Received 13 January 2022
Revised 5 April 2022
Accepted 15 April 2022

Analyzing the international connectivity of the major container ports in Northeast Asia

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Abstract

Purpose – This study aims to identify the characteristics of the maritime shipping network in Northeast Asia as well as compare the level of port connectivity among these container ports in the region. In addition, this study analyses the change in role and position of 20 ports in the region by clustering these ports based on connectivity index and container throughput and route index.

Design/methodology/approach – This study employs Social Network Analysis (SNA) to delineate the international connectivity of major container ports in Northeast Asia. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is used to identify each port's connectivity index and container throughput index, and the resulting indexes are employed as the basis to cluster 20 major ports by fuzzy C-mean (FCM).

Findings – The results revealed that Northeast Asia is a highly connected maritime shipping network with the domination of Shanghai, Shenzhen, Hong Kong and Busan. Furthermore, both container throughput and connectivity in almost all container ports in the region have decreased significantly due to the coronavirus disease 2019 (COVID-19) pandemic. The rapid growth of Shenzhen and Ningbo has allowed them to join Cluster 1 with Shanghai while maintaining high connectivity, yet decreasing container throughput has pushed Busan down to Cluster 2.

Originality/value – The originality of this study is to combine indexes of SNA into connectivity index reflecting characteristics of the maritime shipping network in Northeast Asia and categorize 20 major ports by FCM.

Keywords Northeast Asia, Container port, SNA, TOPSIS, FCM

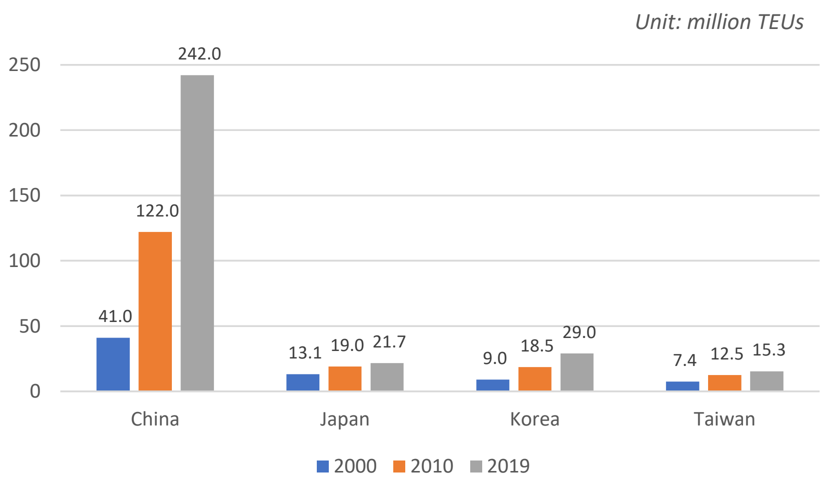
Paper type Research paper

1. Introduction

Ports act as vital nodes in the maritime shipping network and contribute to the development of the multimodal transportation system (Pallis *et al.*, 2011). With a role as a node in the maritime transit network, the port needs to improve the infrastructure, facility, and quality of service to meet the international sea transportation requirement, including precision in time, quantity, and efficiency. These factors also create competitiveness for the port because more and more shipping lines will introduce new shipping routes calling at its port. Besides, combining the different transportation methods allow the port to connect the producer and the consumer through import or export activities (Pettit and Beresford, 2009). Ports being on the global maritime shipping routes can gain certain benefits, such as connecting easily to ports in different areas, attracting more ship calls and improving cargo volumes, gaining more information, having more authority, and having a significant influence over other ports (Nguyen and Woo, 2021).

Northeast Asia plays a significant role as a gateway to Europe and Asia, and the container port system of this region is also a maritime bridge, allowing the domestic, regional, and international distribution of cargo, which is carried primarily by sea transport. Recently, the global container volume center has moved from Europe and America to four Northeast Asia countries, including China, Japan, Korea, and Taiwan (Jiang and Li, 2009). Therefore, the major container ports of these countries have been implementing strategies aiming to improve their competitiveness, such as expanding infrastructure and facilities, enhancing physical capacities to accommodate the larger ships, and offering an attractive business environment for shipping companies, and this allows ports in the region to survive and develop in the fiercely competitive seaport market (Yang and Chen, 2016). These seaport systems of these countries have witnessed a relentless expansion in container throughput over several decades, playing an essential role in international trade and the global maritime shipping network (UNCTAD, 2018, 2019, 2020b). Some major ports in the region have become significant hub-ports, while others have attempted to improve their competitiveness to dominate the seaport market. Many ports in the region have focused on improving international connectivity as part of their strategic growth efforts. The four countries handled nearly 308 million TEUs in 2019, making up approximately 38.7% of global container throughput, and the container ports in the region are the busiest and most dynamic ports globally (UNCTAD, 2020b). Over 20 years, the volume of containers handled by these ports increased by more than four times, with China especially recording a noticeable increase in container throughput, from over 42 million TEUs in 2000 to 242 million TEUs in 2019. Volumes in the Korean container port system have also grown, with container throughput rising from over 9 million TEUs to nearly 29 million TEUs between 2000 and 2019 (see Figure 1).

The major container ports in Northeast Asia have improved their competitiveness to strengthen their leadership and cement their top position in the seaport market (Kim, 2016). Along with investments and upgrades to infrastructure and facilities that have expanded their cargo handling capacity, these ports also enrich maritime connectivity by attracting



Source(s): UNCTAD (2020)

Figure 1. The container throughput of 4 countries in Northeast Asia between 2010 and 2019

more shipping lines to call at their ports. These policies may produce favorable conditions for these ports that enhance container throughput.

