividing major Asian airports into Northeast Asian and Southeast Asian regions (Chung, 2015). In addition,

network analysis with neighboring countries for the domestic air cargo market highlighted the necessity of discussing linkage with adjacent industrial complexes and demand sites to mitigate the centrality of low cargo volume in domestic airports (Lee et al., 2017).

A network analysis study on passenger and cargo presented implications for understanding the changing patterns of aviation networks in Southeast Asia and the development of Incheon Airport through a study on the centrality of Social Network Analysis (SNA) method for about 10 years from 2006 to 2016 (Chen & Lee, 2019).

Opsahl et al. (2010) present a more accurate framework for network analysis by presenting a weighted centrality model based on link weights to overcome the limitations of traditional binary SNA binary network analysis models. Chung et al. (2020) evaluated the connectivity and transshipment hub index of major airports as a mean association index indicating the node strength of the degree of connectivity centrality through weighted centrality analysis, Node

**Table 3**  
Top 50 airports ranked by weighted centrality scores (pharmaceuticals).

Degree Centrality				Closeness Centrality				Betweenness Centrality			
2019		2021		2019		2021		2019		2021	
PVG	1	1	-	PVG	2	1	+1	FRA	1	1	-
FRA	2	2	-	FRA	1	2	-1	PVG	2	2	-
CAN	11	3	+8	CAN	9	3	+6	ICN	9	3	+6
PEK	5	4	+1	PEK	3	4	-1	NRT	6	4	+2
ICN	15	5	+10	ICN	14	5	+9	GRU	15	5	+10
CDG	7	6	+1	SZX	27	6	+21	LHR	4	6	-2
LHR	8	7	+1	XMN	24	7	+17	YYZ	23	7	+16
NRT	12	8	+4	CKG	23	8	+15	PEK	11	8	+3
SZX	43	9	+34	CTU	26	9	+17	EZE	22	9	+13
DEL	13	10	+3	NRT	6	10	-4	CAI	25	10	+15
BOM	16	11	+5	CDG	7	11	-4	BOG	13	11	+2
BRU	14	12	+2	LHR	8	12	-4	LGG	26	12	+14
NBO	29	13	+16	HGH	35	13	+22	CAN	27	13	+14
CKG	39	14	+25	TAO	32	14	+18	CDG	8	14	-6
XMN	51	15	+36	BRU	12	15	-3	DXB	10	15	-5
DUB	22	16	+6	NBO	11	16	-5	KIX	28	16	+12
MAD	26	17	+9	BOM	4	17	-13	HKG	29	17	+12
MXP	27	18	+9	MXP	15	18	-3	SCL	30	18	+12
TLV	30	19	+11	DEL	5	19	-14	DEL	31	19	+12
GRU	28	20	+8	LGG	51	20	+31	SYD	24	20	+4
CTU	48	21	+27	NKG	39	21	+18	TPE	32	21	+11
SYD	36	22	+14	BLR	21	22	-1	DOH	33	22	+11
HGH	73	23	+50	MAA	19	23	-4	MIA	34	23	+11
YYZ	35	24	+11	KIX	18	24	-6	SIN	14	24	-10
EZE	37	25	+12	TLV	13	25	-12	AMS	5	25	-20
BLR	49	26	+23	YYZ	31	26	+5	ORD	35	26	+9
MUC	19	27	-8	MAD	20	27	-7	LAX	7	27	-20
MAA	47	28	+19	HYD	25	28	-3	LEJ	36	28	+8
BOG	44	29	+15	MUC	16	29	-13	LUX	37	29	+8
FCO	34	30	+4	FCO	17	30	-13	BKK	19	30	-11
YVR	42	31	+11	CGK	22	31	-9	CGN	38	31	+7
KIX	40	32	+8	SYD	29	32	-3	ISL	16	32	-16
TAO	57	33	+24	YVR	33	33	-	JFK	3	33	-30
HYD	54	34	+20	GRU	28	34	-6	MEM	39	34	+5
LGG	83	35	+48	DUB	10	35	-25	BOM	18	35	-17
CGK	45	36	+9	EZE	30	36	-6	ATL	40	36	+4
SCL	62	37	+25	HKG	45	37	+8	SGN	41	37	+4
HKG	61	38	+23	CAI	42	38	+4	OAK	42	38	+4
XIY	67	39	+28	TSN	40	39	+1	PHL	43	39	+4
BCN	52	40	+12	XIY	46	40	+6	SDF	44	40	+4
DXB	63	41	+22	BNE	41	41	-	AUH	45	41	+4
NKG	69	42	+27	BUD	37	42	-5	MNL	46	42	+4
SJO	65	43	+22	SCL	43	43	-	KUL	47	43	+4
BNE	58	44	+14	BCN	34	44	-10	CGK	48	44	+4
CAI	70	45	+25	YYC	48	45	+3	MXP	49	45	+4
TSN	64	46	+18	BOG	36	46	-10	BRU	50	46	+4
ATH	84	47	+37	DXB	44	47	-3	HAN	51	47	+4
KMG	71	48	+23	NGO	38	48	-10	MEX	12	48	-36
KHN	92	49	+43	KHN	52	49	+3	SZX	52	49	+3
BUD	56	50	+6	SJO	50	50	-	HNL	53	50	+3

Betweenness Centrality as an evaluation indicator for a transshipment hub airport, and triangle betweenness centrality that can effectively reflect passenger traffic at Asian hub airports.

### 2.1. Network analysis on pharmaceuticals

Domestic and international literature on supply chain management of pharmaceuticals is summarized. [Bocek et al. \(2017\)](#) addressed how blockchain can be applied to the pharmaceutical industry to ensure quality management and compliance with regulations on the transportation of pharmaceuticals. In transporting pharmaceuticals, sensors presented processes utilized for definite data corruption and open access to temperature records. [Kumar et al. \(2019\)](#) used the Fuzzy Analysis Hierarchy Process (AHP) to prioritize risks to categorize potential risks when adopting Green Supply Chain (GSC) management in the pharmaceutical industry. The result found that cold chain technology and supply chain risk categories were highly prioritized by organization managers to achieve sustainability

from an operational perspective. [Shamsuzzoha et al. \(2020\)](#) investigated the inbound process of Finnish pharmaceutical companies and compared it with the developed model of a centralized pipeline system and how a centralized logistics system can minimize transportation costs to support environmental damage and provide benefits to the target country's entry process. The study found that centralized pipeline systems are proven to provide improved information flow, increased cargo capacity and reduced carbon dioxide emissions to support environmentally friendly and sustainable supply chains and logistics processes. [Sharma & Modgil \(2019\)](#) tested and evaluated alternative models through structural equation modeling the effects and interconnections of Total Quality Management (TQM), operational performance, and Supply Chain Management (SCM) practices on operational performance. The study found that TQM practices have a direct impact on operational performance. However, TQM practices have a direct impact on supply chain components, which in turn affects overall operational performance. When comparing alternative models, a model in which TQM

