CONFIGURATION OF MARITIME CONTAINER NETWORK ON TOPOLOGICAL ASPECTS BASED ON COMPLEX NETWORK

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Port management body (i.e. port authority) have made several port strategies to be competitive port. Complex networks which focus on topological aspects of various networked systems have not developed as the evaluation indicator of the effect of policies. The objective of this study is to evaluate the maritime container network focused on topological aspects. Specifically, we analyze the undirected and weighted network of cargo to/from Japan. We find that Busan port keep the function as hub ports for cargo to/from Japan. Kobe, Osaka and Yokohama ports which are the main target ports of the policy of International Container Strategic Port (ICSP) decrease the function as hub ports. The conversion of cargo to/from Japan from Busan port, which is the purpose of ICSP, have not realized.

Key Words : *maritime network, complex network, Japanese port, Busan port*

1. INTRODUCTION

Container ports that are with efficient infrastructure and competitive transportation services, can raise the benefits beyond the container port users to the whole of society (Notteboom and Yap 2012). Port management body (i.e. port authority) have made several port strategies to be competitive port. As an example, the Ministry of Land, Infrastructure, Transport and Tourism of Japan launched a policy called the International Container Strategic Port (ICSP) in 2009 to regain transshipped container cargo originating in Japan from the port of Busan. The fundamental idea behind this policy is to consolidate large-scale container ports that are in proximity to one another. The ports in Kobe and Osaka (Hanshin port) and Yokohama and Kawasaki (Keihin port) were designated as targets for consolidation. In 2018, the development of new services and increase of container throughput are confirmed at those ports (MLIT 2019). However, according to Containerisation International Yearbook, the world ranking of container throughput decrease in Kobe from 45st at 2010 to 58st at 2018 and Yokohama from 36st at 2010 to 57st at 2018. Those ports have not become International competitive ports. We should analyze the network changing due to the ICSP to make proper policy.

As the new evaluation indicator, there is a new scientific field called complex network which is also known as network science (Sugishita and Asakura 2020). This field especially focuses on topological aspects of various networked systems. Topological aspects of complex network are good components traditional measures of individual throughput (Ducruet 2010). Topological aspects of complex network are accurate measures of the regional and global importance of a port or a route, which classic statistical techniques cannot show (Montes 2012). For example, topological aspects can appear the difference of network of several vessel types such as dry bulk carriers, container ships and oil tankers (Kalza et al 2010 and Mou et al 2018).

There are several literatures related to the evaluation on maritime network by complex network. We categorize previous studies into two types; variation with time and specific region. The studies about variation with time focus on the topological changings in more than two time periods. For example, Ducruet and Notteboom (2012) analyze the global liner shipping network in 1996 and 2006 and show the rapid change in port hierarchies and liner service configurations. Ducruet et al. (2010) identify regional structures of Atlantic liner networks in 1996 and 2006 by clustering. Gonzalez et al. (2012) assess the changes in the maritime network due to the financial crisis. Montes et al. (2012) explain the evolution of maritime networks of containerized and general cargo maritime routes from 2009 to 2011. Fang et al. (2018) explore maritime network dynamics before and after international events such as military conflict. Those literatures show the topological changings in some specific ports.

The studies about specific area focus on the functions in the area evaluated by the topological factors. Specifically, Ducruet (2016) shows dependence on the Suez and Panama canals by regions. Kawasaki et al. (2019) point out the difference of network in alliance within Intra-Asia network. Calatayud et al. (2017) analyze the vulnerability of networks in the Americas. Liu et al. (2018) shows the difference of topological structures between six areas (Asia, Europe, North and Central America, South America, Africa and Oceania). Mou et al (2018) identify the important nodes in maritime silk road. Additionally, there are several structures focused on specific area such as Japanese and Chinese ports (Hu et al. 2020) and network in Greece (Tsiotas and Polyzos, 2015). Those literatures show important node in specific region.