Although the demise of Hanjin Shipping in 2016 created a negative impact on South Korea's container port system, several major container ports received a grant from the government to deal with the damage caused by Hanjin's collapse (Shin *et al.*, 2019). The major container ports of Korea, such as Busan, Incheon, and Gwangyang, have significant growth potential when they are connected directly or indirectly to other ports in China, Southeast Asia, South America, and the Middle East. Busan, which is South Korea's mega transshipment hub, maintained its standing as Korea's largest container port and the world's sixth-largest container port (Kim, 2016). The container throughput of other ports recorded an impressive growth when new services to China or Southeast Asia were added in recent years.

Taiwan seaport system's container throughput growth seems to be slowing down as major container ports, such as Kaohsiung, Taichung, and Taipei, are struggling amidst the competitive seaport markets (Bai and Lam, 2015). Many shipping lines have expanded and operated new direct maritime routes from Southeast Asia to North America, no longer calling Taiwan's ports. Besides, Taiwan's container port system still suffers increasing competition by transshipment volumes crossing the Taiwan Strait to other ports such as Busan (South Korea) and Xiamen (China). Both of these weaken the competitiveness of Taiwan ports in comparison to other Northeast Asia ports.

The Japanese seaport system plays a vital role in national and local economic growth and development because Japanese seaports manage marine terminals and, at the same time, contribute to the development of port cities (Inoue, 2018). The container throughput of Japan's ports, consisting of mainly four major ports, namely, Tokyo, Yokohama, Kobe, and Osaka, has increased slightly from 2000 to 2019. However, the growth rate in container throughput, number of ship calls, and number of maritime routes in major Japanese ports are considerably less than in other ports in Northeast Asia (Kawasaki *et al.*, 2020). The major Japanese ports are restricted in international maritime connectivity, making them less competitive compared to ports in China or Korea. As a result, a large portion of cargo is transshipped at China and Korea's ports instead of Japan's ports.

After several decades of impressive growth, China seaport's container throughput system has recorded a decline due to supply chain disruptions and the weakening of the global economy brought on by the COVID-19 pandemic (UNCTAD, 2020a; Xu *et al.*, 2021). However, many China container ports are still dominating global container throughput. The major Chinese container ports are not only strengthening their positions as pivotal container shipping ports but also are striving to become top international hubs (Li *et al.*, 2021; Ma *et al.*, 2021). The Chinese container ports have the prerequisite to becoming mega transshipment hubs due to good geographical location, free-trade area, fully modernized equipment, the application of information technology, and the ability to handle the largest ships.

The growth and development of container ports in four countries are different, but all of their major ports have been striving to maintain the leading position or become the hub ports of the region or the world. To achieve this goal, besides enhancing competitiveness by upgrading infrastructure and cargo handling capabilities, modernizing equipment with investments, and increasing service coverage, these ports must improve maritime connectivity by attracting more shipping lines to introduce new services calling at their ports. Container seaports are crucial to the economy of countries in Northeast Asia. The better international connections of the seaports in the region could help seaports increase container throughput and boost the nations' economies. The improvement of international connectivity means expanding the maritime shipping network, allowing ports in Northeast Asia to spread their power in each region, continent, and even the whole world. Therefore, the purpose of the study is to identify the characteristics of the maritime shipping network in the Northeast Asia region as well as analyze the level of port connectivity among these container ports in the region. Besides, the growth and development of major container ports in the region are various, and hence the study categorizes these ports based on "connectivity index" and container throughput index. This categorization aims to analyze the change in role and position of ports and suggests several developing policies for each cluster. The remainder of this study is structured as follows. Section 2 reviews the literature on port connectivity and Social Network Analysis (SNA). Section 3 mentions the methods and data used in the study. Section 4 provides results of the port's connectivity in the region and discusses the change in the role and position of the port. Section 5 presents the findings of the study.

2. Literature review

The connection or interaction among adjoining ports in a region makes the regional shipping network develop and grow significantly (Rodrigue and Notteboom, 2009). Therefore, the connectivity of ports in the global maritime shipping network has received increasing attention in port studies. By analyzing Northeast Asia's shipping network between 1996 and 2006, Ducruet *et al.* (2010) show that the major hub ports may affect the polarization of the overall maritime network. Viljoen and Joubert (2016) employ the complex network theory to analyze the vulnerability of the maritime network, and they found that the global liner network is vulnerable to both a strategy removing the "most between" connection and a strategy removing the "most salient."

The competitiveness of a port is affected by factors such as geographic location, port facility, port cost, cargo volume, service level, and port reputation (Chang *et al.*, 2008; Steven and Corsi, 2012; Nguyen *et al.*, 2020a, b). In general, the port's connectivity is to identify the role of a port in a shipping network with many shipping routes, and the port's connectivity allows the assessment of the port's competitiveness and the characteristics of the shipping network (Steven and Corsi, 2012; Nguyen *et al.*, 2020a, b). Moreover, a good geographical location will positively affect the international connectivity of a port, including increasing the frequency of the shipping service, extending the operating market, and increasing the number of services. It allows a port to become a potential hub port (Wang and Ng, 2011). The improvement of both connectivity and infrastructure creates certain advantages for a port in competing and gaining market shares.

The purpose of a port is to improve its competitiveness and gain market share from other ports. One of the methods to increase competitiveness is to improve international connectivity by attracting more shippers and shipping lines. The connectivity analysis clearly shows the position of a port in the maritime shipping network. SNA is used commonly to examine the connectivity of a container port in a maritime shipping network, and each container port is a node in the shipping routes, including the start and the endpoint. The use of the SNA method with Freeman's indexes, such as degree centrality, closeness centrality, and betweenness, may demonstrate the level of connectivity in a specific maritime shipping network (Wang and Cullinane, 2016). Along with Freeman's indexes, the hub index and author index are used to reflect the centrality of a port. Besides, previous studies applied SNA in the field of sea transportation, such as analysis of the level of cooperation in seaport research (Woo *et al.*, 2013), the impact of the centrality of ports in the network on the container throughput (Kang and Woo, 2017), and the interaction among adjoining ports in the region (Lu *et al.*, 2018).