**Table 4**  
Top 50 airports ranked by weighted centrality scores (cool chain products).

Degree centrality				Closeness centrality				Betweenness centrality			
2019		2021		2019		2021		2019		2021	
ORD	6	1	+5	BOG	2	1	+1	AMS	2	1	+1
LAX	2	2	-	NBO	3	2	+1	ORD	3	2	+1
NBO	1	3	-2	SCL	1	3	-2	PVG	1	3	-2
SCL	3	4	-1	LAX	4	4	-	NRT	4	4	-
JFK	4	5	-1	ORD	8	5	+3	LHR	8	5	+3
BOG	5	6	-1	GRU	7	6	+1	SYD	7	6	+1
MIA	10	7	+3	AMS	5	7	-2	LAX	5	7	-2
BKK	7	8	-1	JFK	6	8	-2	BKK	6	8	-2
SYD	9	9	-	ISL	10	9	+1	SCL	10	9	+1
AMS	8	10	-2	MIA	11	10	+1	CAI	11	10	+1
SFO	11	11	-	SJO	12	11	+1	ISL	12	11	+1
ATL	15	12	+3	CAI	9	12	-3	BOG	9	12	-3
GRU	12	13	-1	EZE	17	13	+4	MIA	17	13	+4
MEX	14	14	-	MEX	13	14	-1	DXB	13	14	-1
ISL	17	15	+2	LHR	14	15	-1	ICN	14	15	-1
CAI	16	16	-	SFO	15	16	-1	JFK	15	16	-1
LHR	13	17	-4	ATL	19	17	+2	MAD	19	17	+2
NRT	32	18	+14	BOM	18	18	-	GRU	18	18	-
BOM	24	19	+5	SYD	25	19	+6	YYZ	25	19	+6
SEA	26	20	+6	TLV	20	20	-	NBO	20	20	-
SJO	30	21	+9	DEL	21	21	-	SFO	21	21	-
CGK	20	22	-2	BKK	16	22	-6	PTY	16	22	-6
IAH	19	23	-4	BLR	32	23	+9	TPE	32	23	+9
YYZ	22	24	-2	PTY	33	24	+9	HKG	33	24	+9
DEL	25	25	-	PVG	23	25	-2	CAN	23	25	-2
KUL	21	26	-5	IAH	22	26	-4	BOM	22	26	-4
PVG	18	27	-9	SEA	31	27	+4	GDL	31	27	+4
IAD	31	28	+3	YYZ	27	28	-1	SVO	27	28	-1
BNE	23	29	-6	MAA	28	29	-1	MEX	28	29	-1
ICN	35	30	+5	CGK	24	30	-6	CDG	24	30	-6
MAD	27	31	-4	NRT	37	31	+6	DOH	37	31	+6
TLV	33	32	1	YVR	29	32	-3	FRA	29	32	-3
YVR	29	33	-4	IAD	26	33	-7	SIN	26	33	-7
MNL	28	34	-6	SDQ	35	34	+1	LEJ	35	34	+1
CDG	36	35	+1	HYD	38	35	+3	LGG	38	35	+3
EZE	38	36	+2	KUL	34	36	-2	LUX	34	36	-2
BOS	37	37	-	ATH	45	37	+8	CGN	45	37	+8
BLR	42	38	+4	HNL	46	38	+8	MEM	46	38	+8
MAA	41	39	+2	TPE	42	39	+3	KIX	42	39	+3
CAN	39	40	-1	FRA	52	40	+12	ATL	52	40	+12
TPE	40	41	-1	GDL	56	41	+15	SGN	56	41	+15
FRA	44	42	+2	BOS	36	42	-6	PEK	36	42	-6
HAN	47	43	+4	MNL	39	43	-4	OAK	39	43	-4
HNL	46	44	+2	MAD	30	44	-14	PHL	30	44	-14
PTY	51	45	+6	CAN	50	45	+5	SDF	50	45	+5
SGN	45	46	-1	BNE	40	46	-6	AUH	40	46	-6
HYD	48	47	+1	ICN	47	47	-	MNL	47	47	-
SDQ	49	48	+1	HAN	51	48	+3	KUL	51	48	+3
GDL	54	49	+5	CDG	48	49	-1	CGK	48	49	-1
PEK	34	50	-16	PEK	43	50	-7	MXP	43	50	-7

practices affect supply chain practices and supply chain practices affect operational performance is considered the most appropriate. Risks affecting pharmaceutical companies could hinder the supply of medicines and the effectiveness of the medical system, and Multi-Criteria Decision Making (MCDM) methodology based on a Fuzzy AHP approach to prioritize and rank risks in the Pharmaceutical Supply Chain (PSC). The five major risk measurements in the Indian PSC identified 24 risks, with supply and supply risks as the most significant risks in the Indian PSC, and argued that for the pharmaceutical supply chain, continuous supply of pharmaceuticals is important (Vishwakarma et al., 2016).

Through a survey for the establishment of a pharmaceutical wholesale animal center in the national industrial complex Incheon, the distribution conditions and actual conditions of pharmaceutical wholesalers were investigated, as well as the logistics conditions and joint logistics of industrial complexes in Incheon. The result of the

SWOT analysis and project feasibility analysis of the Incheon National Industrial Complex found it to be economical with a cost-benefit of 1.03 and concluded it to be feasible to establish a pharmaceutical wholesale animal center. (Jung & Ji, 2011).

### 3. Methodology

#### 3.1. Weighted degree centrality

The network in airlines refers to a set of air routes used to produce and sell transport services on a regular basis. An air network is an organic combination of individual air routes of economic value, operating as a system by combining the number of airports with schedules between each airport.

In a network, the connection of nodes refers to a link, and the basic components of a network are node and link. In this study, in an