Those previous studies about variation with time and specific region tend to simplify network flow and the mutual understanding between the information of network topology and management of transportation system (Sugishita and Asakura 2020). The evaluation of maritime policy by the topological. Therefore, the objective of this study is to evaluate the maritime container network focused on topological aspects. Specifically, we analyze the network cargo to/from Japan and show the effect of ICSP evaluated by the topological aspects.

The rest of this paper is structured as follows. Section 2 show the methodology about data overview about analyzed network and measures of topological aspects in complex network. The results are appeared in Section 3. Finally, Section 4 conclude this study and show directions for further research.

2. METHODOLOGY

(1) Data overview

In this study, we analyze the undirected and weighted network made by the data obtained from Nationwide Flow Survey of Export-Import Container Cargos at 2008, 2018 in Japan. The survey aims to grasp the container flow of export and import from/to Japan. The survey clarifies origin, destination and transshipment port of the cargo to/from Japan. We regard the ports as nodes and the transportation between ports as undirected edge weighted by the amount of container flow.

(2) Measures

An undirected and weighted network (G) consists of two sets; the set of nodes ($\mathcal{N}$) and the set of edges (E). We define the number of nodes as N and refer a node to by its order i in the set $\mathcal{N}$ ($\mathcal{N} \equiv \{n_1, n_2, \dots, n_N\}$) and each of the edges in the set $\mathcal{E}$ as a couple of nodes i and j (e_{ij}). Since we treat the undirected network, we consider the edges whose order of the two nodes are different as same edge $(e_{ij} = e_{ji})$. The network $G = (\mathcal{N}, E)$ can be expressed by its adjacency matrix A which is a $N \times N$ matrix and have entries a_{ij}. The entry a_{ij} take the value of 1 if the edge e_{ij} exists and 0 otherwise. Additionally, we define the weight on the edge e_{ij} as w_{ij} which take the value of 0 if the edge e_{ij} does not exist. We identify the network G with following topological aspects.

The degree (k_i) of node i is the number of edges incident with the node. We calculate the degree in Equation 1. We express the scale-free structure, which is one of basic topological property of a network, by the analysis of the probability distribution of degree $P(k)$. The scale-free networks have an inhomogeneous degree distribution which have a few nodes connected to many other nodes (hub) and many poorly connected nodes (Boccaletti 2006). The network is a scale-free network in the case where a network exhibits a power-law degree distribution $P(k) \sim k^{-\gamma}$. As the value of the power-law coefficient γ increase, the number of hubs decrease and the number of poorly connected nodes increase.

$$k_i = \sum_j a_{ij} \tag{1}$$

Each node is characterized by the strength (s_i) which means the sum of weights of edges in a node. Equation 2 shows the calculation to obtain the strength. We calculate the dependence of nodes on edges by the disparity quantity (Y_i) in Equation 3. If all edges have comparable weights, all weights (w_{ij}) are equal to the value of strength divided by degree (s_i/k_i) and the value of sum of square in the capital sigma becomes inverse square of degree $(1/k_i)^2$. We normalize the value by the degree. If several edges dominate, the value of disparity becomes larger and is close to one otherwise (Boccaletti et al 2006).

$$s_i = \sum_j w_{ij} \quad (2)$$

$$Y_i = k_i \sum_j \left[\frac{w_{ij}}{s_i}\right]^2 \quad (3)$$

The transportation network vulnerability is to quantify its security and stability in the network. We can consider the structural vulnerability by the changing of characteristics after the removal of nodes in a network (Candelieri et al 2019). Equation 4 shows Latatora and Marchiori network efficiency (L) (Latora and Marchiori 2001) to measure the vulnerability of network. We measure importance of some nodes in the network as the vulnerability by measuring the drop in the network efficiency due to removal of the node. As for the distance between nodes i and j (d_{ij}), we obtain from the Shimbel Distance Matrix.