The maritime shipping network analysis provides comprehensive information about the accessibility and connectivity of a port in the network as well as allows comparison among networks with different scales. Centrality indexes are used to determine a port's importance and relative position to the rest of the shipping network. Therefore, this study uses centrality measures to identify the characteristics of the Northeast Asian shipping network as well as analyze the importance of major ports in this shipping network. However, previous studies analyze the port's connectivity separately by degree centrality, closeness centrality, or hub and authority index. For example, based on the centrality indexes, Kawasaki *et al.* (2019) analyze the Intra-Asian maritime network, and the results show that Singapore, Hong Kong, Busan, and Shanghai are centrality ports in the region. There has not been a combination of these indexes into a single connectivity index. This study constructs a Northeast Asian container shipping network from liner service data and employs centrality indexes to analyze the importance and relative position of 20 major ports in the region. In this study, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is used to identify the "connectivity index" based on the results of SNA and the "throughput and route index" based on the container throughput and the number of routes. Compared to other studies, this study has originality. First, we construct a single "connectivity index" and "container throughput and route index" by TOPSIS. Second, these indexes are used to cluster 20 ports into four groups to determine each port's change in role and position between 2017 and 2020.

3. Methodologies and data

3.1 Social Network Analysis (SNA)

The SNA method is used to analyze the connectivity of a network as well as enable one to visualize the entire network (Lovrić *et al.*, 2018). This method uses indicators such as degree centrality, closeness centrality, and betweenness centrality to identify the gap among entities in the network and show the differences in the roles and position of the specific nodes in the network (Freeman, 1977). These indexes do not examine the degree of centrality of each entity in a network; therefore, hub and authority indexes are added (Kleinberg, 1999a). The SNA method is widely applied to measure the connectivity of ports in the shipping network, and each port in the maritime route is a node in the network (Nguyen *et al.*, 2020b). To analyze the port's connectivity, services operated by the shipping lines, including the information about the sequence of port, frequency and periodicity, are collected. The direct and indirect connections among container ports shape the maritime transport network of a region. The vessel calls at multiple ports for loading/unloading cargo in each maritime route, and SNA considers the connection among ports within a given period. The analysis of the liner shipping network structure is a binary approach; accordingly, the direct linkage between any two ports is considered as 1; otherwise, it is 0.

3.1.1 Degree centrality. This index shows the structure of the maritime network by measuring the number of port connections in the maritime shipping network (Wang and Cullinane, 2016). The maritime shipping network is a directed network; therefore, degree centrality includes two indexes, in-degree centrality, which refers to the connectivity of a port to other ports in the network, and out-degree, which mentions the connectivity of other ports to this port. A port is located to be central in a network if its degree of centrality is higher than others.

The degree centrality index can be calculated as shown in Equations (1) and (2).

$$C_{D-in}(i) = \sum_{j=1, j\neq i}^{n} a_{ji}; \tag{1}$$

$$C_{D-out}(i) = \sum_{j=1, j\neq i}^{n} a_{ij} \tag{2}$$

Where $C_{D-in}(i)$ and $C_{D-out}(i)$ are the in-degree and out-degree centrality of port i in binary ties, respectively. $C_{D-in}(i)$ shows that port i can connect directly to how many ports and $C_{D-out}(i)$ shows that the number of ports can link directly to port i.

a_{ji} *and* a_{ij} give the connectivity from port j to port i and from port i to port j, respectively; $a_{ij} = 1$ if port i is connected to port j; $a_{ij} = 0$ if port i is not connected to port j.

3.1.2 Closeness centrality. Closeness centrality is used to identify the central port in a complex shipping network by measuring the average shortest paths between ports (Li *et al.*, 2014). Therefore, the closeness centrality of a port is the average length of the shortest paths from that port to all of the other ports in the maritime shipping network. The closeness to other ports in the network allows a port can gain much more information, has more authority, and has a significant influence compared to other ports. The value of the closeness centrality index value is from 0 to 1. The formula of closeness centrality is defined as follows:

$$I_i^{C_C} = \frac{n-1}{\sum_{j=i;i\neq j}^{n} d_{ij},} \tag{3}$$

Where $I_i^{C_C}$ is the closeness centrality index of the ith port in the port network.

n gives the number of ports in the network;

$n-1$ is the maximum number of ports that a port can link to and

d_{ij} is the number of legs in the shortest path connecting port i and port j.

3.1.3 Hub and authority index. The connections in a network are not identical because all nodes' importance and influence are different. For example, some ports may have a higher impact or importance in the seaport network due to the attractiveness of more shipping companies introducing new maritime services or customers using the port's service. Hub and authority scores are supplemented to identify the weights for each connection based on secondary linkages in the network, which was not mentioned in the Freeman indexes (Kleinberg, 1999b). Normally, hub index reflects the centrality value of a node in its ability to make a linkage with other nodes in the network. By contrast, authority index shows the centrality value of a node based on the number of linkages to the node. In seaport network analysis, the authority score of a port is the sum of the hub scores of all ports that point to it, while its hub score is the sum of the authority scores of all ports that it points to. Hub index of a port increases if that port can connect to many ports with a high authority index, while ports with a high authority index as there are many ports with a high hub index connect to this port (Jeon *et al.*, 2019).

3.2 Technique for order of preference by similarity to Ideal Solution (TOPSIS)

With some advantages of simplicity, comprehensibility, and good computation efficiency, the TOPSIS is one of the most popular methods used to compare alternatives. In this study, major ports in Northeast Asia are alternatives, and TOPSIS identifies these ports "connectivity index" and "container throughput and route index". The TOPSIS steps are as follows:

Step 1: Normalization of data:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{4}$$

The normalized matrix is $R = [r_{ij}]m \times n$.

m and n are alternatives and criteria, respectively. In this study, m is the number of major ports ($m = 20$).

x_{ij} is the value of degree centrality, closeness centrality, hub index, authority index, container throughput, and the number of ship calls.