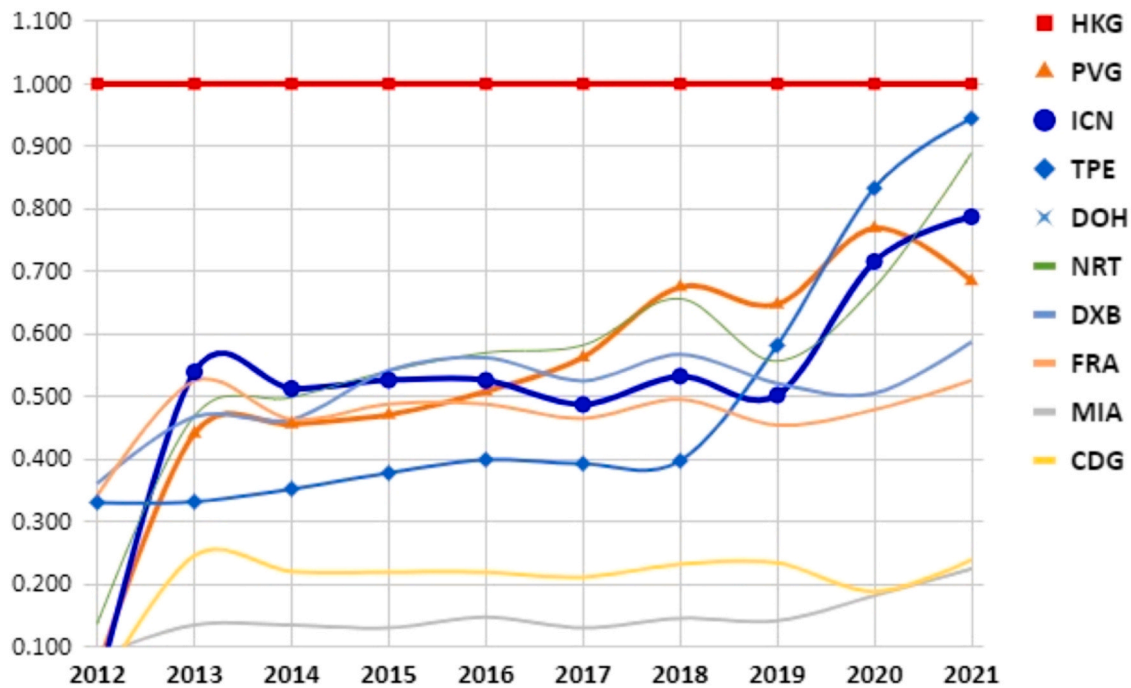


Fig. 1. International cargo weighted degree trend (2012–2021).

air freight network, a node is an airport or a country, and a link is a route operated by an aircraft, connecting nodes.

The study is conducted using the centrality theory of Social Network Analysis.

Centrality was developed with the concept of power and influence which has a structural position of each node in a social network and is the most frequently used index in analyzing social networks. In a social network, the centrality of a node can be defined as an index that expresses the degree of dominance and influence as one

node is located at the center of the entire network. In social networks, nodes with high centrality are referred to as a central node or a hub node.

In general, analyzing the location by the number of links of each node in a network is a binary network centrality index, whereas an index analyzing the location of each node for each weighted network is a weighted network centrality index (Barrat et al., 2004). The types of centrality can be categorized by the analysis method. Among the indicators, weighted degree centrality, weighted closeness

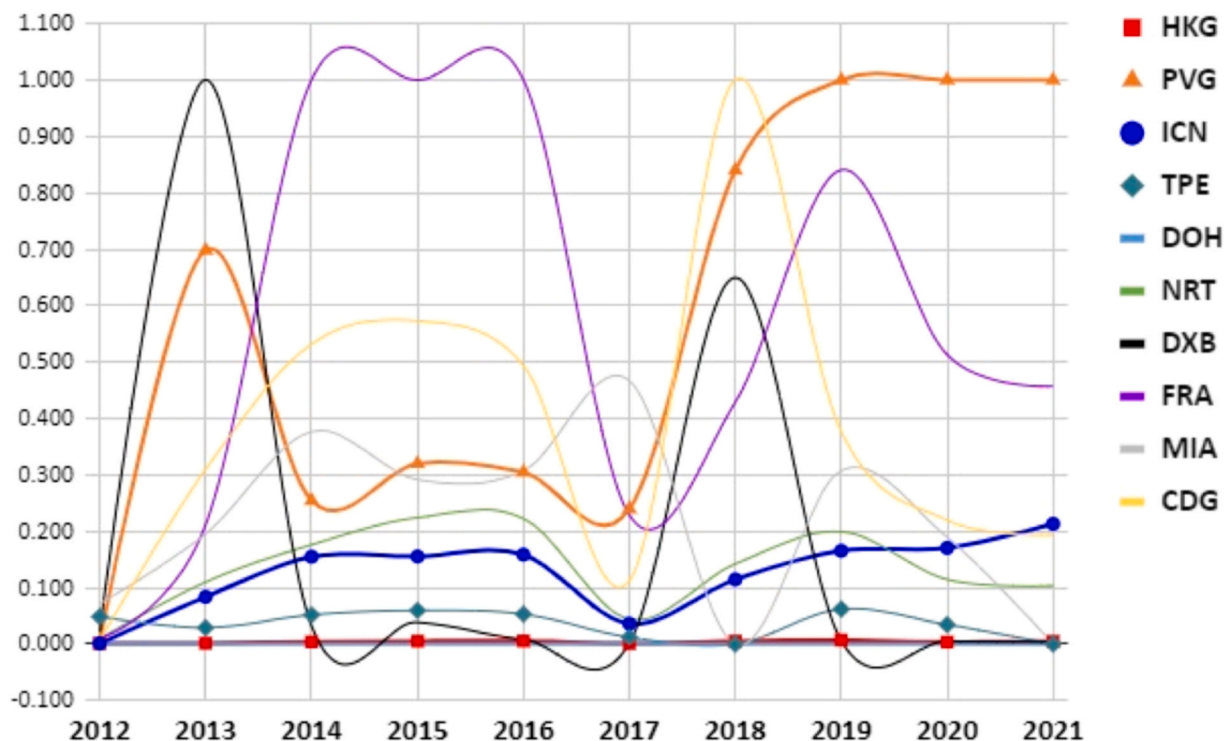


Fig. 2. Pharma weighted degree trend (2012–2021).

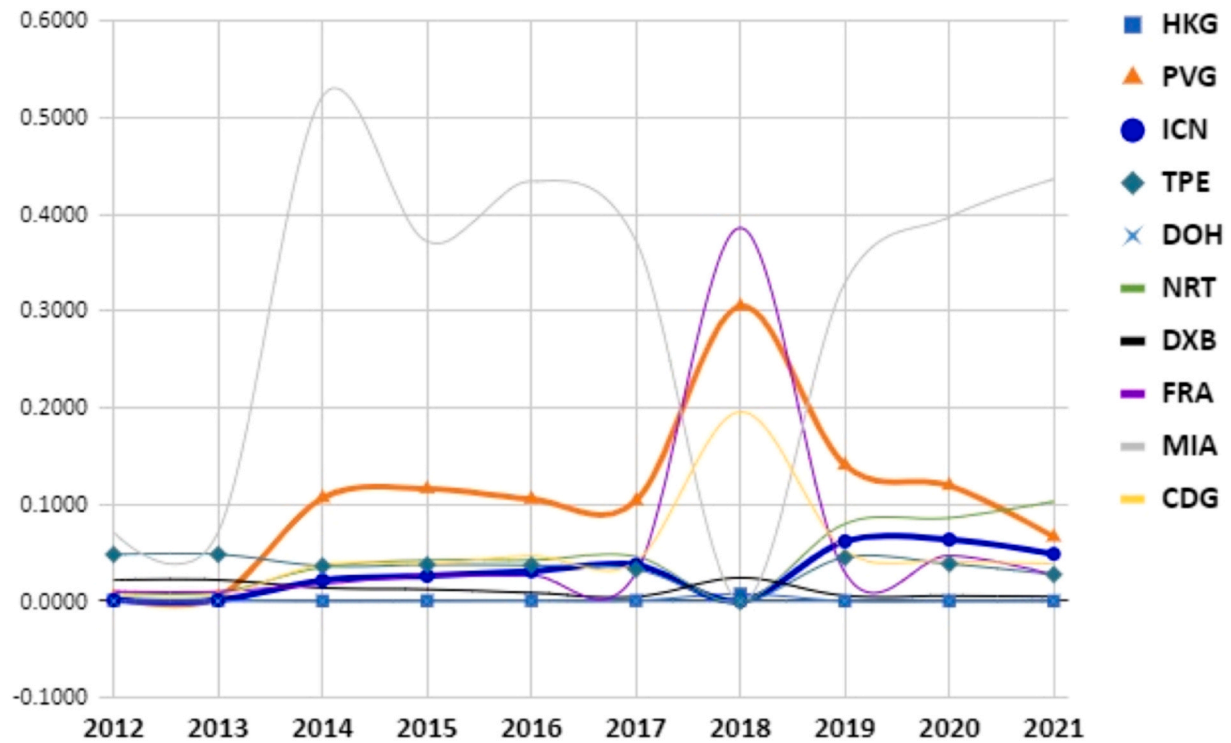


Fig. 3. Cool chain weighted degree trend (2012–2021).

