Paper Impact of COVID-19 on the International Connectivity and Competitiveness of Major Container Ports in Northeast Asia's Maritime Transport Network

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Abstract - As an important network in global maritime transport, the Northeast Asia transportation network has been impacted by the COVID-19 pandemic. This study analyses impact of COVID-19 on the international connectivity and competitiveness of major container ports in Northeast Asia's maritime transport network, using maritime routes and container throughput data from 20 major ports between 2017 and 2021. The international connectivity of the ports is evaluated through a connectivity index that combines degree centrality, closeness centrality, and hub & authority. The study results reveal that the COVID-19 pandemic has reduced the connectivity of many container ports, including those in Japan and Taiwan, while the scale of China's international liner shipping network has increased as its ports maintain their connectivity. With the maintenance of connectivity, Chinese ports such as Ningbo, Tianjin, Shanghai, Qingdao, and Shenzhen have improved their competitiveness by gaining market share from their regional competitors. In general, the policy implication is that maintaining international connectivity during the COVID-19 period leads to higher container throughput. Additionally, measures designed to combat COVID-19 and other diseases should be intentionally set up to minimize their impact on port operations and maritime transportation.

Keywords - Connectivity; COVID-19 Pandemic; Shift Analysis; Northeast Asia

I. INTRODUCTION

Container ports serve as crucial nodes in the global supply chain, facilitating the movement of goods between countries and continents [1]. They provide essential services such as cargo handling, storage, and distribution, serving as gateways for international trade. The development and expansion of container ports have become imperative to accommodate the surging demand for containerized shipments and ensure efficient and seamless trade flows [2]. Container traffic worldwide has increased from around 224.7 million twenty-foot equivalent units (TEUs) to over 857 million TEUs between 2000 and 2021 [3]. The exponential growth in container traffic underscores the need for continuous investments in seaport infrastructure to maintain competitiveness and meet the ever-growing transportation demands of the modern world [4], [5].

Northeast Asia's container port system is an integral part of the global transportation network and holds significant importance in shaping regional dynamics [6]. Ports of 4 countries in Northeast Asia, including China, South Korea, Japan, and Taiwan, play a crucial role in facilitating international trade. They serve as primary gateways for both exports and imports, connecting the region to global markets. The container throughput at these ports has witnessed substantial growth in recent years, driven by the expanding global trade [6], [7] (See Figure 1).

In 2021, container ports in the region handled around 348 million TEUs, accounting for over 40.6% of the global container throughput. These ports are strategically located along major maritime routes, connecting major Northeast Asian economies with the rest of the world. Situated along key transportation routes, they provide convenient access to major markets and function as transhipment hubs for cargo redistribution [8]. Their proximity to significant production centre further enhances their role in global commerce. To enhance operational efficiency and meet the demands of modern trade, Northeast Asia's ports have invested in infrastructure and facilities, improved international connectivity, and adopted advanced technological advancements [9], [10]. These developments aim to accommodate larger vessels, enhance cargo handling efficiency, and ensure seamless trade flows.

