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SPATIAL AND TEMPORAL CHANGES IN THE CRUISE NETWORK STRUCTURE

（クルーズネットワーク構造の時空間変化）

by

HIROHITO ITO

Submitted to the Department of Transdisciplinary Science and Engineering
in Partial Fulfillment of the Requirements of the Degree of

DOCTOR OF ENGINEERING

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ABSTRACT

The cruise industry has experienced continuous growth since the late 1960s. While the global financial crisis of 2008-09 had a major impact on maritime cargo shipping, the cruise industry continued to experience an increase in passenger numbers. Cruise demand is characterized as supply-driven. Ports develop facilities first, and then cruise ships can call at the ports. Therefore, under conditions of uncertain future cruise demand, ports are required to make decisions that require port investments. Conversely, the lack of cruise ships coming to some ports after the opening of port facilities has become a problem.

These undesirable conditions may be due to the supply-driven characteristics of cruise demand under the lack of information in the cruise market. If there were a little less uncertainty about future demand for cruise ships, it might reduce the number of ports that do not receive cruise ships after they are put into service. The situation at sea, where many cruise ships operate between different ports, cannot be understood in terms of just one cruise ship itinerary. By taking the trajectory of all cruise ships navigating in a given area as a network, and by getting a bird's eye view, and understanding the growth areas and timing where cruise lines are deploying ships and developing routes, it may be possible to avoid a situation where cruise ships do not arrive after a port has been built. The purpose of this dissertation is to understand the spatial and temporal changes in the structure of the cruise network using automatic identification system (AIS) data.

Characteristics of spatial and temporal changes in the structure of the cruise network were identified. First, cruise lines continued to operate under the contingency of the terminal high altitude area defense missile (THAAD) disruption of shipping routes, but with a reduced number of ports of call for punctuality. Second, cruise ships continued to be deployed in the Caribbean and Mediterranean, while Asia closed its cruise port early in the outbreak of coronavirus disease (COVID-19). Third, the Northeast Asian cruise network has tended to develop routes for mega- and small-size ships, and for all ship sizes, the quality of community connections tended to improve over time. Finally, seasonality played a role in the cruise industry. Cruise lines took advantage of seasonality to change their deployment areas.

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1.1.1. History of the cruise industry

The cruise industry started with regular passenger ship services. From the mid-19th century liner services supported long-distance passenger transportation between continents, particularly between Europe and North America. The need to accommodate a large number of passengers of different socio-economic statuses for at least a week led to the emergence of specific ship designs radically different from cargo ships where speed and comfort were paramount. The emergence of the cruise industry can be traced to the demise of the ocean liner in the 1960s as it was replaced by fast jet services for which it could not compete. The availability of a fleet of liners whose utility was no longer commercially justifiable incited their reconversion to form the first fleet of cruise ships (Rodrigue and Notteboom, 2013).

Historically, cruise services were offered by ‘regular steamship lines’ and ‘transatlantic companies,’ and are currently provided by ‘cruise lines.’ Regular steamship companies were lines that operated year-round from US mainland ports such as New York, New Orleans, and later Miami, carrying both cruise passengers and cargo (or only passengers) throughout the Caribbean on designated shipping routes. For example, Quebec, United Fruit, Ward (USA), and Furness (UK) fall into this category. As implied by the term, transatlantic companies provided passenger services between North American and European ports, such as Cunard. The term ‘cruise lines’ is used mainly in a post-1965 context, describing those companies such as Norwegian Cruise Line in 1966, Royal Caribbean International in 1968, and Carnival Cruise Lines in 1972, which have remained the large cruise lines (Lawton and Butler, 1987; Garin, 2005).

1.1.2. Cruise market trends

Since the late 1960s, the cruise industry has witnessed uninterrupted growth, except for a temporary negative growth during the 1974-75 oil crisis. While the global financial crisis of 2008-09 had a major impact on maritime cargo shipping, cruise lines and cruise ports continued to experience an increase in passenger numbers. It did so even when an unfortunate event, the COSTA CONCORDIA loss, created the most sustained period of negative publicity for the cruise industry (Pallis, 2015). The cruise industry has expanded since the 1990s. The global cruise population increased from 3.8 million in 1990 to 29.7 million in 2019 (Cruise Lines International Association [CLIA], 2011; 2019; 2020a). The average annual growth rate for the last 30 years is 7.37%.

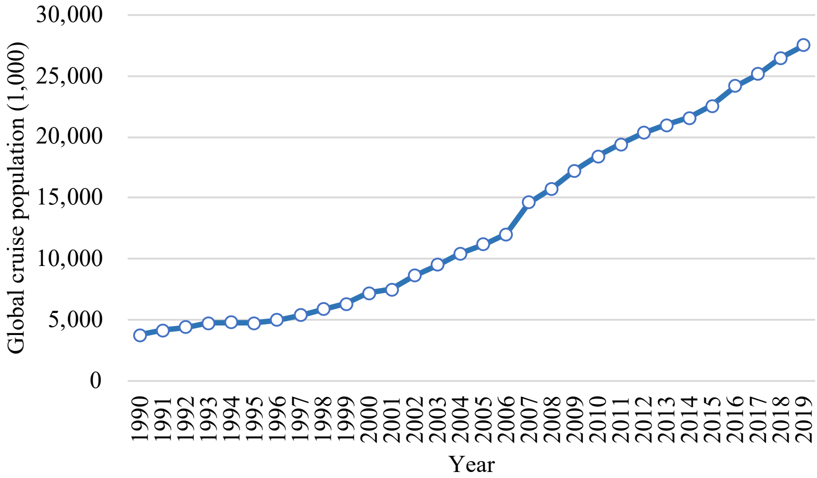

Figure 1-1 Global cruise population

Source: Cruise Market Watch (2022)

1.1.3. Cruise market expanding globally

The global cruise market has expanded from the US-centric market to Europe, followed by Asia and other countries (ROW). In 1990, 93% of the world cruise population was America; by 2000, 91% was America as the European population grew. The U.S. cruise population dropped to 53% in 2010 and less than half by 2019. Recently, the cruise population in China has increased. In 2006, the first year of the Chinese cruise market, the cruise population was 20,000 (Wang, 2017). In 2016, the number reached 2.1 million, and China became the world’s second-largest cruise market, following the United States (CLIA, 2016). Thus, the cruise market is expanding worldwide.

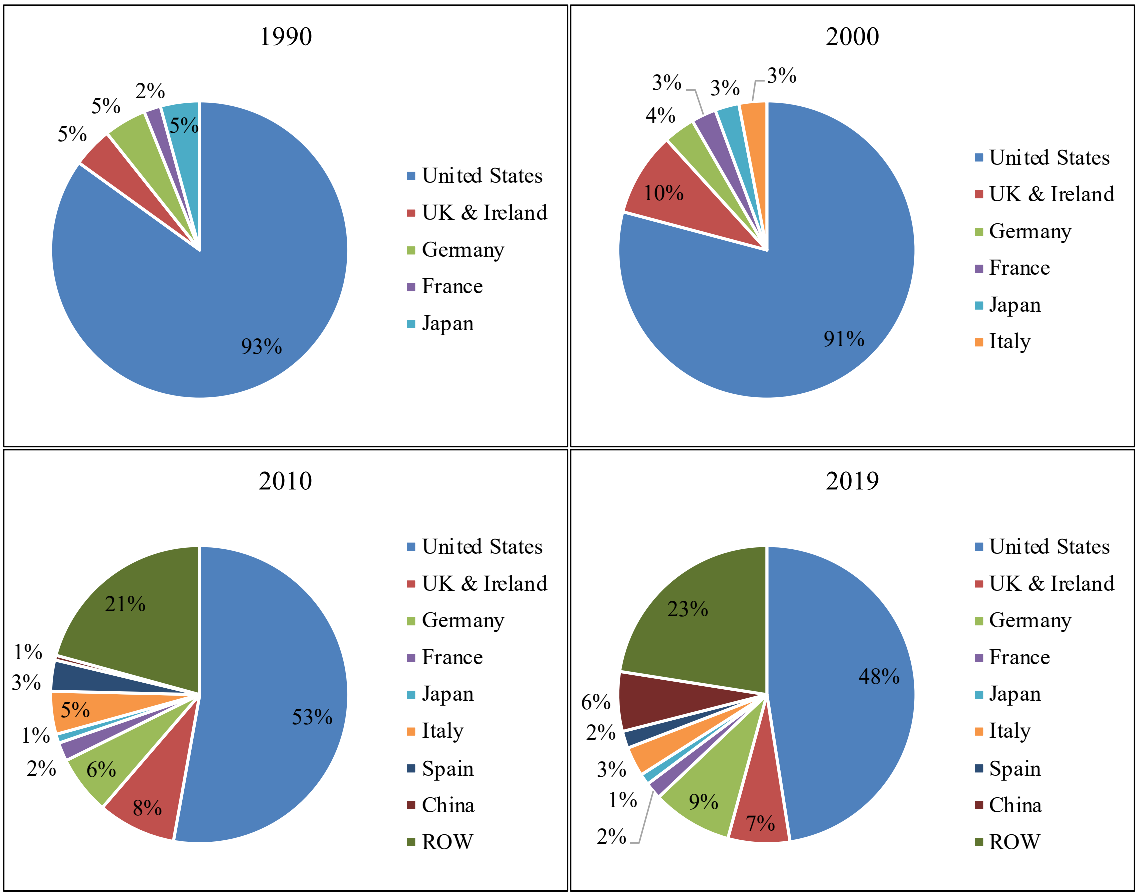

Figure 1-2 Percentage of cruise population by country

Source: CLIA (2011, 2016, 2019, 2020b)

1.1.4. Deployment of mega cruise ships

Cruise lines are deploying larger ships to meet the growing demands of cruise passengers. The first dedicated cruise ships began to appear in the 1970s and could carry about 1,000 passengers. By the 1980s, cruise ships had emerged that could transport more than 2,000 passengers to take advantage of economies of scale. The current large cruise ship, the OASIS OF THE SEAS, was deployed by Royal Caribbean in 2009. This ship is a super-large with a total tongue of 226,838 GT, a passenger capacity of 6,360, and a crew of 2,165. There are plans to introduce mega-sized vessels of 230,000 GT or more after 2022. In terms of average gross tonnage, it was 5,723 GT in 1990, but by 2019 it was 38,907 GT. Including deployment of new ships, this figure shows to grow to 44,957 GT by 2027.