centrality, and weighted betweenness centrality are the most frequently used indicators, as it reflects air transport networks (Freeman, 1978). In this study, weighted degree centrality, weighted closeness centrality, and weighted betweenness centrality are used as indicators for analyzing weighted networks.

Centrality index can be calculated in various methods. The importance here is not how high the value is for the value of the centrality. The centrality values calculated for each node in the

network are not analyzed by the absolute size, but data representing relative rankings. In other words, it represents the relative centrality of nodes within a network.

Weighted degree centrality is expressed as a percentage of other nodes in the network to the maximum number of possible connections and measures how the level of connections. For air routes, only direct routes are considered. Weighted degree centrality is based on the idea that the more node connections an individual has

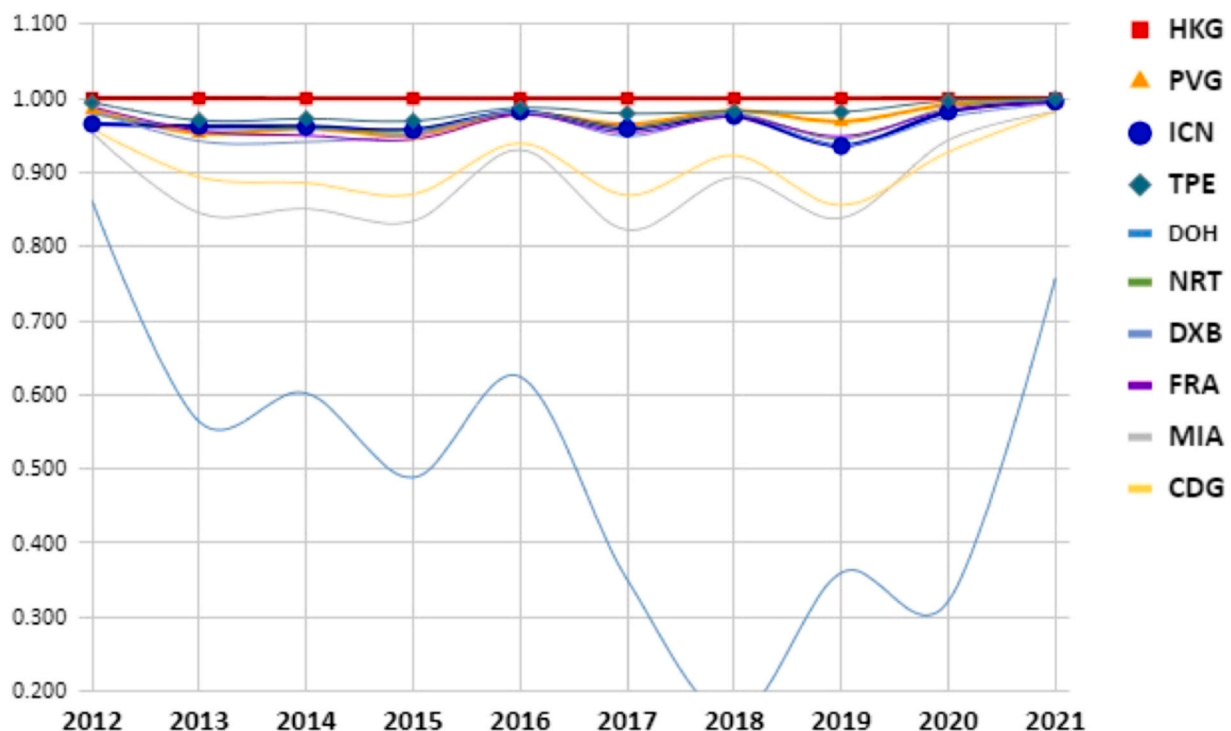


Fig. 4. Cargo weighted closeness trend (2012–2021).



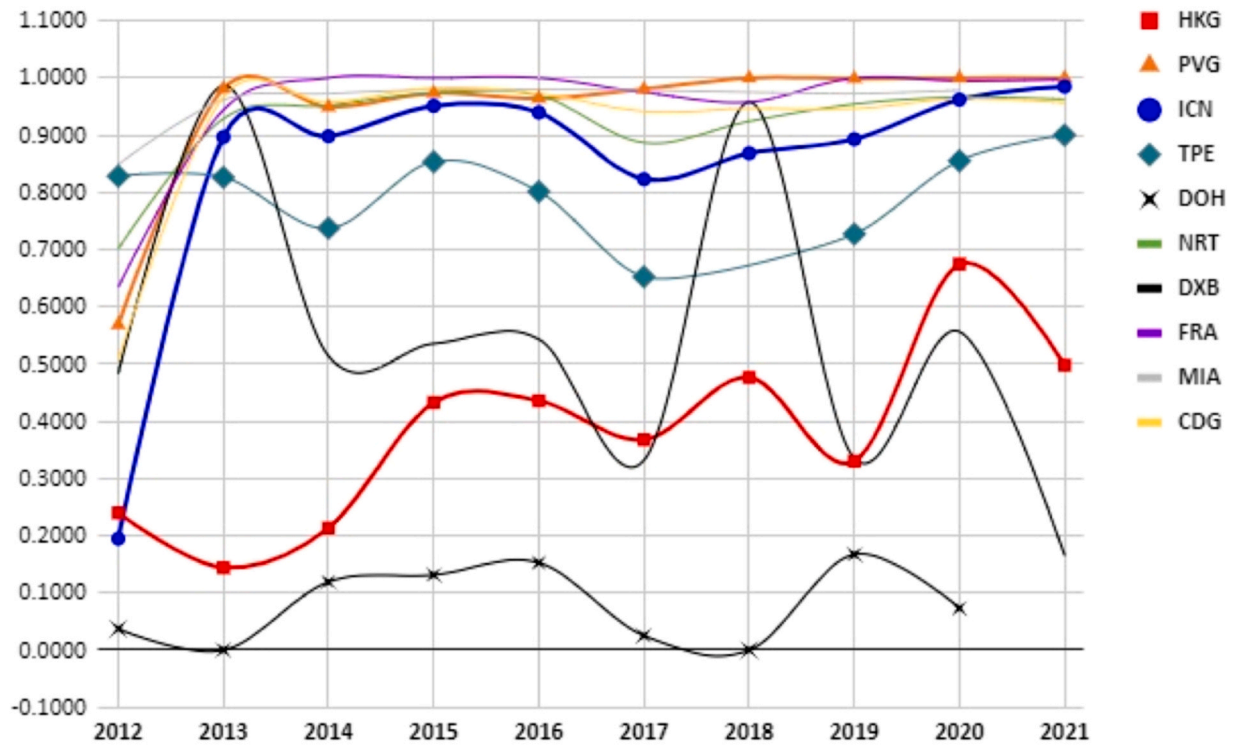


Fig. 5. Pharma weighted closeness trend (2012–2021).

in a network, the more autonomy, control, and power (Hanneman & Riddle, 2005). Nodes with many connections have a stronger influence as they have a wider range of autonomy and more opportunities to choose from.