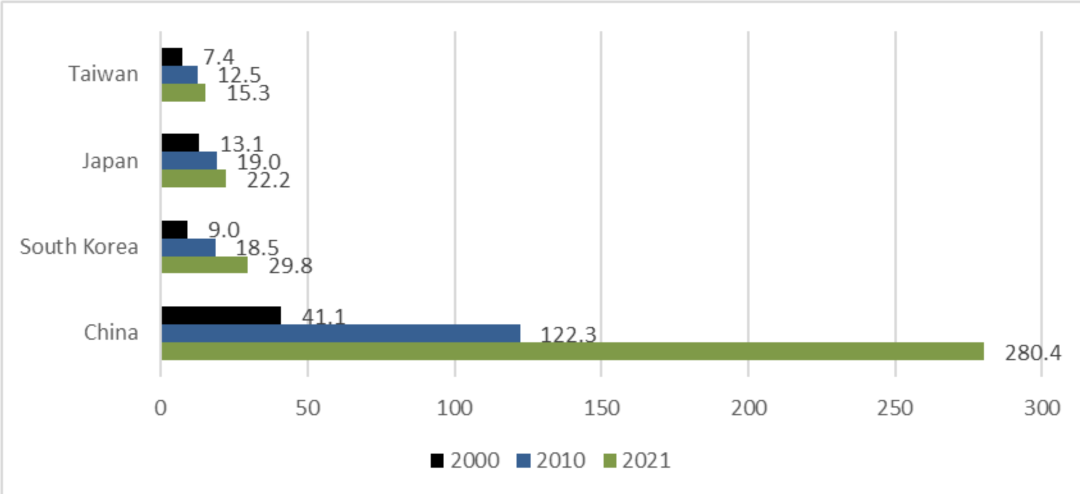

Figure 1. The development of Northeast Asia container port system between 2000 and 2021

The outbreak of the COVID-19 pandemic originated in Wuhan, China, in December 2019, and rapidly spread worldwide, leading to significant fluctuations in economic and societal activities [11], [12]. Governments across the globe had to implement various measures such as lockdowns, social distancing, and travel restrictions to control the virus transmission [13], [14]. Consequently, the global economy has suffered, resulting in widespread unemployment and business closures. The COVID-19 pandemic has resulted over 6.2 million deaths and has profoundly impacted multiple sectors of the economy and society [15]. The effects of the pandemic on port operations have been extensively discussed in numerous recent studies.

The COVID-19 pandemic has caused disruptions in global trade, resulting in a decline in import and export activities [16]–[18]. Measures such as lockdowns, travel restrictions, and reduced consumer demand have impacted the flow of goods, leading to a decrease in container traffic at seaports [19], [20]. Many countries have implemented temporary closures or restrictions on port operations to prevent the spread of the virus, further affecting trade volumes [21]–[23]. Factory closures, labour shortages, and logistical challenges have disrupted the supply of goods, impacting the transportation of cargo through seaports. Stalled production and distribution activities have affected import and export operations, resulting in reduced cargo throughput at seaports. Additionally, the pandemic has brought about changes in trade patterns and the types of goods being transported. Certain sectors, such as tourism and entertainment, have experienced significant downturns, while others, like healthcare equipment and essential goods, have seen increased demand [24]–[26]. These changes have affected the volume and composition of cargo handled by seaports, necessitating adjustments in operations and logistics. Another impact of the pandemic is that shipping lines remove some inefficient ports from their maritime routes [27]–[29]. Some vessels have had to be rerouted or faced longer journeys due to congestion or limitations at ports.

The COVID-19 pandemic has had an impact on the international connectivity and competitiveness of many seaports in the North Asia region. The restrictions and disruptions caused by the pandemic have affected the smooth flow of goods and connectivity between ports and global markets. This has resulted in challenges for seaports to maintain their international trade links and competitiveness [22], [30]. However, amidst the challenges, the COVID-19 pandemic has also presented opportunities for seaports to enhance their competitiveness and gain market share. As the global supply chains faced disruptions and reconfigurations, seaports that were able to adapt quickly and provide efficient and reliable services will have an advantage. Ports that implemented effective health and safety measures, streamlined their operations, and invested in digitalization and automation have been better positioned to handle the changing demands of international trade during the pandemic. Adapting to the changing demands of global trade, implementing effective measures, and capitalizing on emerging sectors have been key factors in seizing these opportunities and maintaining their relevance in the international maritime trade landscape. However, the impact of the COVID-19 pandemic on the international connectivity and the opportunities to increase market share for seaports in the North Asia region remains a research gap that this study will fill.

The objective of this research is to examine the impact of the COVID-19 pandemic on the international connectivity of container ports in the North Asia region using the connectivity index, which are combined of degree centrality, closeness centrality, and hub & authority. The study also analyses the changes in market share between seaports during the pandemic period through shift-share analysis. The structure of the paper is as follows. Section 2 introduce the methodology and data collection. Section 3 shows results. Lastly, Section 4 shows the conclusion part.