$$L = \frac{1}{n(n-1)} \sum_{i,j} \frac{1}{d_{ij}} \quad (4)$$

Clustering coefficient, also known as transitivity, is a typical property of acquaintance networks where two individuals with a common friend are likely to know each other (Boccaletti et al 2006). We can measure the density of network by the weighted clustering coefficient (C_i). High density network consists of many interconnected nodes and paths between any two nodes can be relatively short. The structure is known as small-world and have higher clustering coefficient. We calculate the quantity of clustering coefficient by counting for triangles formed in the neighborhood of the node i as shown in Equation 5 (Barthelemy et al 2005). We count the triangles with the weight distribution by factors within capital sigma and normalize by the factor $s_i(k_i - 1)$ to ensure $0 \leq C_i \leq 1$.

$$C_i = \frac{1}{s_i(k_i - 1)} \sum_{j,h} \frac{w_{ij} + w_{ih}}{2} a_{ij} a_{ih} a_{jh} \quad (5)$$

Community structures are sub sets of highly interconnected nodes in the network G. Nodes in a community connects with many nodes in the same community and with few nodes in different community. We perform the Louvain algorithm (Blondel et al. 2008), which is a kind of greedy algorithm, to reveal the community structure. We can obtain the communities to maximize modularity (Q) that measures the density of edges inside communities as shown in Equation 6 (Newman 2004). The term o_i is the community that node i belongs to, the function $\delta(o_i, o_j)$ takes a value of 1 if nodes i and j belong to the same community ($o_i = o_j$) and $m = (\sum_j w_{ij})/2$.

$$Q = \frac{1}{2m} \sum_{i,j} \left[w_{ij} - \frac{s_i s_j}{2m}\right] \delta(o_i, o_j) \quad (6)$$

3. RESULT

Table 1 shows properties of the network at 2008 and 2018. As shown in Table 1, the number of nodes, edges and average weights increase. This shows the number of trade partner port with Japanese ports and the trade volume to/from Japan increase from 2008. On the other hand, since most of the increased nodes connect 10 or less nodes, average degree in 2018 becomes lower than 2008. This cause the strengthened scale-free, the weakened small-world structure and lower network efficiency in 2018. Specifically, the