Airports with many connections to other airports can enjoy the initiative in terms of location and frequency on the network. There is a high possibility that it will be easy to access other airports in the

network through many connection routes and develop into a hub airport that relays connections between airports.

Freeman (1978) asserted that the degree of a focal node is the number of adjacencies in a network, that is, the number of nodes that the focal node is connected to. In a weighted degree centrality in a network, a node measures the degree to which a node is connected to another node within the network and can be formalized as:

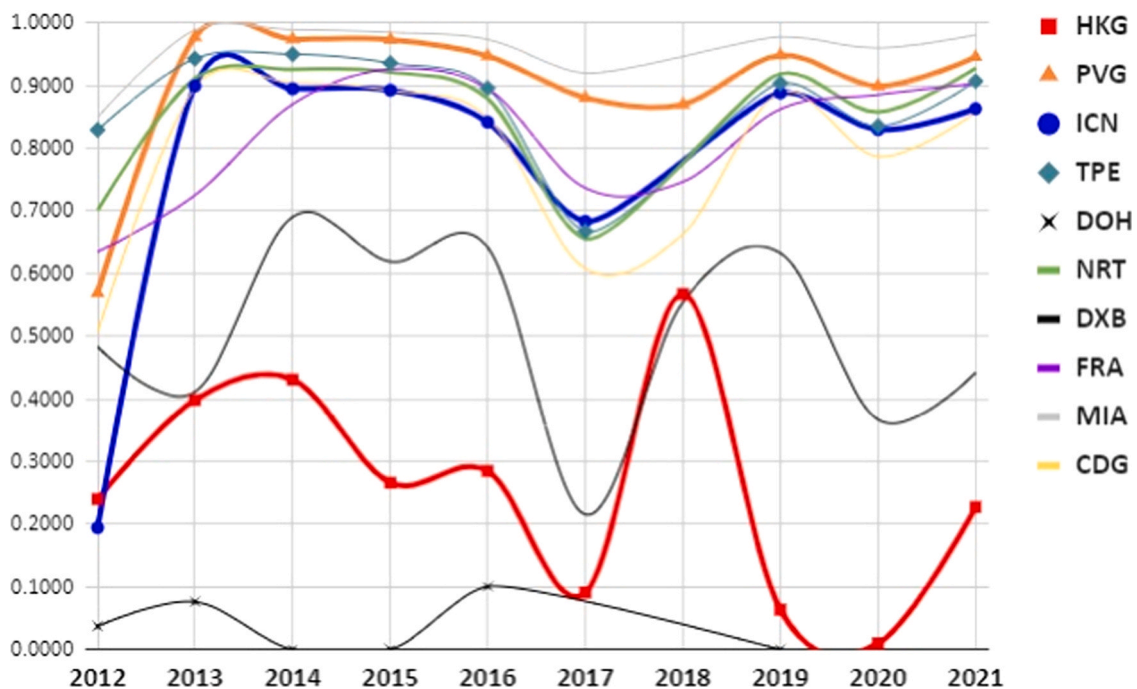


Fig. 6. Cool chain weighted closeness trend (2012–2021).

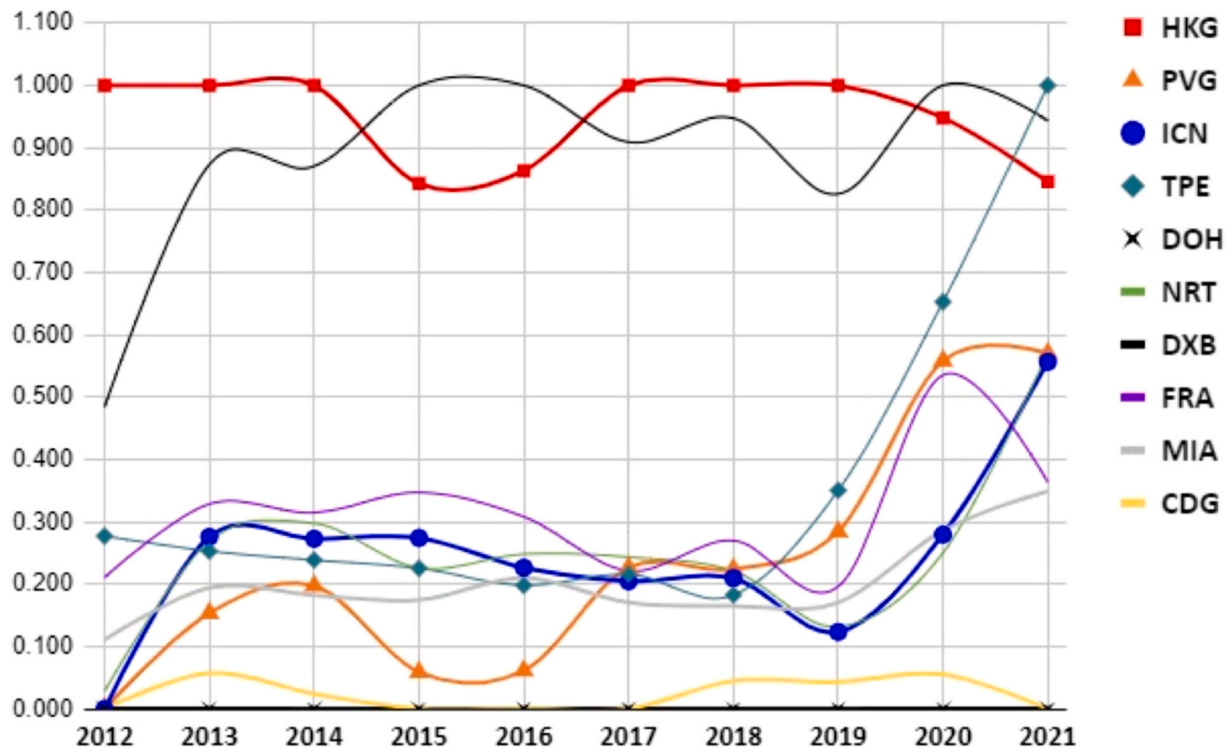


Fig. 7. International cargo weighted betweenness trend (2012–2021).

$$C_D(i) = \sum_j^N x_{ij}, i \neq j$$

where.

i: focal airport.

j: other international airports.

N: total number of airports.

$x$ : adjacency matrix.