II. Methodology and Data

A. Methodology

Social Network Analysis (SNA)

To visually assess the transportation network and the role of each port within the network, the SNA method is commonly used, with indexes such as degree centrality, closeness centrality, hub index, and authority index. In transportation network analysis, ports play the role of nodes. The degree centrality of a port reflects its direct connectivity to other ports across different regions, as well as the potential for other ports to directly connect to it [31]. On the other hand, the closeness centrality of a port measures the average shortest path length from that port to all other ports in the maritime transportation network. A high closeness centrality indicates that the port can access more information, holds greater influence, and has significant importance compared to other ports. The hub and authority index reflects the importance of each port based on its connections to other ports in the network. A port with a high hub index indicates that it has many connections to ports with high authority index, while a port with a high authority index indicates that it is connected to many ports with high hub index [32]. Degree centrality and closeness centrality can be calculated using the following formulas:

$$I_i^{C_D} = \frac{\sum_{j=1}^{n} x_{ij}}{n-1} \quad (1)$$

$$I_i^{C_C} = \frac{n-1}{\sum_{j=i;i\neq j}^{n} d_{ij}} \quad (2)$$

Where

$I_i^{C_D}$ and $I_i^{C_C}$ are degree centrality and closeness centrality;

x_{ij} give the connectivity from port i to port j, x_{ij}=1 or 0 if port i is connected or not connected to port j n is the number of ports in the network

dij is the number of legs in the shortest path connecting port i and port j

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

It is difficult to compare the connectivity among ports if there are differences among indexes in SNA because SNA does not reflect separately port's connectivity. To address this limitation, TOPSIS combines degree centrality, closeness centrality, hub index, and authority index to create a comprehensive connectivity index that accurately reflects the port's connectivity. By integrating these metrics, the TOPSIS approach allows for a more meaningful and unified comparison of connectivity among ports. The TOPSIS steps are as follows:

Step 1: Normalisation of data:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (3)$$

The normalized matrix is R=[r_{ij}]m×n.

xij is the value of degree centrality, closeness centrality, and hub index, authority index.

Step 2: Calculation of weighted normalized matrix:

$$v_{ij} = w_i * r_{ij} \quad (4)$$

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

Step 2.1 Standardisation of data

The criteria are calculated from Equation (5) (6) if they are beneficial or detrimental, respectively [33].

$$x'_{ij} = \frac{x_{ij} - min\{x_j\}}{max\{x_j\} - min\{x_j\}} \quad (5)$$

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

The new index matrix after standardizing is X'= [x'ij]m×n.

Step 2.2 Calculation of index entropy

$$f_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{m} x'_{ij}} \quad (7)$$

$$e_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} f_{ij}.\ln(f_{ij}) \quad (8)$$

Step 2.3 Calculation of index weight

$$w_j = \frac{1-e_j}{n-\sum_{j=1}^{n} ej} \quad (9)$$

Step 3: Determination of the PIS and the NIS, respectively:

$$V^+ = [V_j^+];\ V^- = [V_j^-] \quad (10)$$

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

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

Step 4: Calculation of the distance for the PIS and NIS alternative:

$$S_i^+ = \sqrt{\sum_{j=1}^{n}(v_{ij} - V_j^+)^2}\ ;\ S_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - V_j^-)^2} \quad (11)$$

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

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad (12)$$

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

Shift analysis (SHIFT)

In the port market, shift analysis is a tool used to determine the changes in market share due to external factors such as shifts in trade patterns or internal factors such as infrastructure developments [34], [35]. Shift analysis is calculated based on the overall growth rate of the port system. The shift effect reflects a port's ability to gain market share in response to market changes. Shift analysis enables policymakers and stakeholders to identify the factors driving changes in container throughput at a specific port and develop strategies to enhance the port's competitiveness in the market.

$$SHIFT_i = TEU_{it1} - \frac{\sum_{i=1}^{n} TEU_{it1}}{\sum_{i=1}^{n} TEU_{it0}} * TEU_{it0} \quad (14)$$

B. Data

To examine the impact of COVID-19 pandemic on Northeast Asia's shipping network, the study used the liner services data from Alphaliner's online database [36]. The database included liner services offered by over 200 shipping companies, encompassing nearly all major container transport routes worldwide. The study collected over 950 maritime services that call the major 20 container ports in Northeast Asia region between 2017 and 2021. Besides, container throughput of these ports was collected from the website of Lloyd's List.