Table 1. Topological properties of the network in 2008 and 2018

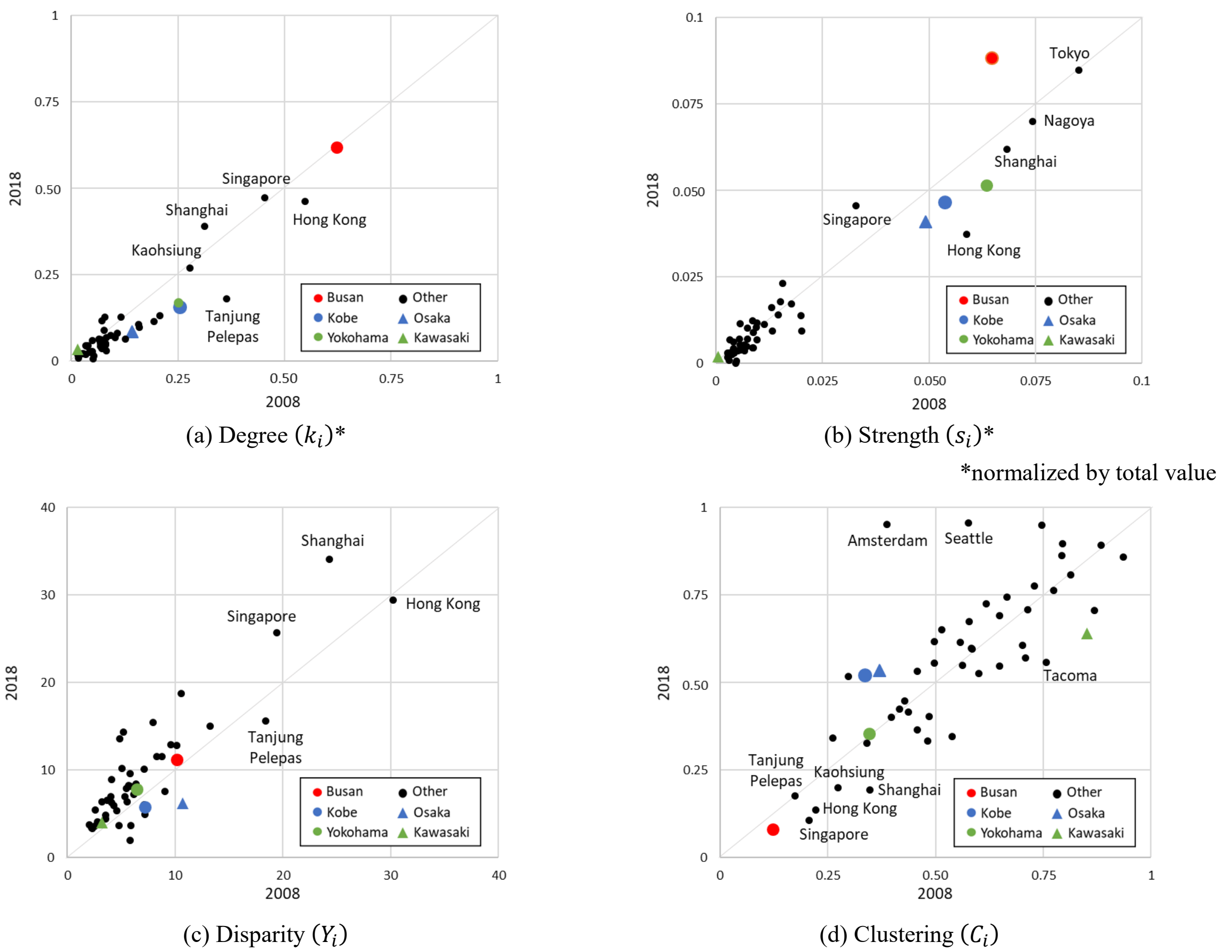
Index	Measure	2008	2018
Network size	No. nodes	655	1026
	No. nodes - 10 or less degree	509	873
	No. edges	3,969	5,056
	Average degree	12.12	9.86
	Average weight [ton]	4,239	5,034
	Max. degree	408	636
	Max. weight [ton]	451,470	534,381
Scale-free	Power-law coefficient (γ)	0.968	1.015
Small-world	Average weighted clustering coefficient (C_i)	0.677	0.627
Vulnerability (Network efficiency: L)	Base	0.451	0.440
	Remove Busan	0.403	0.369
	Remove Kobe	0.444	0.434
	Remove Yokohama	0.450	0.439

power-law coefficient, which can measure the scale-free structure, increases from 0.968 to 1.015. Average weighted clustering coefficient, which can measure the small-world structure, decrease from 0.677 to 0.627. Network efficiency in base decrease from 0.451 to 0.440. The network change to have more inhomogeneous degree distribution and lower density network.

Maximum degree and weighted edges are increasing. The expansion of trade to/from Japan is confirmed. Both maximum nodes in 2008 and 2018 are Busan port and both maximum edges are between Tokyo and Shanghai port. There are no structural changes about the maximum value in the network. As for the vulnerability, the drop of network efficiency in Busan removal is larger compared to other ports. This shows high dependency of Busan port in the cargo to/from Japan. Since the decrease ratio in Busan becomes higher in 2018, the dependency increases from 2008. On the other hand, the drops are not so large and do not so change from 2008 in Japanese two large ports; Kobe and Yokohama ports. This shows the dependency of those two ports are not so large in the network.

Fig.1 shows the comparison between 2008 and 2018 for degree, weighted strength, disparity quantity and weighted clustering coefficient of top 100 nodes in degree at 2008. As shown in Fig.1 (a) and (b), the degree in Busan do not so change and the strength increase. This shows that Busan port keep the function as hub ports for cargo to/from Japan. On the other hand, the normalized degree and strength decrease in Kobe, Osaka and Yokohama ports which are the main target ports of the policy of ICSP as mentioned in Section 1. Those three ports decrease the function as hub ports and the conversion of cargo to/from Japan from Busan port, which is the purpose of ICSP, have not realized. As for the disparity quantity and clustering coefficient, values in Yokohama and Busan do not drastically change as shown in Fig.1 (c) and (d). The network configuration of disparity and density in Yokohama and Busan do not change from 2008. The disparity value decrease and clustering coefficient increase in Kobe and Osaka. Those two ports changed high density network without a dominant edge. Since, one of the targets of ICSP, Kawasaki port, is not so large ports compared to other target ports, the values of degree, and strength in Kawasaki port are small.