$x_{ij}$ : 1 if and only if there is a freight between airport i and j.

0 otherwise.

$\sum_j^N x_{ij}$ : Number of trades between airport i and all other international airports.

$C_D(i)$ : Weighted degree centrality of airport i.

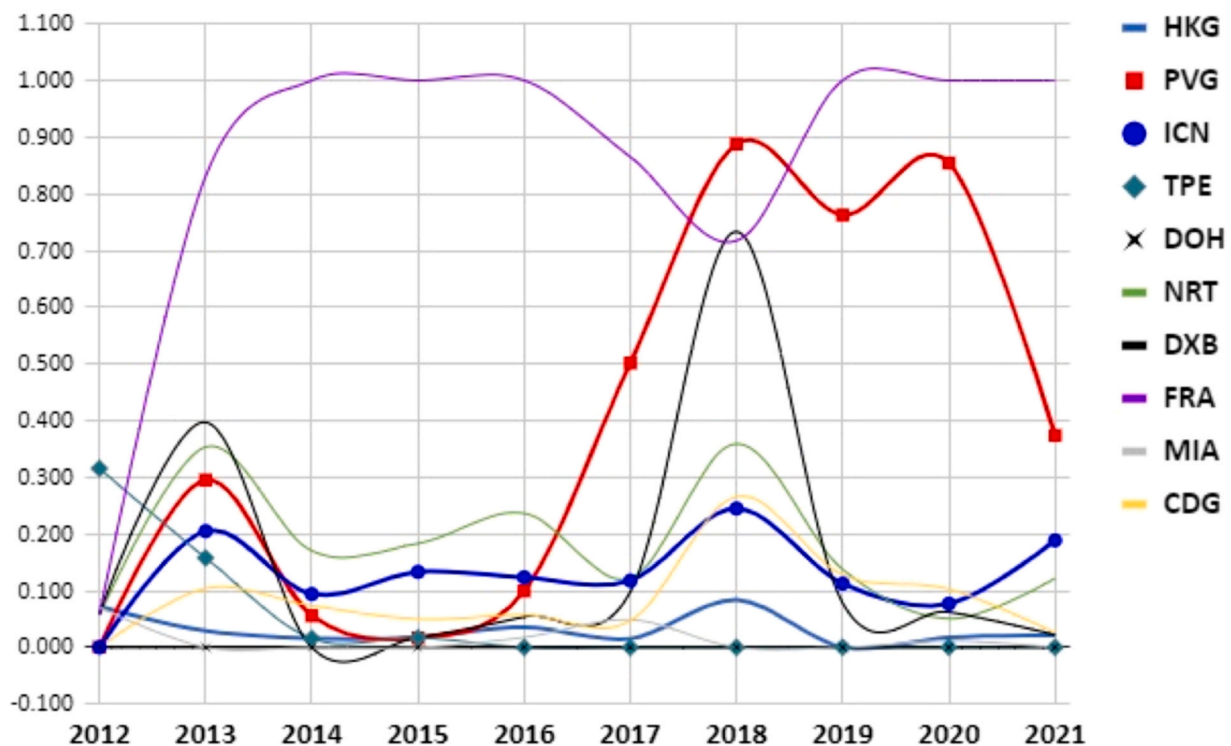


Fig. 8. Pharma weighted betweenness trend (2012–2021).

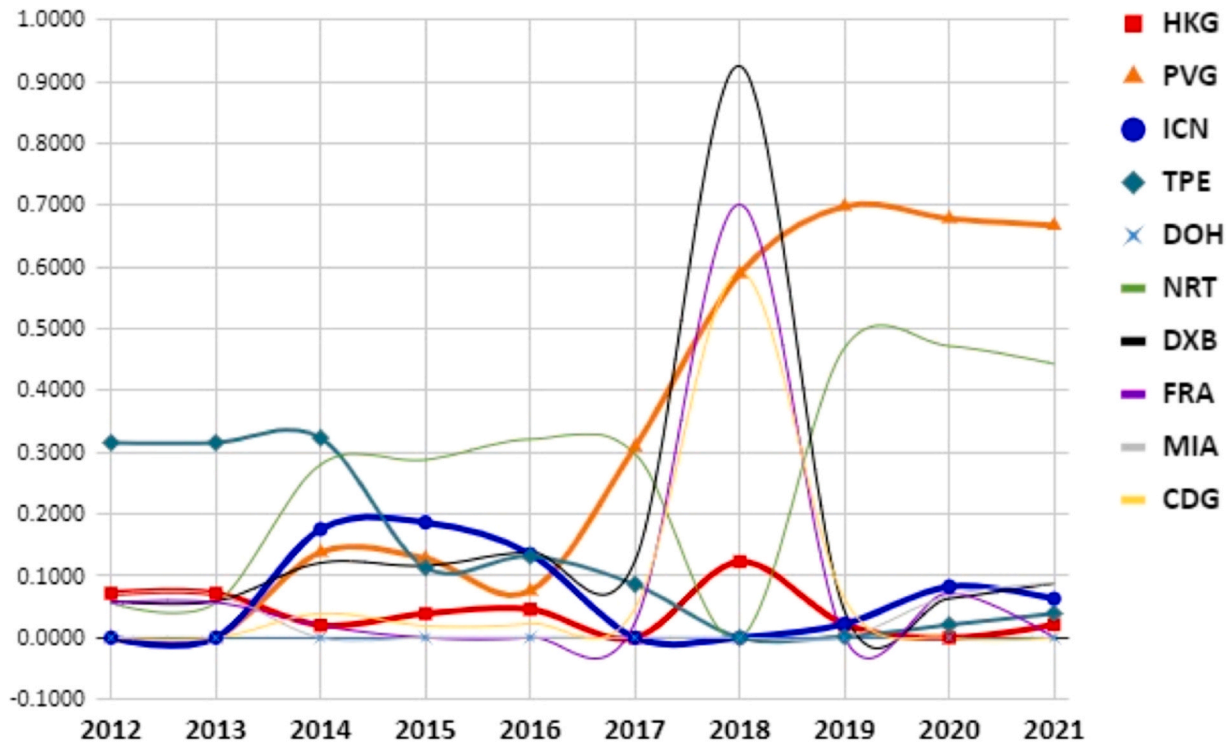


Fig. 9. Cool chain weighted betweenness trend (2012–2021).

Since social network analysis provides binary analysis, it analyzes geographical characteristics that can determine whether flights and routes between specific O-D (origin/departure airport-destination/arrival airport) exist, which may be insufficient for various quantitative data analysis. Therefore, to accurately analyze the air cargo network, we present a model that can grasp the economic meaning through an analysis weighted by O-D traffic.

In general, when analyzing a weighted network, it was expanded to the sum of weights, and the degree of weighted connection was measured and expressed by the equation below Eq. (1) (Opsahl et al., 2010).

$$C_D^w(i) = \sum_j^N w_{ij}, i \neq j$$

where.

i: focal airport.

j: other international airports.

N: total number of export countries.

w: weighted adjacency matrix.

$w_{ij}$ : greater than 0 if there is a freight between airport i and j, and the value represents freight volume between airport i and other international airports.