III. RESULT AND DISCUSSION

A. Impact of COVID-19 pandemic on shipping network

To analyse the impact of COVID-19 on the connectivity of seaport systems in Northeast Asia, the study investigated the changes in international connectivity of seaports before and after the pandemic from three perspectives: degree centrality, closeness centrality, and hub & authority. These three metrics were combined into a single index using the TOPSIS method. From a network perspective, the impact of COVID-19 did not hinder the expansion of the number of maritime routes, as the number of routes increased from 641 in 2019 to 673 in 2020. Seaports in the region have diverse connections, whether direct or indirect, with over 490 ports in various regions of the world. Busan, Shanghai, and Hong Kong are global centre ports, as their connectivity indices are the highest, indicating that they play a crucial role in the global maritime transport network. Goods transportation to Europe, America, and Africa is all transhipped through these ports. The highest closeness centrality scores suggest that these ports have the fastest impact on the Northeast Asian maritime transport network and can easily connect with all other ports. COVID-19 negatively affected the connectivity of many ports, but some ports maintained their connectivity despite the pandemic.

The decline in international connectivity of several seaports in the region, such as Hong Kong, Dalian, and Xiamen in China, Tokyo, Kobe, Nagoya, and Yokohama in Japan, Kaohsiung and Taichung in Taiwan, and Kwangyang in South Korea, was a result of many shipping companies opting to cut back on ports with low demand or those that were not efficient on their shipping routes [29] (See Figure 2). This trend was driven by the need to improve the profitability of their operations and to streamline their shipping routes. As a consequence, the container transport market in 2020 experienced significant fluctuations, with many shippers finding it challenging to secure container space and experiencing delays in delivery times. The reduction in seaport connectivity also had a knock-on effect on the wider logistics and supply chain industries, with some sectors experiencing shortages of key materials and components. Overall, the pandemic-induced disruptions in global trade have highlighted the need for greater resilience and flexibility in the shipping industry, with shipping companies looking to diversify their operations and explore alternative shipping routes and modes of transport.

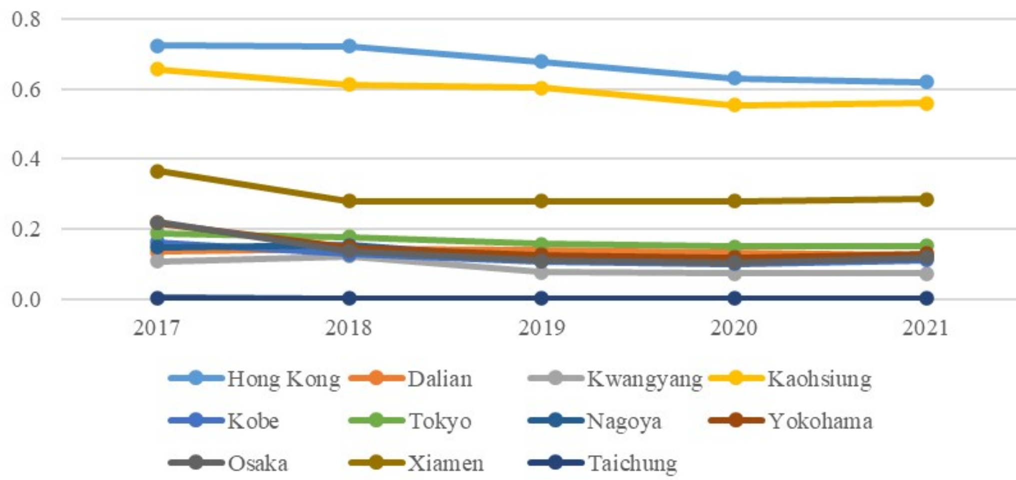

Figure 2. The decrease in international connectivity index of major container ports