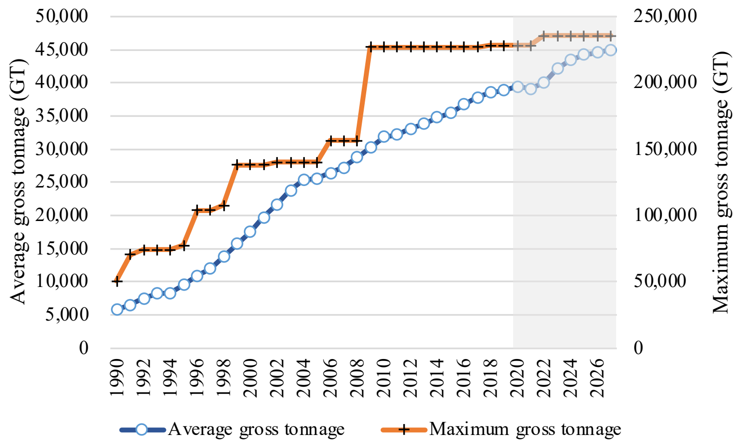

Figure 1-3 Trends in maximum and average cruise ship sizes (Gross Tonnage)
Source: IHS Maritime ship database (2022)
Note: Estimated after 2020.

In terms of maximum passenger capacity, the number has increased from 2,020 in 1990 to 6,654 in 2019. Including the future deployment of new ships, the plan is for the 6,988 mega ships to emerge after 2022. In terms of average passenger capacity, the number has increased from 216 in 1990 to 1,174 in 2019. Including the future deployment of new ships, the number is expected to increase to 1,317 by 2027.

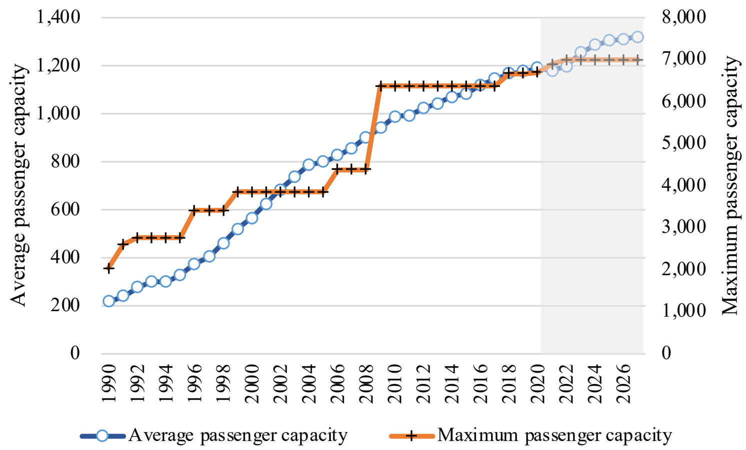

Figure 1-4 Trends in maximum and average cruise ship sizes (Passengers)
Source: IHS Maritime ship database (2022)
Note: Estimated after 2020.

1.1.5. Oligopolistic market with cruise line alliances

The global cruise market is an oligopolistic market with alliances such as Carnival Corporation & plc, Royal Caribbean Cruises Ltd., and Norwegian Cruise Line Holding

Ltd. These three alliances account for more than 80% of the global passenger share in 2014 (OECD, 2015). In the container shipping market, three major shipping alliances (2M, THE Alliance, and Ocean Alliance) were formed in 2017. These three alliances account for 80% of the global container market (xChange Solutions GmbH, 2019). The purpose of the alliance is lower prices and service coverage, which is almost the same for both cruise lines and container liners.

In the case of the cruise industry, cruise lines invest in passenger terminals in popular ports and develop private islands to differentiate their ports of call from competitors. In the cruise terminal concession, for example, Terminal D (Palacruceros) in Barcelona, Spain, is operated by Carnival Corporation & plc. Rome Cruise Terminal in Civitavecchia, Italy, is jointly operated by three cruise lines (Royal Caribbean Cruises Ltd., Costa Crociere, and MSC Crociere Spa).

Table 1-1 Investment in cruise terminals (Concessions)

Terminals	Cruise lines
Terminal D (Palacruceros) in Barcelona, Spain	Carnival Corporation & plc.
Rome Cruise Terminal in Civitavecchia, Italy	Royal Caribbean Cruises Ltd., Costa Crociere, MSC Crociere Spa
Marseille Provence Cruise Terminal In Marseille, France	Costa Crociere, MSC Crociere Spa, Louis Cruises
Galveston, US	Royal Caribbean International, Carnival Cruise Lines, CH2MHILL
Port Everglades, US	Royal Caribbean International
Cagliari, Italy	Royal Caribbean Cruises Ltd.
Kasadasi, Turkey	Royal Caribbean Cruises Ltd., Global Ports Holding (GPH)

Source: Pallis (2015)

The major cruise lines have built private ports on islands reserved for their exclusive use, such as CocoCay (Royal Caribbean), Half Moon Cay (Holland), Castaway Cay (Disney), Princess Cay (Princess), and Great Stirrup Cay (Norwegian). These private facilities are all within one cruise day from the homeports of Florida, offering the option of short three to four days cruises (Rodrigue and Notteboom, 2013). Thus, cruise lines design itineraries that give preference to passenger terminals and private islands in which they have invested themselves.

Table 1-2 Development of private islands

Private islands	Cruise lines
CocoCay	Royal Caribbean Cruises Ltd.
Half Moon Cay	Holland America Line
Castaway Cay	Disney Cruise Line
Princess Cay	Princess Cruises
Great Stirrup Cay	Norwegian Cruise Line

Source: Pallis (2015)

1.1.6. A cruise itinerary is a network

The cruise industry sells itineraries, not a destination (Rodrigue and Notteboom, 2013). The design of new itineraries is always performed with the idea that the cruise industry sells itineraries rather than single ports/destinations (Esteve-Perez and Garcia-Sanchez, 2018). Each cruise ship itinerary is a combination of ports of arrival and departure and ports of call, forming a single network. Each such itinerary becomes a larger network over time. Furthermore, by overlapping multiple cruise ship networks, an even larger cruise network is constructed.

There are two types of itineraries for cruise products: 'Closed itineraries' and 'Open itineraries.' 'Closed itineraries' only have one homeport because the itinerary starts and ends at this port; in this case, the itinerary is a closed loop. 'Open itineraries' have two homeports – itinerary starts and ends at different ports. Ports of call are then needed to complete the itinerary (Esteve-Perez and Garcia-Sanchez, 2018). In practical terms, a seven-day cruise itinerary normally represents a loop with the same beginning and ending home port, and usually three to five ports of call in between (Marti, 1990).

Cruise ports that make up these itineraries are divided into three categories: (a) home (or turnaround) ports, (b) ports of call, and (c) hybrid ports (Marti, 1990). Each type embraces different characteristics and levels of required investment. Homeport means where passengers embark or disembark at the beginning or end of their cruise, respectively. Port of call means the port is part of an itinerary; passengers are at the port for only the duration of their port call. A hybrid port means serving as both ports and ports of call. Itinerary design characteristics should also keep in mind these differences in cruise port types. Thus, by viewing the itinerary as a network, the operational and commercial characteristics of the cruise line may be understood.

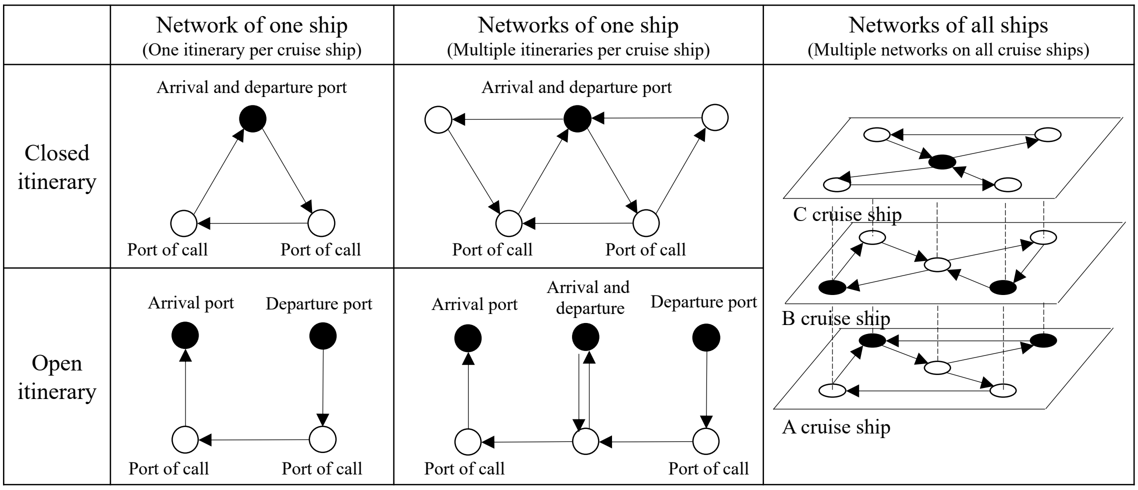

Figure 1-5 What is a cruise network?