Step 2: Calculation of weighted normalized matrix:

The weighted normalized matrix is calculated by multiplying the normalized matrix with the index weight;

$$v_{ij} = w_j{*}r_{ij} \tag{5}$$

w_j is the index weight and is calculated by some steps:

Step 2.1 Standardization of data

The criteria are calculated from Equation (6) if they are beneficial. The cost indexes are determined from Equation (7) (Li *et al.*, 2011).

$$x'_{ij} = \frac{x_{ij} - min\{x_j\}}{max\{x_j\} - min\{x_j\}} \tag{6}$$

$$x'_{ij} = \frac{max\{x_j\} - x_{ij}}{max\{x_j\} - min\{x_j\}} \tag{7}$$

The new index matrix after standardizing is X' = [x′ij] $m \times n$.

Step 2.2 Calculation of index entropy

$$f_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{m} x'_{ij}} \tag{8}$$

$$e_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} f_{ij}.\ln(f_{ij}) \tag{9}$$

Step 2.3 Calculation of index weight

$$w_j = \frac{1 - e_j}{n - \sum_{j=1}^{n} ej} \tag{10}$$

Step 3: Determination of the PIS and the NIS:

PIS:

$$V^+ = \left[V_j^+\right] \tag{11}$$

where $V_j^+ = \max v_{ij}$, the benefit indexes; $= \min v_{ij}$, the cost indexes

NIS:

$$V^- = \left[V_j^-\right] \tag{12}$$

where $V_j^- = \max v_{ij}$, the cost indexes; $= \min v_{ij}$, the benefit indexes

Step 4: Calculation of the distance for each alternative:

The distance from the PIS is

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - V_j^+\right)^2} \tag{13}$$

The distance from the NIS is

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - V_j^-\right)^2} \tag{14}$$

Step 5: Calculation of the “connectivity index” and container throughput for each port:

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-} \tag{15}$$

The value of connectivity and container throughput index is between 0 and 1, and a higher evaluation alternative is better.

3.3 Fuzzy C-means (FCM)

The fuzzy C-means (FCM) algorithm was introduced by Ruspini, developed by Dunn, and improved by Bezdek, and it is one of the most popular fuzzy clustering techniques (Ruspini, 1970; Bezdek, 1973, 1981; Dunn, 1973). This algorithm is applied in different fields due to its efficiency, simplicity, and ease of implementation. Pham *et al.* (2021) used the FCM algorithm to cluster the 32 largest ports in the world from 2013 to 2017. Typically, FCM includes some steps, from selecting the randomly initial cluster center to repeating the algorithm until the results converge to the actual cluster center. To conduct the FCM algorithm, the first step is to identify an objective function that measures the quality of each cluster, and the purpose of the FCM algorithm is to minimize the value of the objective function. The objective function is determined as Equation (16)

$$S_{FCM} = \sum_{k=1}^{p} \sum_{h=1}^{c} (u_{kh})^q ||y_k - z_h||^2 \tag{16}$$

Where:

S_{FCM}: the objective function;

c: number of cluster centers;

p: number of data points;

$||y_k - z_h||^2$ is the squared distance between the element y_k and the cluster center $z_{h;}$

u_{kh}: the degree of membership of y_k in cluster *h and*

q: fuzzy index of the algorithm. $q = 2$ have been often the preferred selection in FCM because it may balance an assumption of an amount of fuzziness in the dataset and the benefit of avoiding a time-consuming calculation of its value (Pal and Bezdek, 1995).

The complete algorithm consists of particular steps:

Step 1: Select the number of clusters (c), value for fuzzy index (q) and randomly initialize the cluster membership value u_{kh} $(\sum u_{kh} = 1)$

Step 2: Calculate the cluster center

$$z_h = \frac{\left(\sum_{k=1}^{p} (u_{kh})^q * y_k\right)}{\left(\sum_{k=1}^{p} (u_{kh})^q\right)} \tag{17}$$

Step 3: update u_{kh} according to the following

$$u_{hk} = \frac{1}{\sum_{l=1}^{c} \left(\frac{||y_k - z_h||}{||y_k - y_l||}\right)^{\frac{2}{q-1}}} \tag{18}$$

Step 4: Repeat steps 2q4 until the objective function (S_{FCM}) improves by less than a specified threshold.

3.4 Data

The container port system of countries in Northeast Asia has a strategic position in international trade and shipping. The container throughput of ports in the region comprises nearly 40% of the global container throughput, and these ports are chokepoints in global maritime shipping, with a large number of services calling these ports. To analyze the port's connectivity of Northeast Asia by SNA, the study collected 928 services that call the major 20 ports in the region from 2017 to 2020. The global databases on ship movements are collected from the website of Alphaliner. Overall, the total number of services in the region slightly increases over four years. The shipping lines constantly change their services, so the number of shipping routes in almost all ports increases, except for Busan port (See Table 1). Even the shipping lines may remove or add some ports in each service.

4. Analysis results and discussion

4.1 The port's connectivity of Northeast Asia's container port system

This study applies the SNA to analyze major ports' connectivity of four countries, namely South Korea, China, Japan, and Taiwan, aim to identify their importance and influence on the national, regional, and global shipping network by degree centrality, closeness centrality, and hub and authority index. These indexes are calculated by Netminer and reflect the structure position of each port in the shipping network. Northeast Asia's major ports have a diversity of connectivity when they can connect directly or indirectly to over 490 ports in all world areas (see Table 2).

Degree centrality includes two indexes, namely out-degree centrality and in-degree centrality. Out-degree centrality reflects the direct connection of these ports to other ports in the world, while in-degree centrality shows that other ports can link directly to these ports. There is a significant difference in the connectivity among ports and countries in Northeast Asia.