The increase in the number of shipping routes while many ports experienced a decrease in their international connectivity is a sign of the highly concentrated transport network in the region. This trend is evident in ports that were able to improve their connectivity despite the pandemic (refer to Figure 3 for details). For example, Busan, the busiest container port in South Korea, has the highest level of connectivity compared to other ports in the region. Meanwhile, many Chinese ports have been successful in leveraging their advantages in geographical location, competitive port fees, infrastructure, and international connectivity to attract shipping lines to add these ports to their routes or introduce new services through these ports. This concentration of transport networks around certain ports can have both positive and negative impacts on the region's economies. On the one hand, it can lead to increased efficiency in transport operations, as well as lower costs and greater convenience for shippers. On the other hand, it can also create imbalances in regional development, with some areas becoming overly reliant on certain ports, while others are left behind. Additionally, the pandemic has exposed the risks of such concentration, as disruptions at a major port can have ripple effects on the entire supply chain. Therefore, it is crucial for policymakers to strike a balance between promoting the development of key ports and ensuring the diversification of transport networks to reduce risks and support more inclusive economic growth across the region.

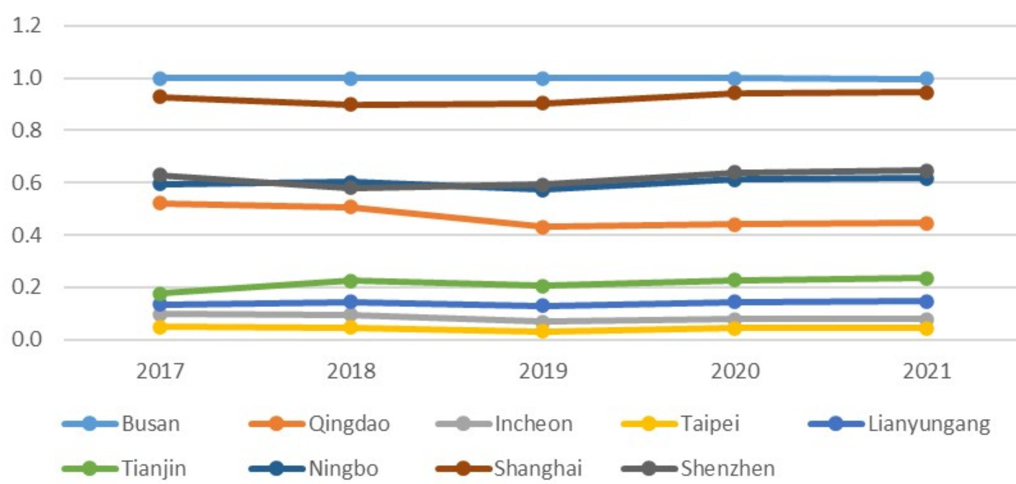

Figure 3. Container ports enhance connectivity

B. Impact of COVID-19 pandemic on competitiveness

Before the COVID-19 pandemic, China's container traffic was the largest in the world, and its ports were critical to global trade. However, Busan, the biggest port in Korea, had the best connectivity in the transportation network due to its exceptional port services and business environment. Many transportation companies preferred to use Busan as an intermediate port due to its efficiency and reliability. The COVID-19 pandemic has had a significant impact on the transportation of goods, including the movement of containers through seaports in Northeast Asia. As countries have implemented different measures to contain the spread of the virus, this has led to disruptions in global supply chains and changes in trade patterns. As a result, container traffic through seaports in the region has been affected, with fluctuations in volume and changes in destinations. These changes in container traffic have been in line with the evolving international connectivity of the region. As countries have sought to diversify their trade relationships and supply chains, new routes and destinations have emerged, while traditional trade flows have shifted. The container shipping industry has had to adapt to these changes, with some ports experiencing increased traffic while others have seen declines.