1.1.7. Supply-driven markets evolve over time

The cruise market is 'supply-driven,' with supply coming first and demand following. Vogel and Oschmann (2012) explained that cruise demand has always been 'supply-led,' starting with the invention of leisure cruising by passenger shipping lines whose scheduled transatlantic services were losing passengers to the airlines. Similarly, Rodrigue and Notteboom (2013) analyzed that the cruise industry works in a 'supply push mechanism' as cruise lines aim to generate demand for cruises by providing new products (itineraries) with a larger and more diversified range of ships. Cruise lines strategically create demand by offering new cruise ships and new itineraries. On the contrary, container shipping companies deploy their ships to ports where demand for containerized cargo appears (or will). In other words, demand comes first, and supply follows. Thus, the movement of cruise ships could provide insight into the operational and commercial characteristics of cruise lines.

1.1.8. Fragility and vulnerability of cruise industry changes itineraries

The cruise business has vulnerable characteristics of being quickly stopped by (a) natural disasters such as hurricanes and storm surges (Travel Agent Central, 2018); (b) political factors such as border blockades, travel bans, and economic sanctions (Reuters, 2019); (c) violence and conflict such as war, terrorism, and piracy (Maritime Cyprus, 2016); (d) port labor strikes such as wage wars, union unification, and port blockades (Cruise Hive, 2019); (e) community opposition such as environmental protection, over tourism (CNN, 2021); and (f) infectious diseases such as norovirus, SARS, MERS, and COVID-19 (McCarter, 2009; Vivancos et al., 2010; Seatrade Cruise News, 2015; Fisher et al., 2018; Ito et al., 2020). On the other hand, container transport, as a logistics activity that supports production in factories, distribution sales in stores, and the daily lives of consumers, cannot be easily stopped. Therefore, an analysis comparing the operational and commercial characteristics of cruise lines under contingency conditions with those under normal conditions is significant.

1.1.9. Different ship sizes form different itineraries

Cruise lines and cruise ships are valued in categories based on ship concept, quality of service, and ticket prices (luxury, premium, casual, etc.). Competition and cooperation occur between two or more rival ports in a given market. The competition is more intense between ports of the same category (Pallis, 2015). However, each rating company has different criteria, and each ship's category rating is different. Bjornsen (2003) gives examples of the differences in cruise duration, ticket price, and ship sizes in different categories. Contemporary is an itinerary of 3 to 7 days, 100-200 USD per day per person, operating mega- and large-size ships. Premium is an itinerary of 7 to 14 days, 150-500 USD per day per person, operating large- and mid-size ships. Luxury is an itinerary of 7 days and upwards, 600-3,000 USD per day per person, operating mid- and small-size ships (Gibson, 2012). Thus, small-size cruise ships typically offer better service and higher ticket prices.

The itinerary varies with the size of the ship. In particular, the itineraries for larger ships (mass cruise tourism) tend to be more stable than for smaller ships. However, the stability in the sailing schedule is not only linked to shipping size, but also the strategies of the cruise operators regarding cruise product, branding, targeted customer base, pricing, and cost and technical considerations related to the ship operations (Bagis and Dooms, 2014). Each cruise line has different target customers and different ship size strategies. So, not all cruise lines necessarily aim to increase the size of their ships. In the container transport industry, shippers need is cheap and fast transportation. Therefore, generally, all container liners aim to make their container ships larger. So, it makes sense to understand the differences in operational and commercial characteristics by cruise ship size.

1.1.10. Seasonality changes itineraries around the globe

Seasonality plays a key role in the cruise industry (Charlier, 1999; Charlier and McCalla, 2006). Cruise lines are attempting to optimize the utilization of their assets year-round by repositioning to take advantage of the seasonality of cruise markets. The

Caribbean is dominantly serviced during the winter while the Mediterranean experiences a summer peak season. The two markets are not functioning independently but are interconnected operationally, through the repositioning of ship units to cope with variations in seasonal demand among the geographical markets. The seasonality of Alaska, Bermuda, and Canada/ New England is also evident (Rodrigue and Notteboom, 2012). The seasonality pattern of cruise destinations is conditioned not only by weather and market demand constraints but also by other neighboring destination regions (Esteve-Perez and Garcia-Sanchez, 2019). The characteristic of frequent changes in cruise ship deployment based on seasonality is not found in container transport. Therefore, it is necessary to understand the seasonal differences between the operational and commercial characteristics of the cruise industry.

1.2. Introduction

1.2.1. Background

Cruise demand has the characteristic of being supply-driven. In other words, supply-side initiatives such as port development are planned first, followed by demand in the form of cruise ships and passengers. The history of the cruise industry, which has been growing steadily since the late 1960s, shows that this supply-driven approach to stimulating demand has been successful in expanding the market. Conversely, supply-driven port development does not lead to success in all ports. Some ports have experienced problems with cruise ships not coming after the passenger terminals and other facilities have been put into service. Accommodating a cruise ship in a port can be expected to generate economic benefits through the consumption of passengers and crew members, in addition to the expenses of the cruise lines such as port entry fees and wharves. The port needs to be improved and a passenger terminal should be constructed. Therefore, understanding the port and ship operations in a given area is important to avoid wasting investment in port improvements and consequently, cruise ships not coming to the ports.

In addition, the shutdown of cruise ship operations due to emergencies leads to uncertain future demand for cruise ports. The cruise industry is characterized by its fragility and vulnerability to the closure of ports and disruption of shipping routes due to a variety of factors that could bring cruise ship operations to a halt. For example, in Northeast Asia, the terminal high altitude area defense missile (THAAD) event halted cruise ship calls from China to South Korea in March 2017, disrupting all China to South Korea routes, including between the ports of Shanghai and Jeju, where cruise ship traffic was busiest at the time, and has not yet recovered at this time. Also worldwide, cruise ship operations have been suspended since March 2020, when the outbreak of coronavirus disease (COVID-19) continued to spread. In addition to these political factors and infectious diseases, cruise ship operations are frequently suspended due to various factors such as natural disasters, conflicts, and over-tourism. Frequent shutdowns of cruise ships lead to lost employment opportunities as well as lost economic benefits at the ports. Therefore, understanding the changes in the spatial and temporal structure of the cruise network during a contingency is essential to implementing proactive measures to ensure that cruise operations do not come to a halt during a contingency.

1.2.2. Problems

The problem in the supply-driven cruise industry is that there is not enough information available to decide on whether to invest in port development. Data on the cruise industry worldwide and in major ocean regions is published by CLIA. Table 1-3 lists the 2019 reports published by CLIA before the COVID-19 infection. The information contained in these reports can be divided into three categories: cruise ship movements, passenger numbers and characteristics, and economic impact. Cruise ship movements are the number of cruise ships deployed worldwide and in major ocean areas and the number of port calls by port. Passenger information is the cruise population and the age, number of cruise days, and destinations of passengers by residence. The economic impact is the number of direct and indirect benefits and jobs created by the cruise industry.

Table 1-3 Cruise industry data published by CLIA

Region	Data	Source (e.g. quotation)
Global	Passenger capacity, Number of ships, Deployment, Economic impact	2019 State of the Industry (CLIA, 2019b)
	Passenger Volume (from source markets, by destination/ trade route), Average duration, Average age	2019 Global Market Report (CLIA, 2019a)
	Direct cruise sector expenditures, Passenger and crew spending, Economic contribution, Output, Income, Employment	The Economic Contribution of the International Cruise Industry Globally in 2019 (CLIA, 2020a)
North, and South America	Passenger volume (from source markets, by destination/ trade route), Average duration, Average age	2019 North American Market Report (CLIA, 2020c), 2019 South American Market Report (CLIA, 2020d)
	Direct cruise sector expenditures, Passenger and crew spending, Economic contribution, Output, Income, Employment	The Economic Contribution of the International Cruise Industry in the United States in 2019 (CLIA, 2020e), in Canada in 2019 (CLIA, 2021)
Europe	Passenger volume (from source markets, by destination/ trade route), Average duration, Average age	2019 Europe Market Report (CLIA, 2020f)
Asia	Passenger volume (from source markets, by destination/ trade route), Average duration, Average age	2019 Asia Market Report (CLIA Asia, 2020)
	Number of ships, Cruise ship segments, Length of cruises, Capacity, Total cruises & voyages, Port calls by country, and port	2019 Asia Cruise Deployment and Capacity – Cruise Industry Report (CLIA Asia, 2019)

Source: CLIA (2019ab, 2020acdef), CLIA Asia (2019, 2020)

Thus, there is too little information about the cruise industry for ports that are planning their facilities. In particular, there is no information available for ports to know the areas and timing of potential growth, where cruise lines can deploy cruise ships, develop routes, and enhance the function of hub ports as bases. In other words, the problem may be that ports are required to make decisions on port development under conditions of uncertain future cruise demand. In the cruise industry, which is characterized as supply-driven, reducing the uncertainty of future demand may prevent unnecessary port investments. Reducing uncertainty about future demand requires an understanding of the network structure of specific sea areas.