As for other ports except the targets of ICSP, there are several ports which have outstanding network



(a) Degree (k_i)*

(b) Strength (s_i)*

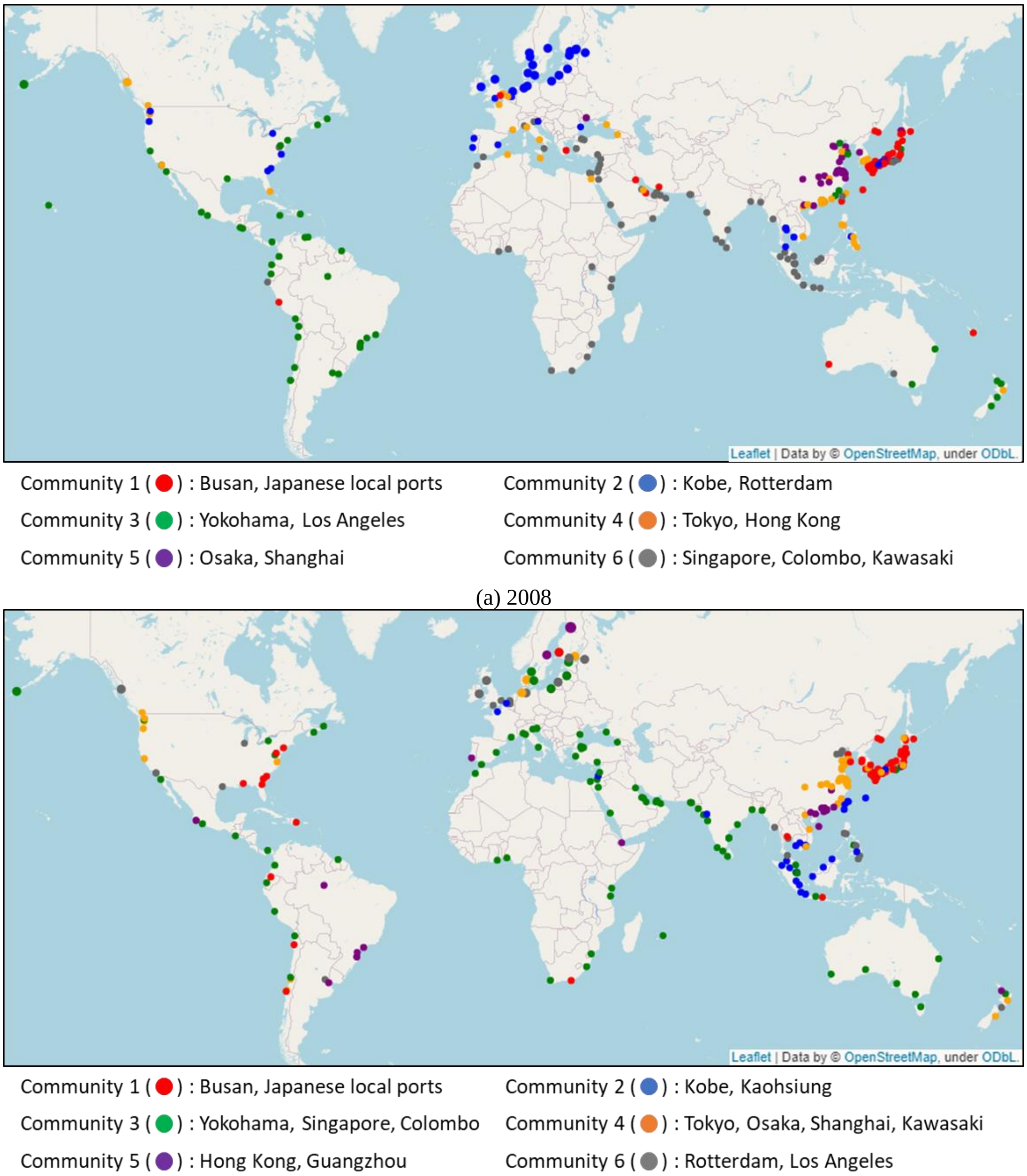
*normalized by total value

(c) Disparity (Y_i)