$\sum_j^N w_{ij}$ : Freight volume between airport i with all other international airports.

$C_D^w(i)$ : Weighted degree centrality of airport i.

This is equal to the definition of degree if the network is binary, that is, each tie has a weight of 1. Conversely, in weighted networks, the outcomes of these two measures are different.

To compensate for the disadvantage of not reflecting the number of connected links when the weights are numerically added, an equation (2) reflecting the weighted degree centrality combining connection degree centrality and node strength was proposed to adjust the relative importance to parameter  $\alpha$  (Opsahl et al., 2010).

$$C_D^{w\alpha}(i) = C_D(i) \times \left( \frac{C_D^w(i)}{C_D(i)} \right)^\alpha = C_D(i)^{(1-\alpha)} \times (C_D^w(i))^\alpha$$

where  $\alpha$  is a positive tuning parameter that can be set according to the research setting and data. In the weighted degree centrality equation, if the strength parameter is 0, then the outcome would be the same as degree centrality, and if it is 1, then the node and strength are equal. If it is greater than 1, then as the level of connection decreases, the centrality increases. In the study, we set the parameter value to 1.

In the air transportation network, an airport with a high degree centrality means it is highly connected with other airports (Chung et al., 2020). Weighted degree centrality is used to measure the strength of the volume of air freight increasing products between countries or airports.

### 3.2. Weighted closeness centrality

The closeness of one node is a concept that refers to the shortest distance, or route distance, from all other nodes in the network. Closeness centrality is to see how close one node is to the other node, which is measured based on the shortest distance between the two nodes. The smaller the sum of the route distance from one node to all other nodes in the network, the higher the closeness centrality of the corresponding node. Since nodes with the shortest link distance occupy a good location to easily reach several other nodes, nodes with a higher closeness centrality generally are in the center of the network. In general, the closer the distance between airports from the network status, the more connecting routes are made.

Since it measures how close one node is to the other, closeness centrality (Freeman, 1978) is expressed as a function of the shortest path distance from all other nodes, formalized as:

$$C_c(i) = \left[ \sum_j^N d(i, j) \right]^{-1}, i \neq j$$

where  $\sum_j^N d(i, j)$  is the sum of binary shortest country distances between two countries.

In a binary network, the path distance between nodes is measured by the number of connection steps, but the sum of the reciprocals of each link weight constituting that path is considered as the path distance in the weighted network. The shortest path between nodes is expressed as follows (Opsahl et al., 2010).

$$d^{wa}(i, j) = \min \left( \frac{1}{(w_{ik})^a} + \frac{1}{(w_{jk})^a} \right)$$

In the equation,  $a$  is a parameter that adjusts the degree to which the weight is reflected. If  $a$  is 0, the number of steps of the path becomes a binary network centrality, if less than 1, a short path with a weak weight is preferred as the shortest distance, and if  $a$  is greater than 1, it tends to be preferred as the shortest path with a strong weight. In this study, the analysis was conducted by setting the weight parameter to 1, to account for the empirical scenario where the route distance between airports A and B is not affected by the number of airports between the adjacent airports.

The definition of weighted proximity centrality (Opsahl et al., 2010) based on the path distance in the weighted network is formalized as:

$$C_c^w \alpha(N_i) = \left[ \sum_j^N d^{w\alpha}(i, j) \right]^{-1}$$

In this paper, weighted betweenness centrality is used to assess whether a country or an airport is located at the shortest distance between all other countries or airports.

### 3.3. Weighted betweenness centrality

Betweenness centrality measures the degree to which a node is located 'between' other nodes in a network and represents the degree to which it controls or relays relationships between nodes that are not directly connected. Betweenness centrality targets the entire network containing the corresponding node rather than the adjacent network, and the location of the corresponding node within the entire network becomes an important factor in determining centrality. Thus, betweenness centrality is measured to the extent that a particular node is located on a line connecting the shortest distance, the shortest path connecting a pair within the network, i.e. the shortest path. In this paper, weighted betweenness centrality is used as an indicator to evaluate the probability of control or brokerage between two nodes in a network and is recognized as a good representation of the function of transshipment airports in an air network (Kim & Ahn, 2017a). The expression of betweenness centrality (Freeman, 1978) is proposed the following measure:

$$C_B(i) = \frac{g_{jk}(i)}{g_{jk}}, i \neq j \neq k$$

where  $g_{jk}$  is the number of binary shortest routes between the airports, and  $g_{jk}(i)$  is the number of those routes that go through airport  $i$ .

The definition of weighted closeness centrality (Opsahl et al., 2010) based on the path distance in the weighted network is formalized as:

$$C_B^{w\alpha}(i) = \frac{g_{jk}^{w\alpha}(i)}{g_{jk}^{w\alpha}}$$

In the weighted closeness centrality equation,  $C_B^{w\alpha}(i)$  is the number of shortest paths between nodes.

### 3.4. Data and network

Data from Global Trade Data (Accenture, 2022) provided by Accenture were used as inputs for the analysis of pharmaceuticals. For pharmaceuticals (Level 2, Pharmaceuticals) by country of air transport by item, the statistics on export countries (origin), import countries (arrival), and air transport weight statistics were analyzed. From the annual data collected, a cold chain transport network model was conducted for 10 years (from 2012 to 2021). For network nodes, import and export countries, which are aggregated units of pharmaceutical trade data, were used instead of airports. The airport route was a link to the network, and the network was established by considering the weight of the link for the weight ton of international air cargo, pharmaceuticals, and cool chain products between airports. To avoid data bias due to underlying outliers, only routes with an annual volume of 1 ton or more were included in the dataset.

The study analyzes three different commodity groups of international air cargo transport. First is the total volume of international air cargo, to analyze evolutions and trends of the overall air cargo network of the leading countries. Second is the pharmaceuticals group, since due to the influence of COVID-19, the lack of supply of essential pharmaceuticals and medical supplies has occurred in various parts of the world, and the establishment of a stable supply chain for pharmaceuticals, including COVID-19 prevention vaccines, is emerging as a key policy task for each country. Third is the cool chain group, representing overall temperature-sensitive items transported by air. The study mainly focuses on the trends and comparative performances of air cargo, and temperature-sensitive items, especially focusing pharmaceuticals, to capture the competitiveness of each country's ability to secure critical items.

For the analysis of weighted network centrality for medicines, tnet of program R was used. Pharmaceuticals are classified as a subcategory of chemical industrial products. The weighted degree centrality, weighted closeness centrality, and weighted betweenness centrality were analyzed using global trade data provided by Accenture, which is more adequate for global air cargo network analysis.

Pharmaceutical statistics of level 2 in Global Trade Data provided by Accenture (2022) were used for this study. The scope is pharmaceutical air cargo transport data for 20 years from 2000 to 2019, and air transport data from exporting countries to importing countries were analyzed. To avoid data bias due to outliers having extremely low volume, only routes with annual drug volume of more than 1 ton were included in the list, and the top 100 ranking airports (ACI, 2021) in international air cargo metric tons were included (Table 1).