There are many previous studies on cruise lines' port selection factors and their approach to itinerary design. Marti (1990), Manning (2006), Wang *et al.* (2014), Castillo-Manzano *et al.* (2014), Gui and Russo (2011), and Lekakou *et al.* (2009) suggest that port specifications, transportation access, and tourism resources are necessary conditions for ports to be selected by cruise lines. Rodrigue and Notteboom (2013), Marti (1990), Pallis (2015), and Rodrigue *et al.* (2013) identify conditions for cruise line itinerary design in terms of maximizing revenues, minimizing costs, and improving passenger satisfaction. Why do some ports not receive cruise ships even though they meet the requirements indicated in these previous studies? Other possible causes include spatial and temporal changes in cruise lines' strategies, seasonal factors that cause ships to shift to distant areas, political factors, outbreaks of infectious diseases, and other contingencies that close ports or disrupt shipping routes. The port selection behavior of cruise lines, influenced by these macroeconomic conditions and their interactions through competitive relationships, cannot be determined simply by analyzing the itineraries of each (single) cruise ship.

Analyzing the movements of all cruise ships operating in a given area as a network would provide a better understanding of the spatial and temporal structural changes in the cruise network. Specifically, some network science methods can measure temporal and spatial changes in the number of ports and routes in a sea area, the number of routes per port, the percentage of port groups in a triangular relationship, hub ports playing a central role, and port groups (communities) with dense route connections. This allows each port to infer the best timing and location for port development. For the cruise industry, which is characterized as supply-driven, the movements of all cruise ships operating in a particular area are tracked by AIS data and viewed as a network. Then, using network science methods and other techniques, the results of the analysis of spatial and temporal changes in the structure of the cruise network may help to reduce some of the uncertainty of future demand. This is significant because it may reduce the number of ports that do not receive cruise ships after they are put into service.

1.3. Literature review

The cruise industry, which has the characteristic of being supply-driven, requires a decision on the need for port development under conditions of uncertainty about future cruise demand at the time of port planning. Therefore, it is important to analyze the spatial and temporal changes in the structure of the cruise network, as this will improve the accuracy of decisions on the need for port improvements. Analyzing the movement of all cruise ships operating in a given area as a network would provide a more realistic understanding of the port selection behavior of cruise lines based on the actual number of ports and routes, the existence of hub ports, the connections between ports, and the response under contingency conditions, as well as the market environment and competitive relationships. This could reduce the uncertainty of future cruise demand and reduce the number of ports that do not receive cruise ships after they are put into service.

1.3.1. Port selection conditions

Ports selected by cruise lines are required to have many features, specifications, attractions, etc. For example, the port's key natural and cultural assets are the port, port facilities, location access to other destinations and the homeport, security, infrastructure (vehicles, well-trained multilingual guides, and coordinators, etc.), provisioning (local supply of food, drink, and clean water), port costs (dockage fees, etc.), and marketing (the variety of itineraries available for passenger selecting), etc. are necessary (Manning, 2006). In addition, the attractiveness of tourist destinations (Wang *et al*., 2014), ports located in densely populated areas, with large airports nearby, ports that use their quays with ferries rather than using them for container ships, and a minimum water depth are necessary (Castillo-Manzano *et al*., 2014). When cruise lines add new ports of call to their itineraries, it is important to ensure the quality of security in addition to port charges to improve the tourism experience offered and the impact on profitability in the short and medium term. Other factors such as customs and immigration handling, anchorage facilities, proximity to airports, cab and coach services, and quality port of call sightseeing and shopping areas are also necessary (Gui and Russo, 2011). In addition, Lekakou *et al*. (2009) noted that cruise lines place a high priority on security and safety, yet require the convenience and reliability of air routes.

Table 1-4 Previous studies on the conditions required for cruise ports

Port selection factors	Source
• Site and situation, physical or cultural qualities	Marti, 1990
• Natural and cultural assets, port facilities • Location access to destinations and homeport • Security, infrastructure, provisioning, port costs	Manning, 2006
• Tourism attractions	Wang et al., 2014
• Located in populous areas, closer to large airports • Ports not specialized in container traffic • Sharing facilities with ferries traffic • Minimum depth of water	Castillo-Manzano et al., 2014
• Port entry characteristics • Customs and immigration handling • Docking and anchorage facilities • Service and port area infrastructure • Airports, taxi fleets, coach services • High quality shore excursions and shopping area	Gui and Russo, 2011
• Significance of air connections • Reliability of air transports • Availability of international airport	Lekakou et al., 2009

Source: Marti (1990), Manning (2006), Wang *et al.* (2014), Castillo-Manzano *et al.* (2014), Gui and Russo (2011), Lekakou *et al.* (2009)

1.3.2. Factors to consider in the itinerary design

Cruise lines also consider a variety of matters when designing their itineraries. For example, cruise ship operators constantly focus on developing new ports to develop products that can differentiate them from their competitors, and they determine the number of ports they can call depending on the location of the port of embarkation and the port of call, the ship's speed, and the number of voyage days (Marti, 1990). They also design itineraries by considering four factors: sailing speed, port of embarkation, voyage duration, and tourist destinations (Rodrigue *et al.,* 2013). Cruise lines also want to build itineraries in a way that includes different ports. Cruise lines also want to build itineraries that include different ports, because the different attractions of each port offer different opportunities for different experiences. And in the process of seeking new ports of call, cruise lines consider the geopolitical factors and political stability of the port of call and the level of security in the port and after tourism, to provide a safe and comfortable itinerary (Pallis, 2015) Cruise lines need to develop more competitive cruise products and, at the same time, to minimize operating costs constantly considering how to optimize the deployment of their cruise fleet in terms of minimizing and maximizing revenues. Other factors that influence cruise ship operators' deployment strategies and itinerary design include the seasonality of cruise demand, optimal cruise vacation periods, the balance between sailing and anchoring times, the presence of well-known ports of call, and customer satisfaction. At the same time, cruise lines consider port anchoring capacity, accessibility at sea, port-to-port distances between ports of call, and connectivity with air service (Rodrigue and Notteboom, 2013).

Table 1-5 Previous studies on the conditions required for cruise itineraries

Itinerary design factors	Source
• Minimizing operating costs and/or maximizing revenue • Seasonality in demand, the optimal duration • Balance between sailing time and shore time • Existence of 'must see' destinations • Overall guest satisfaction • Berthing capacity and nautical accessibility • Distance between ports of call • Synchronization with air transfers	Rodrigue and Notteboom, 2013
• Vessel operating speed, embarkation port, voyage duration, spatial pattern of destination ports • Location of embarkation ports, relative to destination ports • Vessel speed and the number of days	Marti, 1990
• Seeking new destinations consider the geopolitical factors and institutional stability • Security level of ports and tourist hinterlands to provide "secure-comfortable" itineraries	Pallis, 2015
• Mix of must-see ports, marquee ports and discovery ports • Must-see locations/marquee ports are world-famous ports • Discovery ports are not world-famous	Rodrigue et al., 2013

Source: Rodrigue and Notteboom (2013), Marti (1990), Pallis (2015), Rodrigue *et al.* (2013)

1.3.3. Cruise sector analysis using AIS data

Few studies have used Automatic Identification System (AIS) data for analysis in cruise shipping. Tichavska and Tovar (2015) used AIS data to measure the pollution status of exhaust gas from cruise ships calling at the Las Palmas Port in the Canary Islands. Vicente-Cera *et al.* (2019, 2020a) arranged the cruise ship's operating hours, repair times, and berthing times, estimated seawater pollution status by cruise ships, and assessed environmental pressures related to global cruise traffic along their paths based on AIS data. Vicente-Cera *et al.* (2020b) used AIS data to aggregate cruise ship calling patterns at European ports and evaluated the diversity of cruise ship calls at each port. Ito *et al*. (2020) organized the port call patterns before and after the suspension of cruise ship operations by COVID-19 and analyzed the relationship between cruise ship operations and the spread of infection at the port of call using AIS data.

1.3.4. Network science techniques for the cruise sector

Few studies have analyzed cruise ship networks using network science techniques. Tsiotas *et al.* (2018) showed the double role of the cruise network, which is composed of the profit-driven strategies of cruise companies and port authorities, using data from the 2013 itineraries of Costa Cruises and MSC Cruises in the Mediterranean cruise market. Jeon *et al.* (2019) investigated the centrality of cruise ports in the Asian cruise shipping market while proposing the hubs and authorities centrality (HACC) metric as a directional synthesis of the hubs centrality and authorities centrality to explore cyclical and directional characteristics of centrality in the cruise shipping network. In a recent cruise network study, Kanrak and Nguyen (2021) revealed that the cruise shipping network is scale-free using itinerary data from Asian and Australian cruise network websites. Lopez Rodriguez *et al.* (2021) suggested that Caribbean ports are the most important concerning hub and authority centrality, using 2018 itineraries for each cruise line from the sites for 902 ports in the Caribbean and Northern Europe.

1.3.5. Originality

Thus, Marti (1990), Manning (2006), Wang *et al*. (2014), Castillo-Manzano *et al*. (2014), Gui and Russo (2011), and Lekakou *et al*. (2009) have examined cruise line port selection behavior in terms of port specifications and necessary conditions for ports, such as transportation access and tourism resources, but not as a network. Rodrigue and Notteboom (2013), Marti (1990), Pallis (2015), and Rodrigue *et al*. (2013) also analyze cruise line port selection behavior from an itinerary perspective, including revenue maximization, cost minimization, and passenger satisfaction, but not as a network.

Tichavska and Tovar (2015) and Vicente-Cera *et al*. (2019, 2020a) analyze cruise ship movements using AIS data for purposes such as measuring the environmental impact of ships, but not for changes in network structure. Furthermore, Tsiotas *et al*. (2018), Jeon *et al*. (2019), Kanrak and Nguyen (2021), and Lopez Rodriguez *et al*. (2021) analyze each port as a network to understand its position and role in the region but do not analyze changes in the network structure.