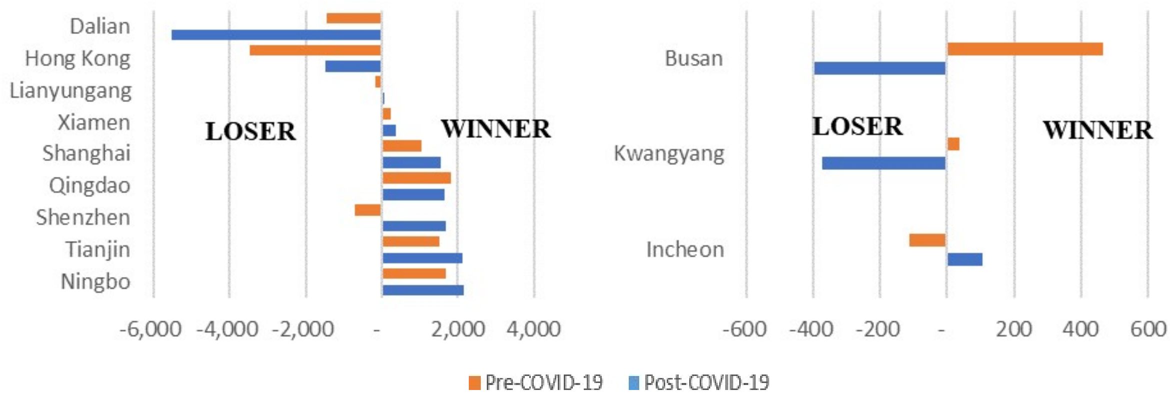

Figure 4. A shift analysis for major container ports in China and Korea

When the pandemic hit, the global shipping industry faced numerous challenges, such as disruptions to supply chains and reduced demand for goods. Despite this, the connectivity of Chinese ports improved during the pandemic. They were able to capitalize on this opportunity to increase their competitiveness and gain market share. With the recovery of China's economy and the resumption of global trade, Chinese ports remain a dominant force in the shipping industry. The results of shift analysis in Figure 3 indicates that the container throughput growth rate of Shanghai, Qingdao, Tianjin, and Ningbo is higher than the regional average, so these ports have gained market share both before and after the COVID-19 pandemic. On the other hand, Dalian and Hong Kong are the ports that have lost the most market share in the region. In addition to the impact of the COVID-19 pandemic reducing the demand for transhipment in Hong Kong, its decrease in container throughput is also due to slower adoption of information technology such as automation compared to other competing ports in the region. Meanwhile, the serious decline in container throughput of Dalian is attributed to weak trade conditions, COVID-19-related disruptions and changes in trade patterns and cargo types, as well as the port's strategy of transferring cargo volumes to Yingkou port.

The COVID-19 pandemic had a negative impact on Busan's container throughput, which fell short of expectations and caused the port to lose market share. However, Busan remains a crucial hub-port with highly international connectivity. To remain competitive, the port is investing in infrastructure and technology to enhance efficiency. It has also expanded its services to include logistics, warehousing, and distribution, which has attracted more transportation companies to the port. These efforts have helped Busan to cope with the sharp increase in shipping demand that occurred after major economies emerged from extended lockdowns. The impact of COVID-19 and carrier consolidation has taken a toll on Kwangyang, with a significant decline in container traffic similar to that of Busan during the pandemic. In addition, the inefficiency of operations at the port has been a contributing factor to the reduction in container traffic. Many shipping lines have opted to terminate their services at Kwangyang due to issues with productivity and cost-effectiveness. For example, SM Line discontinued its American CPX service that previously called at Kwangyang Container Terminal in April 2020, following the consolidation of its operations by Kwangyang West Container Terminals. In 2020, despite the COVID-19 pandemic, Incheon Port achieved a record high container throughput of nearly 3.3 million TEUs, being the only port to gain market share. The government's effective response to the pandemic played a crucial role in this success. Unlike other high-income countries that implemented strict measures, the government allowed businesses to remain open, issuing stay-at-home orders only in late 2020. This approach boosted both imports and exports and contributed to the port's growth. In particular, Incheon saw a rise in container import and export volumes, with imports from Vietnam, Thailand, Indonesia, and Malaysia exceeding 2019 levels.