Busan, Shanghai, Shenzhen, and Hong Kong are global hub ports, so both in-degree and out-degree centrality of these ports are the highest. This also implies that they play an essential role in the global maritime shipping network. The cargo transportation to Europe, America, and Africa are transited through these ports. The degree centrality of these ports witnessed a growth between 2017 and 2020, except for Shenzhen, when its in-degree centrality drops slightly from 51 to 49. Busan – South Korea's busiest container port – has the most connectivity compared to other ports in the region. For the shipping lines, high port

Table 1. Number of services of the top 20 ports in Northeast Asia from 2017 to 2020

No	Port	2017 Number of services	2017 Container throughput (10^3 TEU)	2018 Number of services	2018 Container throughput (10^3 TEU)	2019 Number of services	2019 Container throughput (10^3 TEU)	2020 Number of services	2020 Container throughput (10^3 TEU)
1	Shanghai	399	40,233	391	42,010	399	43,303	447	43,503
2	Ningbo	318	24,607	314	26,351	328	27,530	396	28,720
3	Shenzhen	329	25,208	290	25,740	326	25,770	363	26,550
4	Busan	330	20,493	293	21,663	305	21,992	314	21,824
5	Qingdao	246	18,262	235	19,315	244	21,010	291	22,010
6	Hong Kong	369	20,770	362	19,596	377	18,361	398	17,953
7	Tianjin	152	15,010	184	15,972	160	17,264	187	18,353
8	Xiamen	203	10,380	186	10,702	227	11,122	280	11,410
9	Kaohsiung	228	10,271	215	10,446	214	10,429	182	9,622
10	Dalian	125	9,707	149	9,770	121	8,760	142	5,110
11	Tokyo	135	4,500	84	4,570	78	4,510	91	4,262
12	Incheon	74	3,050	102	3,106	104	3,092	129	3,272
13	Yokohama	142	2,927	160	3,036	149	2,990	183	2,662
14	Kobe	127	2,925	133	2,944	134	2,872	144	2,647
15	Nagoya	118	2,784	140	2,876	137	2,844	152	2,471
16	Osaka	102	2,327	117	2,413	122	2,456	134	2,352
17	Gwangyang	135	2,230	141	2,410	125	2,378	160	2,159
18	Taichung	74	1,661	81	1,744	93	1,794	94	1,821
19	Taipei	42	1,562	51	1,660	65	1,620	73	1,620
20	Ulsan	36	466	39	490	73	517	71	536
	Total	669	219,372	645	226,814	641	230,614	673	228,857

Source(s): The data are collected from Alphaliner, Lloyd's List, and the website of each port

Table 2.
Degree centrality of major ports in Northeast Asia from 2017 to 2020

		In-degree				Out-degree			
Country	Port	2017	2018	2019	2020	2017	2018	2019	2020
Korea	1. Busan	71	75	75	75	79	80	79	81
	2. Incheon	21	22	22	21	22	23	22	23
	3. Gwangyang	17	19	18	19	22	24	22	21
	4. Ulsan	8	8	8	8	12	13	13	13
Japan	1. Yokohama	33	31	31	31	29	26	26	25
	2. Kobe	32	33	32	31	19	16	16	17
	3. Nagoya	29	31	31	30	18	18	16	17
	4. Tokyo	21	21	21	19	31	32	33	32
	5. Osaka	14	15	15	14	30	31	31	31
Taiwan	1. Kaohsiung	39	43	43	42	45	42	42	39
	2. Taipei	13	13	13	13	19	19	19	20
	3. Taichung	10	10	11	11	8	7	9	8
China	1. Shanghai	57	57	57	60	58	57	57	63
	2. Shenzhen	51	48	48	49	32	32	33	36
	3. Hong Kong	42	40	44	43	50	54	45	51
	4. Ningbo	39	40	40	39	39	42	41	45
	5. Qingdao	33	33	31	30	41	43	41	43
	6. Xiamen	29	28	30	30	33	28	28	28
	7. Dalian	24	26	26	26	24	24	25	26
	8. Tianjin	23	21	20	21	35	34	35	36

efficiency, favorable geographical location, reasonable port charges, adequate infrastructure, and connectivity to other ports are factors in port choice for their maritime services (Tongzon, 2009). Among these factors, infrastructure and connectivity are the most important criterion affecting the port choice decision for their services (Ng *et al.*, 2013; Vega *et al.*, 2019; Zhu *et al.*, 2021; Baştuğ *et al.*, 2022). Therefore, the improvement of its infrastructure and facility may make shipping lines add Busan to their shipping routes or introduce new services that call this port. According to the Korean Ministry of Oceans and Fisheries, a total of won 13.6 trillion will be invested to increase the quay length, improve water depth, and apply a 5G digital twin innovative port logistics platform for container ships that allows terminal owners, shipowners and other port users can optimize their decisions. According to the long-term business plan of Busan Port Authority, Busan New Port has also expanded and completed in January 2021 to handle up to 3.2 million TEU per year.

Due to the negative impact of the COVID-19 pandemic on sea transportation, the shipping line reduced some services or changed the number of ports in each route. As a result, the out-degree and in-degree centrality of many ports decreased. This means that several ports cannot link directly to major ports in Northeast Asia or these ports have a limitation of connection to other ports. There is no improvement in the connectivity at Japan's major ports, and even the degree of centrality of Yokohama, Kobe, Nagoya, and Tokyo decreased between 2017 and 2020. This is appropriate for the fall in container throughput of these ports. Although Taiwan's government has been planning to develop Kaohsiung to become an important hub-port in Asia–Pacific region, Kaohsiung did not gain the market share from Busan and other ports on the Taiwan Strait (Teng *et al.*, 2004). Therefore, both its container throughput and out-degree centrality witnessed a significant fall from 2017 to 2020.