Therefore, the actual movements of cruise ships are tracked by AIS data, and the aggregated data is captured as a network to analyze the spatial and temporal changes in the structure of the cruise network based on the number of ports and routes in a particular sea area, the existence of hub ports, connections between ports, and responses under contingency situations.

Analyzing the movements of all cruise ships operating in a given area as a network will enable a more realistic understanding of the situation in the area, including the number of ports and routes, the existence of hub ports, connections (communities) among ports, and emergency responses, compared to analyzing the movements of a single cruise ship on an itinerary-by-itinerary basis. This enables us to grasp the situation of the sea area based on the actual situation. This allows us to understand the growing areas and timing in which cruise lines will increase their deployment of cruise ships, develop routes, strengthen the functions of hub ports, etc., and continue to invest in the future. This will reduce the uncertainty of future cruise demand and eliminate ports that will not accept cruise ships once they are in service. This is the significance and originality of analyzing in a network.

1.4. Objectives

In the supply-driven cruise industry, many ports invest huge amounts of money in the construction of port facilities such as passenger terminals in anticipation of future demand. Each port learns from previous studies on port selection factors and itinerary design conditions by cruise lines so as not to waste these investments. However, some ports are not used after construction. Why are some ports not used after service, even though the cruise ship meets the factors that call at the port and the design conditions of the itinerary? A possible problem with this question is that the cruise industry on the supply side does not have sufficient information to decide whether to invest in port improvements.

Other possible causes include spatial and temporal changes in cruise lines' strategies, seasonal factors that cause ships to shift to distant areas, political factors, outbreaks of infectious diseases, and other contingencies that close ports or disrupt shipping routes. The movement of cruise ships influenced by these macroeconomic conditions and their interactions through competitive relationships cannot be understood simply by analyzing the itineraries of each (single) cruise ship. Analyzing the movements of all cruise ships operating in a given area as a network would provide a better understanding of the network structure in a given area.

The following are examples of what can be learned by aggregating the movements of all cruise ships operating in a given area as a network, rather than the itineraries of a single cruise ship.

- The number of nodes represents the number of ports where cruise ships have called, and provides an understanding of the progress being made in port development and port of call development in the sea area. The higher the number of nodes, the greater the number of ports where cruise ships call and the greater the diversity of ports of call.

- The number of edges represents the number of routes that cruise ships have sailed between ports, indicating the progress made by cruise lines in developing routes in the sea area. The higher the number of edges, the more routes cruise ships are navigating, meaning that the routes are more developed.

- The average degree indicates the number of routes in service per port and indicates the multidirectional nature of the shipping routes in the sea area. The higher the average degree, the more routes are connected per port, meaning that the routes are more multidirectional.

- Density represents the ratio of the number of actual routes to the number of routes that can be served between ports in the region and indicates the progress that cruise lines are making in developing routes with the development of ports in the region. If the number of ports is constant and the density is high, it means that the development of routes by cruise lines is advanced. If the development of routes is more advanced than the development of ports, the density is higher.

- Degree centrality represents the number of routes served by each port, indicating that ports with high degree centrality are hub ports that play a central role with routes connecting to many ports. A port with a high degree centrality means that it is a hub port with a large number of route connections to neighboring ports.

- Degree centralization represents the degree of bias in the number of routes connecting to a port in a sea area, with areas with a high degree centralization being heterogeneous (routes are biased toward hub ports). A high degree of degree centralization means that the development of routes by cruise lines is biased toward hub ports.

- Community is the same group of ports that are closely connected by routes, and the quality of community division can be measured by modularity. The higher the modularity of the sea area, the higher the quality of the division of the community that closely connects the ports.

- The average clustering coefficient represents, for example, the percentage of cruise ships that have routes in service between Port B and Port C that also have routes in service between Port A and Port C. However, the cruise ships that sail between each port are not necessarily the same ship or the same itinerary. A sea area with a high average clustering coefficient has many identical itineraries connected by triangular routes (A→B→C→A), or cruise ships of competing carriers are in service but are connected by routes. A higher average clustering coefficient indicates a more triangular route, i.e., an itinerary consisting of two ports of call for one arrival and departure port, or a network with many routes that are not connected to the same itinerary but appear to be triangular. Areas with high average clustering coefficients may tend to have more short cruise itineraries with only two ports of call and a short number of days compared to areas with low average clustering coefficients.

- Diameter represents the maximum number of routes leading from one port to another without considering connections on the same itinerary, and waters with longer diameters tend to have different cruise lines and ships calling different ports from each other. Direct connections between ports in the itinerary are not taken into account, but the longer the diameter of the sea area, the longer the reach where the ports are connected.

- The average shortest path length represents the minimum number of routes that lead from one port to another without considering connections on the same itinerary, and areas with shorter average shortest path lengths tend to have to compete for shipping lines and ships calling only at similar ports. Direct connections between ports in the itinerary are not considered, but the shorter the average shortest path length, the shorter the number of reaches that the ports are connected to.

This study analyzes not a single itinerary, but a network of all ports and ships operating in a given area. All cruise ship movements are analyzed as a network of aggregated AIS data. This may allow us to understand the changes in the network structure over time, geography, seasonality, and under contingency, reflecting the impact of market conditions, competitive relationships, and other factors.

Whether or not cruise ships call at a port after the port has been developed is not only determined by the response of cruise lines to the requirements and itinerary design concepts of the port, but is also affected by the movements of all cruise ships operating in the entire sea area, including those attracted by the port in question, and the development of surrounding ports. The movements of all cruise ships operating in a particular sea area are tracked by AIS data and viewed as a network, and the results of analysis of spatial and temporal changes in the structure of the cruise network can be useful information for understanding the state of the entire sea area. By using several methods of network science, the number of ports and routes in a sea area, the number of routes per port, the percentage of port groups in a triangular relationship, hub ports playing a central role, and port groups (communities) with dense route connections can be measured in time and space, so that suitable port development timing and location can be inferred. This could lead to more efficient port development, etc., by reducing the uncertainty of future demand related to the port in question and possibly reducing the risk of cruise ships not coming to the port after it is in service.

Why would a network analysis reduce the number of ports that do not receive cruise ships? This is because, by capturing the trajectories of all cruise ships navigating in the area as a network and measuring the areas of growth and timing, it is possible to prevent a situation where cruise ships do not arrive after the port is developed. This is not possible with the movement of a single cruise ship or the allocation behavior of a single cruise ship company. Growth areas are places (or communities) where cruise lines are increasing the number of ships and developing routes, and if a port is planned to be developed in such an area, it is more likely that cruise ships will continue to call at the port after it is put into service than in a non-growth area. In addition, the timing of growth is a time when cruise lines are deploying ships and developing routes, and planning port development at a time when the market is growing makes it more likely that cruise ships will arrive after the port is put into service than at a time when the market is stagnant.

The network indicators of these growing locations and timing indicate that the number of nodes, edges, average degree, density, etc. are all high and increasing. In addition, the region has hub ports with routes connecting to ports in many directions and is in the process of acquiring more routes. Conversely, the average clustering coefficient, diameter, average shortest path length, and degree centralization are determined by the characteristics of the geographical situation in which each port is located and the characteristics of the cruise ships it targets. Therefore, the purpose of the dissertation is to understand the spatial and temporal changes in the structure of the cruise network. To this end, the movements of cruise ships are tracked by AIS data, and the aggregated data are viewed as a network to understand the spatial and temporal changes in the structure of the cruise network based on the actual situation of the number of ports and routes in a particular sea area, the existence of hub ports, connections between ports, and responses under emergencies.

To this end, this dissertation proposes the following four sub-objectives.

- Sub-objective 1 (SO_1): To clarify the differences in the structure of the cruise network between normal and contingency situations. The THAAD event, which has been stopping routes between China and South Korea since March 2017, is a case study.

  SO_1 proposes a method to analyze the differences in cruise line operational and commercial connections between ports under normal and contingency conditions using AIS data. This is because the cruise industry is characterized as fragile and vulnerable. A case in point is the THAAD event that has stopped cruise ship calls from China to South Korea since March 2017 (Crew center, 2017). Before the THAAD event, port-to-port connections between Shanghai, Jeju, and Hakata were the most frequent in Northeast Asia. However, after March 2017, cruise ship calls from China to South Korea suddenly stopped, and the popular shipping route between Shanghai and Jeju disappeared. The structure of the cruise network is analyzed using AIS data to determine how it differs between ports during normal and contingency periods.

- Sub-objective 2 (SO_2): To observe changes in the cruise networks during the early stages of the COVID-19 outbreak, such as port closures. The relationship between the cruise industry and the COVID-19 outbreak is analyzed.

  SO_2 proposes a network-wide impact of port closures in one area. The movement of cruise ships has the potential to be a major trigger of coronavirus disease (COVID-19) outbreaks. The U.S. Centers for Disease Control and Prevention (CDC) banned cruise ship operations in waters surrounding the United States on March 14, 2020 (CDC, 2020a). Since the area around the Caribbean Sea from Florida is the center of the global cruise market, this rule has resulted in the cessation of cruise ship operations around the world. The ports of Shanghai at the end of January 2020 and Japan and Taiwan at the beginning of February 2020 had already refused to allow cruise ships to call at their ports (Cruise Industry News, 2020a, 2020b, 2020c, 2020d). The reason was to prevent the spread of the COVID-19 infection by cruise passengers around the ports. In other words, these countries wondered if there might be some relationship between the landing of cruise passengers and the spread of infection in port cities. How the closure of the port affects the entire cruise network is analyzed by observing cruise ship operations from January to March 2020.