## 4. Empirical analysis

### 4.1. Weighted degree centrality

Tables 2–4 show the top 50 airports ranked by weighted centrality scores of international air cargo, pharmaceuticals, and cool chain products. There are subtle changes among the top ranks of international air cargo, but rank changes of pharmaceuticals and cool chain products after COVID-19 are significant. HKG, TPE, NRT, ICN, PVG, DXB, ISL, FRA, AMS, and LHR are the top airports by weighted degree centrality of international air cargo in 2021, but PVG, FRA, CAN, PEK, ICN, CDG, LHR, NRT, SZX and DEL are those by degree centrality of pharmaceuticals, ORD, LAX, NBO, SCL, JFK, BOG, MIA, BKK, SYD, and AMS are those by degree centrality of cool chain products.

In terms of weighted degree centrality of international air cargo, indices of TPE, NRT, and ICN are continuously improving after COVID-19 (see Fig. 1). But the score of PVG fell after that. CAN, ICN, SZX, NBO, CKG, and XMN are significantly improved in weighted



degree centrality scores of pharmaceuticals (see Fig. 2). The top 10 airports except MIA show reduction after COVID-19 in weighted degree centrality scores of cool chain products (see Fig. 3).

#### 4.2. Weighted closeness centrality

Weighted closeness centrality has a high correlation with degree centrality, because the closer the distance is, the higher the possibility of connection.

HKG, TPE, NRT, LAX, ICN, FRA, AMS, DXB, and BKK are the top airports by weighted closeness centrality of international air cargo in 2021, PVG, FRA, CAN, PEK, ICN, SZX, XMN, CKG, CTU, and NRT are those by weighted closeness centrality of pharmaceuticals, BOG, NBO, SCL, LAX, ORD, GRU, AMS, JFK, ISL, and MIA are those by weighted closeness centrality of cool chain products.

In terms of weighted closeness centrality of international air cargo, the top 10 airports except DOH maintain high scores after COVID-19 (see Fig. 4). CAN, ICN, SZX, XMN, CKG, CTU, HGH, and TAO are significantly improved in weighted closeness centrality scores of pharmaceuticals (see Fig. 5). The top 10 airports except DXB, HKG, and DOH maintain high scores after COVID-19 in weighted degree centrality scores of cool chain products (see Fig. 6).

#### 4.3. Weighted betweenness centrality

Weighted betweenness centrality refers to the degree to which relationships between nodes that are not directly connected are controlled. Weighted betweenness centrality is calculated for the entire network containing the node, rather than the adjacent network, and the location of the node becomes an important factor in deciding centrality. Weighted betweenness centrality is recognized for accurately indicating the status of transshipment airports in air transport, as it best captures important nodes within the network.

According to the centrality analysis, TPE, DXB, HKG, ISL, NRT, PVG, ICN, FRA, MIA and AMS are top-ranked airports in terms of betweenness centrality of international air cargo (see Table 2). These airports are at the top in most betweenness centrality indicators. Betweenness centrality index of TPE is drastically improved from 0.277 in 2012, 0.653 in 2019–1.000 in 2021 (see Fig. 7). This is believed to be due to the increased role of Taiwan due to the global supply chain crisis of semiconductors (Fig. 8).

Considering that weighted betweenness centrality is an indicator of transshipment function, it shows that the role as a hub in the pharmaceuticals transport route in FRA, PVG, ICN, NRT, and GRU is increasing due to the rise in the volume of pharmaceuticals (see Table 3). However, the role of HKG, TPE, DOH, and DXB are found to be insignificant in pharmaceutical networks, even with substantial increases in international transshipment cargo.

AMS, ORD, PVG, NRT, and LHR are the top airports by weighted betweenness centrality of cool chain products in 2021 (see Table 4). DXB, FRA, and CDG scored high in the weighted betweenness of cool chain products in 2018, but they drop after COVID-19. On the other hand, the PVG and NRT remain on the rise after COVID-19 (see Fig. 9).

## 5. Conclusion

In this paper, we have analyzed the international air cargo network from a weighted network approach to overcome the limitations of traditional social network analysis, which usually adopts unweighted centralities. The weighted centrality measures are more advantageous than the traditional ones as their calculation is based on link weights, which allow a more precise analysis of the network. Network analysis was performed using the international air cargo origin-destination traffic and global trade data from 2012 to 2021.

In order to accurately analyze the network for major commodities of air cargo, a model that can grasp economic significance

through weighted network analysis is presented. The traditional binary social network analysis has shortcomings of only focusing on the existence of flights and routes between O-D (origin-destination), whereas this study uses weighted social network analysis which can analyze air cargo networks for cold chain commodities including pharmaceuticals and cool chain products.

An airport with a high weighted degree centrality score is highly connected with other airports. As a result of the analysis on the weighted degree centrality of international air cargo and cold chain commodities, HKG, TPE, NRT, ICN, and PVG are the top five airports of air cargo, PVG, FRA, CAN, PEK, and ICN are those of pharmaceuticals, while ORD, LAX, NBO, SCL, and JFK are those of cool chain products. Asian hub airports are found in the top ranks of weighted degree centrality for air cargo and pharmaceuticals.

An airport with a high weighted betweenness centrality score can be interpreted as a transfer hub that mediates two other neighboring airports. TPE, DXB, HKG, ISL, and NRT are the top five airports by weighted betweenness of international air cargo, while AMS, ORD, PVG, NRT, and LHR are those of pharmaceuticals, AMS, ORD, PVG, NRT, and LHR are those of cool chain products. They constituted large parts of the network, having many connections and air cargos, playing intermediary roles, and influencing other small airports.

The characteristics of the international air cargo and cold chain network of the current states are interesting and there are some meaningful changes after COVID-19. First, we found that we proposed a set of three weighted centralities measures to supplement the unweighted indicators in the analysis of the centrality of airports in the network. Weighted degree centrality, which provides more opportunities to connect other airports and develop routes, can be effectively used, especially when evaluating the ranking of airports for cold chain commodity traffic. Weighted betweenness centralities are complementary indices to measure the mediator role of airports. Furthermore, we identified the airports where the centrality ranking of pharmaceuticals and cool chain products significantly increased or decreased after COVID-19. Such analysis can help us to identify which airports are growing as hub airports in high-value commodities such as pharmaceuticals and cool chain products.

There are various micro and macro factors affecting the growth of overall air cargo, and temperature-sensitive items, and the changes in the trends are severe, as they can easily be affected by unexpected and inexplicable changes. To prevent shortages of key items, especially temperature-sensitive items requiring short lead time, the underperforming groups can identify and benchmark key hubs of the air cargo items.

This study had a limited dataset that was based on international air cargo traffic data which is unable to distinguish transit shipment of pharmaceuticals and cool chain products. It is expected that more accurate analysis will be possible for high-value commodities in transit, which could contribute to the development of hub airports. Furthermore, If the economic attributes of the characteristics of airports or routes for air cargo networks are analyzed together, it is judged that the competitiveness and value of airports and routes can be more objectively and reasonably evaluated.

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## Declaration of Competing Interest

None.

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