Table 3 shows the closeness centrality of major ports in Northeast Asia. This index is useful for identifying how close a port is to all other ports in the maritime shipping network. Overall, ports with a high degree centrality, such as Busan, Shanghai, and Shenzhen, remain at the top position with respect to the closeness centrality. The values of in-closeness and out-closeness centrality show that Busan, Shanghai, and Shenzhen have influenced the Northeast

Country	Port	In-closeness 2017	2018	2019	2020	Out-closeness 2017	2018	2019	2020
Korea	1. Busan	0.396	0.401	0.408	0.382	0.432	0.427	0.423	0.392
	2. Incheon	0.316	0.319	0.321	0.308	0.352	0.344	0.341	0.325
	3. Gwangyang	0.328	0.330	0.331	0.316	0.372	0.374	0.367	0.345
	4. Ulsan	0.307	0.310	0.313	0.301	0.313	0.314	0.312	0.297
Japan	1. Yokohama	0.335	0.336	0.339	0.323	0.372	0.371	0.368	0.344
	2. Kobe	0.350	0.353	0.365	0.344	0.362	0.347	0.342	0.331
	3. Nagoya	0.327	0.332	0.335	0.319	0.347	0.344	0.337	0.324
	4. Tokyo	0.337	0.340	0.348	0.325	0.369	0.366	0.366	0.343
	5. Osaka	0.307	0.309	0.314	0.295	0.364	0.362	0.359	0.339
Taiwan	1. Kaohsiung	0.367	0.371	0.374	0.353	0.407	0.396	0.395	0.368
	2. Taipei	0.314	0.310	0.314	0.301	0.352	0.352	0.350	0.333
	3. Taichung	0.299	0.300	0.306	0.295	0.317	0.303	0.311	0.288
China	1. Shanghai	0.387	0.389	0.396	0.372	0.411	0.412	0.414	0.392
	2. Shenzhen	0.390	0.383	0.391	0.368	0.389	0.385	0.382	0.368
	3. Hong Kong	0.281	0.378	0.382	0.359	0.329	0.408	0.404	0.374
	4. Ningbo	0.368	0.368	0.377	0.356	0.397	0.399	0.395	0.372
	5. Qingdao	0.357	0.357	0.359	0.329	0.397	0.398	0.393	0.368
	6. Xiamen	0.336	0.335	0.362	0.342	0.387	0.384	0.379	0.354
	7. Dalian	0.322	0.326	0.329	0.316	0.365	0.365	0.364	0.345
	8. Tianjin	0.323	0.321	0.325	0.312	0.390	0.388	0.383	0.359

Table 3. The closeness centrality of major ports in Northeast Asia from 2017 to 2020

Asia shipping network most quickly and can easily connect to all other ports. There is no significant gap in closeness score among ports in the region, which implies that Northeast Asia is a highly connected maritime shipping network.

The degree centrality and closeness centrality do not address the influence of a port on the entire shipping network operations, so the hub and authority index is also calculated (Kleinberg, 1999a). Figure 2 presents the hub and authority index of 20 major ports in Northeast Asia. Like the values of degree centrality and closeness centrality, the hub and authority index values emphasize the strong dominance of Busan, Shanghai, Shenzhen, and Hong Kong. The high hub index of these ports implies that they are connected with high-impact ports. These ports are important hub ports allowing easy access for container ships. This is demonstrated by Yap *et al.* (2006) after analyzing the competition among container

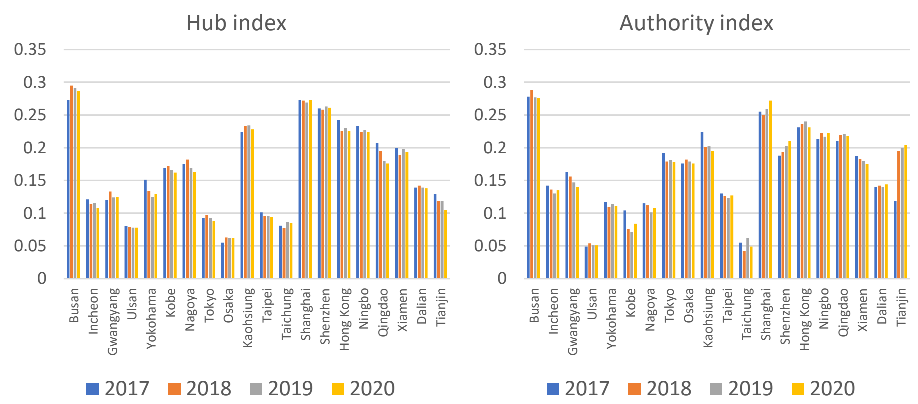


Figure 2. The hub and authority of major ports in Northeast Asia from 2017 to 2020

ports in East Asia. With geographical advantages, these ports can easily access other regions. Regarding the authority centrality, the findings are very similar to the results of the other indexes, and the major ports still show strong connectivity to high-impact ports.

4.2 Categorizing ports based on fuzzy C-means clustering

The previous studies analyze port's connectivity to identify the advantages and disadvantages of an individual container port in the dynamic maritime shipping network, and the results are based mainly on each connectivity index in SNA. However, it is not easy to compare the connectivity among ports if there are differences among indexes in SNA because SNA does not reflect separately port's connectivity. To solve this drawback, TOPSIS is employed to unite degree centrality, closeness centrality, hub index, and authority index to form a unique connectivity index exactly reflecting the port's connectivity.

Table 4 shows the value of the connectivity index of 20 ports from 2017 to 2020. Although there is a slight drop in the closeness centrality, hub index, and authority index, Busan's connectivity ranks first in four years. In the region, the connectivity of almost all of China's ports, including Shanghai, Shenzhen, Dalian, Ningbo, and Tianjin, improved dramatically, while the connectivity of other ports decreased.