- Sub-objective 3 (SO_3): To identify changes in spatial and temporal changes in the structure of the cruise network by ship size. A case study is the Northeast Asian cruise market 2014-2019, which has experienced rapid growth in recent years.

  SO_3 proposes a method to understand the spatial and temporal changes in the structure of the cruise network. How connections between ports in the cruise network vary geographically and temporally with ship size are analyzed. As a case study, the focus is on Northeast Asia, where the cruise market has been expanding rapidly in recent years. By using some network science techniques, it may be possible to analyze changes in spatial and temporal changes in the structure of the cruise network in Northeast Asia by ship size.

- Sub-objective 4 (SO_4): To understand how seasonality changes the structure of the cruise network by ship size around the world, both spatially and temporally. A case study is the global cruise network in 2019.

SO4 proposes a method for analyzing seasonal geographic deployment area differences in the spatial and temporal structure of the cruise network. AIS data for all cruise ships operating worldwide in 2019 is divided into four seasons and analyzed for geography, seasonality, etc. of the cruise network structure using several network science methods. Through this analysis, annual patterns of spatial and temporal structural change in the cruise network are elucidated by ship type.

These results may lead to more efficient port development, etc., as they may reduce the uncertainty of future demand related to the port in question and reduce the risk of cruise ships not coming to the port after it is in service.

1.5. Dissertation outline

The rest of this dissertation is organized as follows.

Chapter 2 presents an analysis of changes in the cruise network in Northeast Asia during the route disruption due to the THAAD event using AIS data from 2016 to 2018.

Chapter 3 analyzes the changes in the global cruise network during the early stages of the COVID-19 outbreak, such as port closures using AIS data from January to March 2020.

Chapter 4 describes an analysis of the spatial and temporal changes in the structure of the cruise network in Northeast Asia, using AIS data from 2014 to 2019.

Chapter 5 analyzes the changes in the global cruise network due to seasonality, using AIS data from all cruise ships worldwide in 2019.

Finally, Chapter 6 concludes the dissertation. The overall picture of the dissertation is as follows.

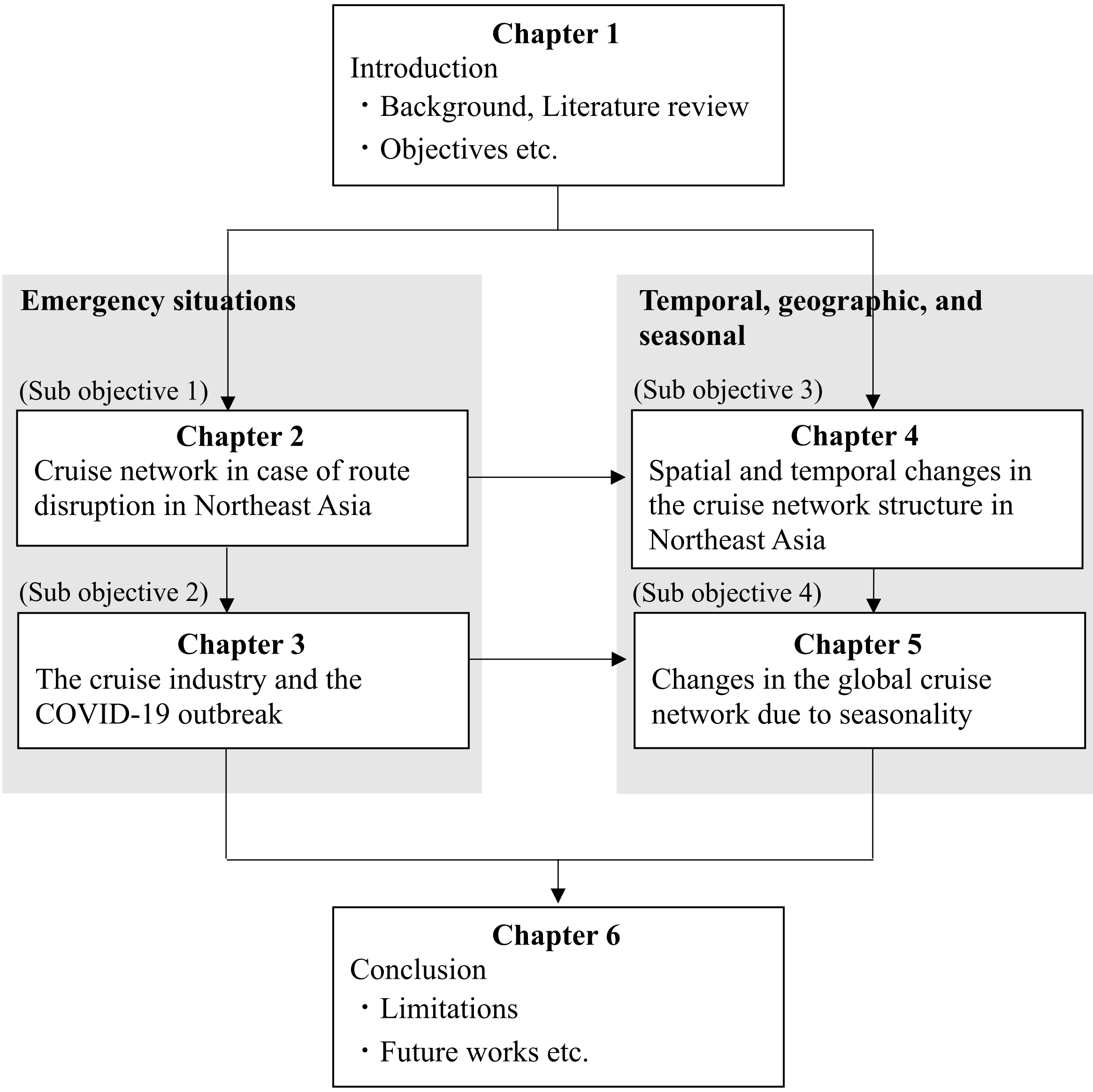

Figure 1-6 Dissertation framework

2. CRUISE NETWORK IN CASE OF ROUTE DISRUPTION IN NORTHEAST ASIA

2.1. Introduction

Around 3,300 Chinese passengers refused to leave the COSTA SERENA at Jeju port in South Korea on March 11, 2017, in a spontaneous protest against South Korea's plans to install the THAAD missile system in the country in response to North Korea's missile development programs (Crew center, 2017). A few days after the event, cruise ships from China stopped calling South Korea, and even after more than five years, cruise ships have not yet gone to South Korea.

The route between China and South Korea played an important role in the Northeast Asian cruise industry. Figure 2-1 shows the total number of voyages by partner countries in China and South Korea from 2014 to 2016. There were 1,336 voyages between the Chinese port and the Korean port. For China, the number of shipping routes connected to South Korea accounted for 37% of all routes. For South Korea, the number of shipping routes connected to China accounted for 47% of all routes. The disruption of the shipping route, which occupied such a large share, should have had a great impact on the port selection behavior of the cruise line.

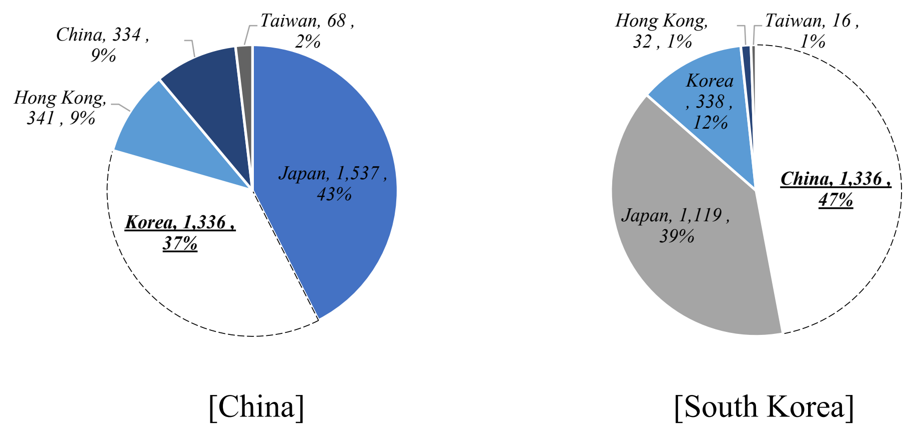

Figure 2-1 Total number of voyages by country from 2014 to 2016

Source: IHS Maritime AIS data (2020)

Understanding the port selection behavior of cruise lines in emergencies, which is different from normal times, is important in building a risk-resistant cruise market where cruise operations do not stop even if the port is closed or the route is interrupted. By analyzing an itinerary constructed by connecting multiple ports rather than a single port, it may be possible to understand the port selection behavior of cruise lines in a more realistic emergency.

There are many previous studies on cruise lines' port selection factors and their approach to itinerary design. Marti (1990), Manning (2006), Wang *et al*. (2014), Castillo-Manzano *et al*. (2014), Gui and Russo (2011), and Lekakou *et al*. (2009) found that port specifications, transportation access, and tourism resources are necessary conditions for ports to be selected by cruise lines. Rodrigue and Notteboom (2013), Marti (1990), Pallis (2015), and Rodrigue *et al*. (2013) identify conditions for cruise line itinerary design in terms of maximizing revenues, minimizing costs, and improving passenger satisfaction. However, all of the previous studies are aimed at port selection behavior and itinerary design during normal times, not in an emergency.

The purpose of this chapter is to see how major port interruptions affect cruise lines' port selection behavior. An example of a major port disruption would be the March 2017 THAAD event. AIS data is used to track the movements of cruise ships before and after the THAAD event. Cruise ships featured in this chapter are several ships scheduled to call South Korea in the "2017 Jeju Port Booking List" published before the THAAD event. Further, time-series itinerary data for arrival and departure ports and ports of call is generated.