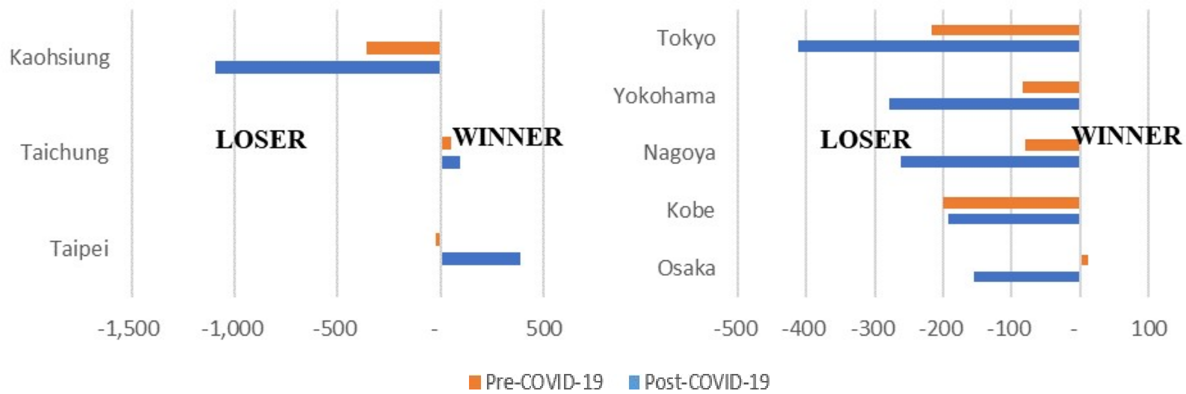

Figure 5. A shift analysis for major container ports in Taiwan and Japan

The container port of Taiwan is facing many challenges during the COVID-19 pandemic. Kaohsiung, the largest transhipment port in Taiwan with over 70% of the national container volume, has been affected by the disruption of trade flows. Many shipping lines have reduced their capacity at the port, resulting in fewer vessel calls and decreased cargo volume. While Taipei and Taichung have seen positive signs of growth in container throughput, congestion at these ports has been increasing due to inadequate port infrastructure and equipment.

It can be said that Japan's container ports have been hit the hardest among the four countries in the region, as most ports have lost market share except for Osaka. The decline in Japan's port throughput is due to both a decrease in exports and imports. The demand for imported cars from many markets such as China, the United States, and Thailand has decreased as these countries have implemented economic lockdown measures. In addition, the volume of domestic goods from Japan's major trading partners has also declined. The cancellation of connections to Japan's container ports is also a factor causing a decrease in international connectivity and container throughput. For example, the shipping conglomerate Maersk has chosen to cancel trips on the TP1 route across the Pacific linking the West Coast of North America with Yokohama and other ports in the Far East due to many Chinese ports being closed and transportation demand decreasing.

IV. CONCLUSION

The widespread outbreak of COVID-19 has caused significant damage to the maritime industry, particularly to seaports. This study investigates the impact of COVID-19 on the operations of ports in the Northeast Asia region, focusing on two aspects: international connectivity and market share changes. The key findings are as follows. Firstly, the reduced international connectivity of many ports in the region, such as Hong Kong, Dalian, and Xiamen in China; Tokyo, Kobe, Nagoya, and Yokohama in Japan; Kaohsiung and Taichung in Taiwan; and Kwangyang in South Korea, is the result of many shipping companies cutting off inefficiently ports from their transportation routes. Secondly, Chinese ports remain dominant forces in the maritime transport industry, as their connectivity has continued to improve during the pandemic due to the recovery of the Chinese economy and the resumption of global trade. Thirdly, changes in container traffic align with the development of international connectivity in the region. Ports that experienced a decline in connectivity have lost market share, while ports that maintained their international connectivity have gained market share. Finally, the region's transportation network has become more concentrated as the number of maritime routes has increased, but many ports have experienced a decrease in connectivity.

Based on these findings, the study proposes the following practical implications. Firstly, it is crucial to maintain international connectivity to ensure the growth of container traffic. Secondly, disease control policies need to be established to minimize the impact of pandemics on seaport operations. Thirdly, development policies should avoid excessive concentration on a few ports, which can lead to imbalances. Overall, these measures aim to mitigate the negative effects of COVID-19 on the maritime industry and ensure the resilience and efficiency of seaport operations in the North Asia region

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