The strategic goal of the container port is to enhance the container throughput to increase profit; therefore, the analysis of the port's connectivity needs to be related to the number of routes and the volume of the container. Similar to calculating the connectivity index, TOPSIS is also used to identify the container throughput and route index by combining container throughput and the number of ship calls of 20 major ports in the region. Table 5 indicates the container throughput and route index of 20 ports in Northeast Asia. This index is calculated based on the number of routes and container throughput of these ports from 2017 to 2020. In 2020, all container ports in the region faced difficulties caused by the COVID-19 pandemic. However, several of China's container ports, including Shanghai, Shenzhen, Qingdao, Ningbo, Tianjin, and Xiamen, rebounded strongly during the second half to more than offset pandemic-triggered losses. This allowed them to retain and increase the container throughput and route index in 2020. The strategy of transferring volumes to Yingkou, along with the worst impact of weak global trade conditions in 2020, caused the container throughput of Dalian to record a dramatic drop of around 42% in 2020. Many container ports in the region were hit by the COVID-19 pandemic when their container throughput witnessed a fall in 2020.

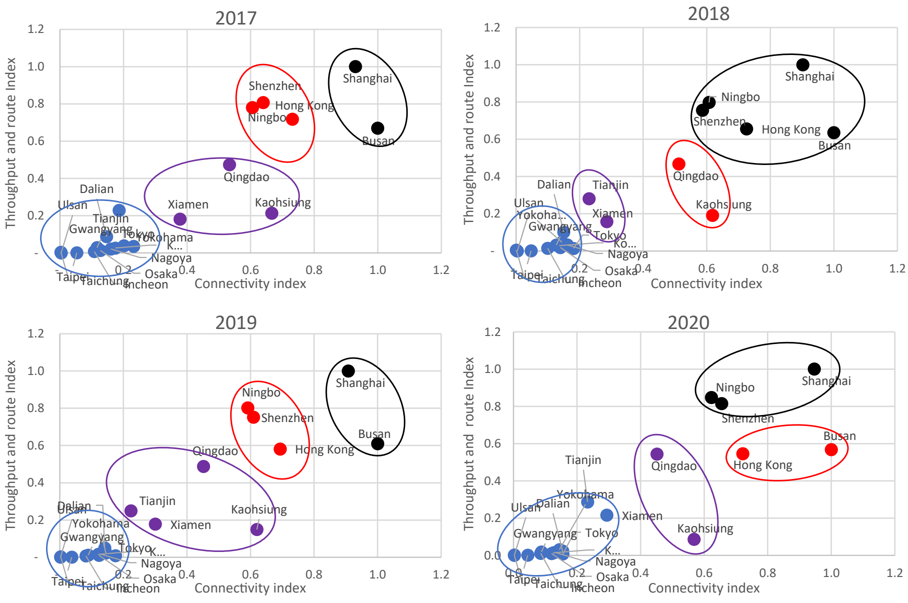
Port	2017	2018	2019	2020	Port	2017	2018	2019	2020
Korea					Taiwan				
1. Busan	1.000	1.000	1.000	1.000	1. Kaohsiung	0.667	0.619	0.620	0.569
2. Incheon	0.108	0.099	0.082	0.086	2. Taipei	0.053	0.047	0.037	0.045
3. Gwangyang	0.117	0.127	0.089	0.088	3. Taichung	0.003	0.001	0.003	0.002
4. Ulsan	0.004	0.004	0.002	0.003	China				
Japan					1. Shanghai	0.930	0.902	0.908	0.947
1. Yokohama	0.232	0.145	0.145	0.145	2. Shenzhen	0.639	0.587	0.610	0.655
2. Kobe	0.174	0.136	0.121	0.125	3. Hong Kong	0.731	0.726	0.683	0.722
3. Nagoya	0.160	0.161	0.129	0.130	4. Ningbo	0.606	0.607	0.592	0.623
4. Tokyo	0.201	0.181	0.175	0.156	5. Qingdao	0.534	0.512	0.452	0.452
5. Osaka	0.127	0.139	0.123	0.120	6. Xiamen	0.378	0.286	0.301	0.294
					7. Dalian	0.147	0.150	0.141	0.155
					8. Tianjin	0.186	0.230	0.224	0.233

Table 4.
Connectivity index of the top 20 ports in Northeast Asia

Port	2017	2018	2019	2020	Port	2017	2018	2019	2020
Korea					Taiwan				
1. Busan	0.670	0.636	0.609	0.568	1. Kaohsiung	0.213	0.191	0.149	0.087
2. Incheon	0.007	0.015	0.007	0.011	2. Taipei	0.001	0.001	0.001	0.000
3. Gwangyang	0.029	0.032	0.011	0.018	3. Taichung	0.004	0.005	0.003	0.002
4. Ulsan	0.000	0.000	0.000	0.000	China				
Japan					1. Shanghai	1.000	1.000	1.000	1.000
1. Yokohama	0.035	0.047	0.023	0.030	2. Shenzhen	0.807	0.756	0.752	0.815
2. Kobe	0.026	0.029	0.016	0.014	3. Hong Kong	0.718	0.655	0.581	0.545
3. Nagoya	0.021	0.033	0.017	0.016	4. Ningbo	0.780	0.798	0.802	0.848
4. Tokyo	0.039	0.014	0.008	0.007	5. Qingdao	0.473	0.468	0.487	0.544
5. Osaka	0.013	0.019	0.010	0.010	6. Xiamen	0.181	0.158	0.178	0.216
					7. Dalian	0.087	0.102	0.050	0.023
					8. Tianjin	0.228	0.281	0.249	0.287

Table 5. Container throughput and route index of the top 20 ports in Northeast Asia

It is clear that the "connectivity index" and "container throughput and route index" reflects the connectivity and competitiveness of major container ports in Northeast Asia's maritime shipping network. However, the importance and role of these ports in the network may change over time. Therefore, from the "connectivity index" and "container throughput and route index", FCM is employed for a more comprehensive analysis of the development of 20 ports in the region. The essential criteria to evaluate the clustering effect are divergence and compactness (Liang *et al.*, 2010). With the study's dataset, the optimal number of clusters are 4 to ensure that the inter-cluster distance should be as big as possible, and the intra-cluster distance should be as small as possible. Twenty container ports are divided into 4 clusters, and the results of FCM are presented in Figure 3. With a high "connectivity index" and



Source(s): Based on fuzzy C-Means clustering

Figure 3. Categorizing ports based on FCM clustering

"container throughput and route index", the black colored cluster (Cluster 1) is the best while the blue-colored cluster (Cluster 4) is the worst because both of connectivity index and container throughput and route index is low. Cluster 2 is in red, and Cluster 3 is in purple. The growth and development of ports in the region make a considerable change in cluster members from 2017 to 2020.