Our research question is "When cruise lines cannot visit desired ports due to some trouble, what are their priorities, and how do they recover? How does cruise line's port selection behavior under these risks change over time?" In particular, this chapter asks three questions. (1) Immediately after the THAAD event, what is the priority of cruise lines to keep their cruise business? (2) How long does it take to recover to an original operating level? (3) How does the cruise market in Northeast Asia change because of the THAAD event? In this chapter, the analysis is based on the BCP concept proposed by the Cabinet Office, Government of Japan (2013). Because the BCP is a concept for integrated business continuity and disaster recovery planning for efficient and effective resuming and recovery of critical operations after being disrupted.

The rest of this chapter is organized as follows. Section 2.2 presents a literature review.

Section 2.3 outlines methodologies such as AIS data. Section 2.4 presents the results and discussion of the chapter. Finally, section 2.5 provides conclusions.

2.2. Literature review

2.2.1. Creation of cruise products

Rodrigue and Notteboom (2013b) argue that the cruise industry sells itineraries, not destinations. The cruise industry is challenged to develop competitive cruise packages but at the same time, they have to optimize the deployment of their cruise ship fleet given minimizing operating costs and/or maximizing revenue per passenger slot. Esteve-Perez and Garcia-Sanchez (2018) mention that cruise lines focus on seeking new ports to meet demand in an attempt to create differentiated products based on the ports that compose the itinerary. Further, Vogel and Oschmann (2012) explain that cruise demand has always been "supply-led", starting with the invention of leisure cruising by passenger shipping lines whose scheduled transatlantic services were losing passengers to the airlines. Similarly, Rodrigue and Notteboom (2013b) analyze that the cruise industry works in a "supply push mechanism" as cruise lines aim to generate demand for cruises by providing new products (itineraries) with a larger and more diversified range of ships.

Bagis and Dooms (2014) point out that the cruise industry continually needs to introduce new itineraries and ships with new amenities and destinations as well as redeploy older and smaller vessels in their itineraries. Then, Pallis (2015) explains that cruise lines wish to create itineraries that include ports of different sizes, as each type of port provides different types of experiences by blending different types of attractiveness and permitting future passengers to select from among various options to access the departing port. In a set of ports of call, there is a mix of "must-see" ports/marquee ports and discovery ports; each type differs according to the tourism attractiveness of the port. "Must-see" locations/marquee ports are world-famous ports that are necessary for every itinerary. Discovery ports are not world-famous but offer the sense of discovering an unknown treasure (Rodrigue *et al*, 2013a). In addition, Marti (1990) looks at four components – vessel operating speed, embarkation port, voyage duration, and the spatial pattern of destination ports – set the bounds on cruise-ship itineraries.

2.2.2. Port of call selection

The selection of the cruise port place is a very important and complex problem.

Manning (2006) suggests that the main influencing factors include the key natural and cultural assets of the port, port facilities, location access to other destinations and the homeport, security, infrastructure (vehicles, well-trained multilingual guides, and coordinators, etc.), provisioning (local supply of food, drink, and clean water), port costs (dockage fees, etc.), and marketing (the variety of itineraries available for passenger selecting). The location of embarkation ports, relative to destination ports, along with vessel speed and the number of days allocated to complete each round-trip voyage also governs how many ports can be visited. The norm in most popular cruising areas on a seven-day voyage is three to four different ports of call (Marti, 1990). Bagis and Dooms (2014) point out that cruise ports compete within the limits of certain geographic regions. These limits are mainly shaped according to the location of the regional homeports.

When choosing and adding a new port of call to the itinerary, cruise lines consider the improvement to the tourist experience offered and the effect on profitability over both the short and medium term. In addition to port charges, cruise lines are strongly concerned about the quality and security issues of their passengers. Their requirements often include a wide range of dedicated infrastructures and services such as port entry features, customs, and immigration handling, docking and anchorage facilities, service and port area infrastructure, airports, taxi fleets, coach services, and high-quality shore excursions and shopping area (Gui and Russo, 2011). Lekakou et al. (2009) insist that security and safety are major issues in the contemporary transport industry. The significance of air connections and reliability of air transport are expected results, as they are related to the leading “availability of international airport” criterion. Wang et al. (2014) showed that “tourism attractions” was the most considerable issue taken into consideration when a cruise ship is selecting a port of call location. Castillo-Manzano et al. (2014) study the determinants that affect the capacity of ports to attract cruise ships in Spain. The conclusion was that the likelihood of having cruise traffic was linked to ports located in populous areas and close to large airports, ports not specialized in container traffic but share facilities with ferries traffic, and ports having a minimum depth of water.

2.3. Methodology

Since the end of March 2017, cruise ships from China to Korea have not called yet. Therefore, this chapter analyzes the movement of the cruise ship before and after the THAAD event. The year before the THAAD event from April 2016 to March 2017 (FY2016) occurred, is defined as "Before." After THAAD is defined as April 2017 to March 2019 (FY 2017 to FY2018).

2.3.1. What is the BCP concept?

Figure 2-2 shows the BCP concept proposed by the Cabinet Office, the Japanese government. This Business Continuity Plan (BCP) is a plan describing the policy, systems, procedures, etc. by which enterprises can avoid suspension of their critical business or can recover the critical business quickly if it is interrupted, even when contingencies arise, including natural disasters such as major earthquakes, communicable disease pandemics, terrorist acts, serious accidents, disruption of supply chains and abrupt changes in a business environment, or they can recover business quickly if their business is interrupted. For example, if a large-scale disaster occurs, demand for certain products and services will increase compared with normal times, or demand for one company's products and services will temporarily increase if other companies in the same business are hit by the disaster. Therefore, the operating rate may exceed 100% in response to such an increase in demand. Sahebjamnia et al. (2015) propose the BCP concept as a novel framework for integrated business continuity and disaster recovery planning for efficient and effective resuming and recovering of critical operations after being disrupted.

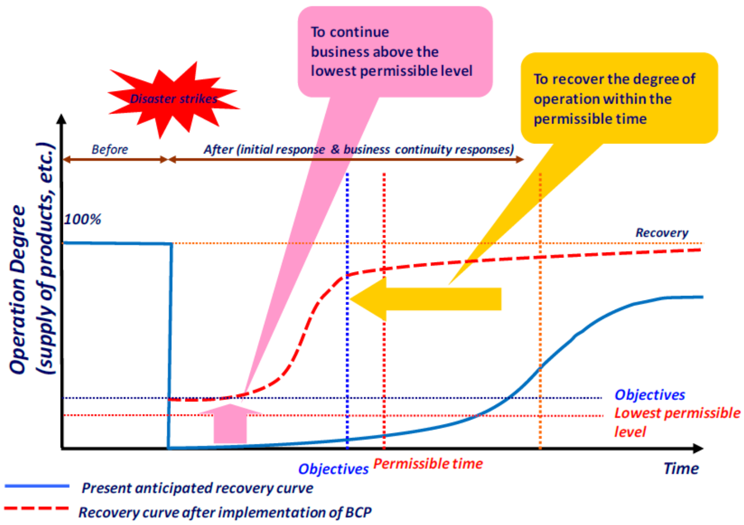

Figure 2-2 Business continuity plan

Source: The Cabinet Office, the Japanese government (2013)

Figure 2-3 depicts an image of a recovery curve of the THAAD event regarding the BCP concept. The horizontal axis indicates time, and the vertical axis indicates operating level. The time indicates before and after the THAAD event, and the operating level indicates the degree of business continuity for the cruise line in Northeast Asia.

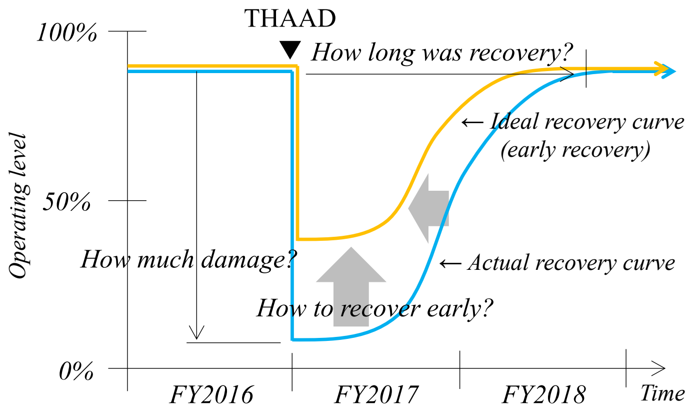

Figure 2-3 Concept of cruise business continuity plan

2.3.2. What indicator should be used to evaluate the operating level?

What indicator should be used to evaluate the operating level for the Northeast Asian cruise lines? In simple terms, the operating level in the "cruise market" will be calculated by the number of arrivals and departures of cruise ships and the number of passengers demanded by cruise ships. However, the operating level defined by the "cruise line" will be different from the operating level in the "cruise market". This is because the operating level for the "cruise line" is not just the number of passengers or the number of port calls, but profitability and passenger satisfaction.

Lekakou et al. (2009) point out that passenger satisfaction is only one of the major reasons for a cruise line to select and change itineraries. Rodrigue et al. (2013a) analyze that cruise lines are challenged to develop competitive cruise packages but at the same time, they have to optimize the deployment of their cruise ship fleet given minimizing operating costs and/or maximizing revenue per passenger slot. According to Bagis et al. (2014), to maximize the commercial potential and utilization of the ship assets, the selection of ports of call and itineraries are pondered carefully. Yet, Gui et al. (2011) suggest when choosing and adding a new port of call to the itinerary, cruise lines consider the improvement to the tourist experience offered and the effect on profitability over both the short and medium term. Based on this literature, the operating level is defined as a situation where a cruise line can achieve both high profitability and high passenger satisfaction.