(d) Clustering (C_i)

Fig.1 Comparison of degree, strength, disparity and clustering coefficient configuration. For example, disparity value of Shanghai port increase and the number of dominant edges increase in Shanghai. Although, Hong Kong ports have high degree and strength, the values decrease. Since degree and strength in Singapore ports increase from 2008, we observe the importance of Singapore port in cargo to/from Japan. The degree and clustering coefficient in Tanjong Pelapas port are high degree but the strength is not so high. This shows the amount of trade volume is not so large but the number of trading ports is high in Tanjung Pelepas port. The clustering value in Seattle increase but the value in Tacoma decrease. There is a difference in the Northwest Seaport Alliance which was formed by the consolidation between Seattle and Tacoma in 2015.

Fig.2 shows the community structures and major ports in the community in the network at 2008 and 2018. Note that Fig. 2 shows the location and belonging community of top 300 ports in the strength. Six communities maximize the amount of modularity, which measures the density of edges inside communities, in both 2008 and 2018. Those six communities have following properties. Busan port belongs the same community with Japanese local ports in 2008 and 2018 as the community 1. This shows the importance of Busan port in cargo to/from Japan as confirmed in other topological property such as degree. As shown in community 2, Kobe port belongs the same community with European ports in 2008, but becomes to belong the same community with South East Asian ports in 2018. This imply that there are higher interconnections between Kobe and South



(b) 2018

Fig.2 Community structures in the network at 2008 and 2018

East Asian ports in 2018 and expansion of Europe routes in Kobe port, which is one of the purposes of ICSP, is not realized in the sense of community structure. Yokohama port belongs the same community with North and South American ports in 2008. In 2018, due to the higher interconnection with Singapore port, Yokohama ports belongs to the same community with South Asian, Australian and African ports. Tokyo ports belongs the community which consists of sparse ports in the world in 2008. Due to the higher interconnection with Shanghai ports, Tokyo port becomes to belong the same community with Shanghai and Osaka port which belong the same community in 2008 as community 5. As for the consolidation as Hanshin and Keihin ports which is one of the purposes of ICSP, Kobe and Osaka ports which Hanshin port consists of and Yokohama and Kawasaki ports which consists of Keihin ports belong different community, respectively. Burt (1992) mention the inefficiency of highly interconnected network in sense of the less diverse information. Therefore, the consolidation is effective methods in the sense of diversity.

4. CONCLUSION

In this study, we analyze the network cargo to/from Japan by the topological aspects for evaluation of the effect of the ICSP. We analyze the undirected and weighted network made by the data obtained from Nationwide Flow Survey of Export-Import Container Cargos at 2008, 2018 in Japan. The study presents the following findings.

First, the network expands from 2008 and 2018. Since most of the increased nodes connect 10 or less nodes, the network change to have more inhomogeneous degree distribution and lower density network. On the other hand, there are no structural changes about the maximum value in the network. Second, Busan port keep the function as hub ports for cargo to/from Japan. Kobe, Osaka and Yokohama ports which are the main target ports of the policy of ICSP decrease the function as hub ports and the conversion of cargo to/from Japan from Busan port, which is the purpose of ICSP, have not realized. This is also confirmed in community structure. Busan port belongs the same community with Japanese local ports in 2008 and 2018. Finally, Kobe and Osaka ports which Hanshin port consists of and Yokohama and Kawasaki ports which consists of Keihin ports belong different community, respectively. Therefore, the consolidations as Hanshin and Yokohama ports are effective methods in the sense of diversity.

This study has several limitations. For example, we just calculate the amounts of topological measures. We should implement several statistical methods such as Data envelopment analysis to find stastical trend and estimate proper network. Those should be investigated by future research.

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