With the domination of connectivity and container throughput, Shanghai still strengthens its position as a pivotal port for container shipping as well as a top-class international maritime center. Therefore, Shanghai is still in Cluster 1 for over four years. The growth in both connectivity index and container throughput and route index of Ningbo and Shenzhen allows these ports to move from Cluster 2 to Cluster 1 with Shanghai. Ningbo and Shenzhen have shown resilience amid the negative influence of the COVID-19 pandemic. This satisfactory performance is due to their efforts to launch new maritime routes, develop intermodal transports, increase digitalization and port automation, enhance infrastructure, and push paperless port systems. By contrast, Busan port maintains the top position in the connectivity index, but it failed to expand container throughput. The result is that Busan slipped down from Cluster 1 to Cluster 2 between 2017 and 2020. Hong Kong is still in Cluster 2, but its "connectivity index" and "container throughput and route index" decreased. To cope with rising competition from ports in South China, Hong Kong has conducted expansion terminal yard space, the up-gradation of facilities, and improvement of navigation depth. However, due to the difficulty in accommodating the large vessels and high cost, Hong Kong is less competitive than its competitors; and the result is that it has lost market share to competitors such as Shanghai, Ningbo, Shenzhen and Guangzhou port (Do *et al.*, 2015; Fan, 2019; Wang *et al.*, 2022). Ports in Clusters 3 and 4 represent the weak in both connectivity and volume of the container. These ports were hit by the COVID-19 pandemic when the container throughput decreased, and the port's connectivity was not improved.

5. Conclusion

This study analyzes the development of 20 major container ports in 4 countries in Northeast Asia, namely China, Korea, Japan, and Taiwan, by using the SNA method, TOPSIS, and FCM. The results from the study show that (1) container ports in Northeast Asia are being operated in a highly connected maritime shipping network; (2) there is a big gap in port connectivity among countries in the region. The transshipment hubs, including Shanghai, Hong Kong, Shenzhen (China), and Busan (Korea), have dominated container throughput and port connectivity. Major ports in Taiwan and Japan are less competitive in connectivity than others in China and Korea; (3) in each country, a port or some ports is dominating other ports in connectivity, for example, Busan (Korea), Kobe, and Yokohama (Japan), Kaohsiung (Taiwan), and Shanghai, Shenzhen, Hong Kong (China); (4) the negative impacts of the COVID-19 pandemic made the container throughput and connectivity of almost all container ports in the region to decrease significantly in 2020. This causes a significant change in cluster members between 2017 and 2020.

The study results show that the connectivity of container ports in Japan and Taiwan are less than that of ports in China and Korea. However, ports in Japan and Taiwan can improve connectivity through several policies. Some previous studies show that developing the international and domestic maritime shipping network of seaports in Taiwan and Japan plays an essential role in the national and local economies because these countries are pivotal points for shipping routes crossing the Pacific Ocean (Ding *et al.*, 2019; Hu *et al.*, 2020). Therefore, port operators and managers of these countries may implement the following strategies to enhance connectivity as well as the competitiveness. First, an expansion of the berth's length and depth allows these ports to accommodate larger container vessels; therefore, these ports can attract more shipping lines to open new services. In addition, Japan's and Taiwan's container ports should streamline the clearance procedures and push paperless port systems to enhance their competitiveness. Further, to cope with a rapidly changing technology, ports in these countries should apply Artificial Intelligence (AI) and 5th Generation (5G) connections to increase digitalization and port automation and construct smart ports. The application of AI allows terminals to operate more effectively due to the improvement of productivity and work environment at the port, optimization of decision-making, detection of accidents or breakdown cargo. This is also evidenced by the application of 5G and AI in the Port of Singapore. AI and 5G play an important role in the automation, remote operation, and give Singapore port certain competitive advantages (Huseien and Shah, 2022). Final, enhancement of connectivity to domestic logistics centers is at the core of the increasing competitiveness of Japan's and Taiwan's container ports. These policies were also mentioned partly in Taiwan's 2008 I-Taiwan 12 Construction Plan and Japan's 2006 Super Hub Port Establishment Program and 2010 International Strategic Port Plan (Yang and Chen, 2016).

The study identifies the connectivity of major container ports in Northeast Asia's shipping network as well as characteristics of this shipping network over the period 2017–2020 using the connectivity indexes. The dataset on the ship movements in the region was constructed by collecting maritime services from the website of Alphaliner. This is the first paper to establish the "connectivity index" based on centrality indexes and "container throughput and route index" based on container throughput and the number of routes by using TOPSIS. In addition, the results of connectivity, container throughput, and the number of routes are employed to categorize 20 major container ports in the region using FCM.

The results of the study suggest that improvement of port connectivity is not the first and unique priority of ports. Busan, Ningbo, and Shenzhen are clear evidence to prove that it is necessary to combine port connectivity improvement and container throughput growth. A high port's connectivity index but low container throughput index makes Busan move from Cluster 1 to Cluster 2. By contrast, the improvement in connectivity and container throughput allows Ningbo and Shenzhen to join Cluster 1 together with Shanghai.

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