Based on this definition, how should the operational level of Northeast Asian cruise lines be evaluated? From the viewpoint of minimizing operating costs, the optimization of sailing distances in designing an itinerary is a key question because fuel costs have a major impact on the total shipping costs and fuel consumption has an exponential dependence on sailing speed (Esteve-Perez and Garcia-Sanchez, 2018). On the other hand, in terms of maximizing revenue, the main sources of cruise revenue are ticket sales, passenger transportation to and from the ships, on-board sales, cancellation fees, as well as sales of insurance, and pre-and post-tours (Vogel, 2012). Furthermore, from a customer satisfaction perspective, there are differences in preferences between first-time cruisers, who tend to demand more intensive port itineraries, and more experienced cruisers, who appear to prefer a more relaxed itinerary with more days at sea (Cartwright and Baird, 1999; Lingard, 2002; Haller, 2005).

Based on such preliminary research, the realization of the operating level in Northeast Asia can be measured by, for example, the following indicators. (1) Cost minimization: port distance, ship speed. (2) Maximizing revenue: ticket prices, pre-, and post-tour sales. (3) Passenger satisfaction: number of ports of call per itinerary. In this chapter, the number of ports of the call per itinerary is adopted as an indicator to measure the recovery of the operating level, taking into account the limitations of data. According to the Shanghai International Cruise Business Institute (2017), 90% of Chinese cruise passengers are new customers. In other words, since most passengers are first cruisers, it is defined that an itinerary with more ports of call per trip is more satisfying than an itinerary with fewer ports of call.

In this chapter, the operating level is defined as the percentage of itineraries that call at more than one port. The operating level (*OL*) of the cruise market in Northeast Asia includes the total number of trips (N_m) for services calling at multiple ports (*m*) and the number of trips (N_s) for services calling at only a single port (*s*). It is the number divided by the number of itineraries. The formula is as follows.

$$OL = \frac{N_m}{N_m + N_s} \tag{1}$$

2.3.3. Movement of cruise ship using AIS data

There is no data on the calling routes of cruise ships in Northeast Asia. The annual reports compiled by CLIA (2018; 2019) are based on plans and not actual data. In addition, although the data on the number of calls by cruise ships at each port is publicized, there is no data on the network on where to come from and where to go. Therefore, changes in the cruise market in Northeast Asia are analyzed by organizing data on ship movements using AIS data. This aggregated data was picked up from cruise ships around the world registered as “Passenger (Cruise) Ship” in a database called IHS Maritime Sea-web (2020), and the data were organized using International Maritime Organization (IMO) ship identification number. AIS was introduced to enhance safety at sea, improve navigation efficiency and protect marine environments. IMO International Convention for Safety of Life at Sea (SOLAS) requires AIS to be fitted onboard international voyaging ships above 299GT.

Jeju port in Korea is the busiest port in Northeast Asia before the THAAD event. Table 2-1 is a compilation of the “2017 Jeju Port Booking List” published by Jeju Special Self-Governing Province on February 28, 2017. This booking list is a list of cruise ships that cruise lines have pre-booked and have been allowed to use the berths of Jeju Port. The data consists of the following items. Date/ Ship's name/ Arrival time/ Departure time/ Former port/ Next port/ Berthing time. At this time, 525 cruise ships are to call at Jeju port by the end of 2017. The COSTA SERENA operated by Costa Cruises in Italy is 82 times, the GLORY SEA operated by Diamond Cruise in China is 81 times, the COSTA ATLANTICA operated by Costa Cruises in Italy is 75 times, the SKYSEA GOLDEN ERA operated by the SkySea Cruises in China is 72 times, and the CHINESE TAISHAN operated by Bohai Cruise in China is 55 times. This chapter tracks the movement of these five cruise ships before and after the THAAD event. Incidentally, these five ships account for 70% of Jeju port’s 2017 bookings.

Table 2-1 Top 5 Cruise ships by number of bookings to Jeju port in 2017

No.	Ship Name	Number of Calls	Cumulative percentage
1	COSTA SERENA	82	16%
2	GLORY SEA	81	31%
3	COSTA ATLANTICA	75	45%
4	SKYSEA GOLDEN ERA	72	59%
5	CHINESE TAISHAN	55	70%
Others		160	70%
Total		525	100%

Source: Jeju Port Booking List (2017)

2.4. Results and discussion

2.4.1. The number of arrival and departure, port of calls before and after THAAD

Figure 2-4 shows the location of major cruise ports in Northeast Asia.

Figure 2-4 Major cruise ports in Northeast Asia

Figure 2-5 shows the number of arrival and departure by the port in Northeast Asia. In FY2016, Shanghai port top with more than 500 times, followed by Tianjin port, Hong Kong (SAR), and Keelung with more than 100 times. It can be seen that many cruise ships depart from Shanghai port before the THAAD event. After the THAAD event, while the number of arrival and departure at Shanghai and Tianjin ports in northern China dropped, the number at Keelung port, Tokyo and Yokohama ports, and Xiamen and Shekou ports increase. In other words, after the THAAD event, the arrival and departure ports tend to move south.

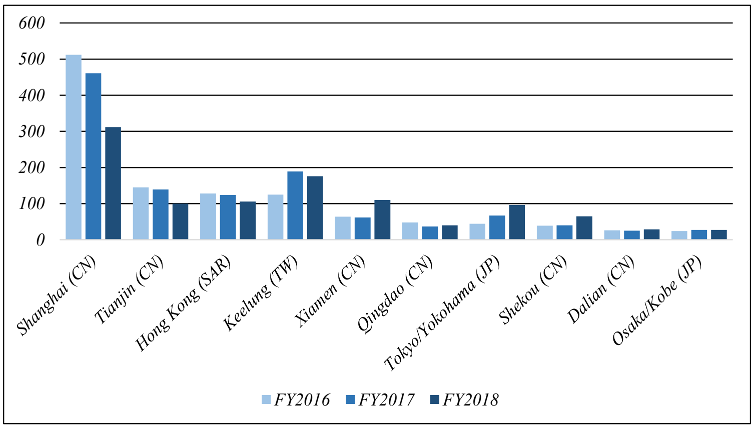

Figure 2-5 Trends in the number of Arrival and Departure at the top 10 ports

Figure 2-6 shows the number of ports of call by port in Northeast Asia in FY2016. Jeju port in Korea tops with more than 500 times, followed by Hakata port in Japan with more than 300 times, and Nagasaki port in Japan with more than 200 times. It can be seen that many cruise ships visit Jeju port before the THAAD event. After the THAAD event, the number of calls at Korea's Jeju and Busan ports drops sharply, while the number of calls at Japan's Okinawan archipelagos Naha, Ishigaki, and Hirara ports increased. In other words, it can be seen that the port of call tends to move southward after the THAAD event.

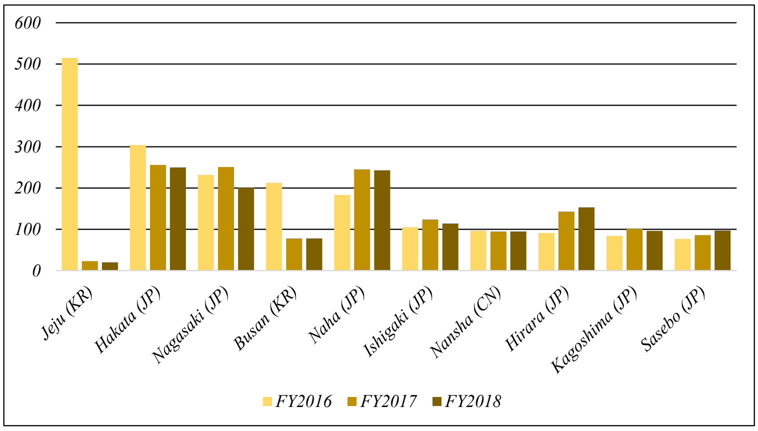

Figure 2-6 Trends in the number of calls at the top 10 ports

2.4.2. Movement of the five cruise ships

The movement of the five cruise ships booked at Jeju port before the THAAD event is analyzed. Here, the location of the itinerary, which is a combination of the country where the port of arrival and departure and the port of call is located, and the trend of changes in the number of times are analyzed.

a) COSTA SERENA

In Figure 2-7, the front side shows the departure and arrival ports and ports of call, and the numbers in the figure show the number of quarterly itineraries for the three years from FY2016 to FY2018, from April 2016 to March 2019. The bottom rows show the number of itineraries and itinerary patterns per quarter. The COSTA SERENA goes to both a port in Japan and a port in Korea from the Shanghai port in FY2016. Some of the itineraries include a port for Korea only and a port for Japan only. However, after the THAAD event, the COSTA SERENA does not change the arrival and departure from/to Shanghai port in FY2017 but changed it to a pattern that calls only at a single port in Japan. In FY2018, it is gradually improving its itinerary to call at two or more ports in Japan. The bottom row shows the number of arrival and departure per quarter. There is no change between FY2016 and FY2017 before and after the THAAD event, indicating that the sailing days do not change. However, the number gradually decreases in FY2018, indicating that the sailing days extend. In addition, the other bottom row shows the number of itinerary patterns per quarter. There is no change between FY2016 and FY2017 before and after the THAAD event, indicating that the itinerary patterns do not change. However, the number gradually increase in FY2018, indicating that they are seeking for new ports to create a new itinerary.

▼*THAAD* *Number of Itineraries*

Arrival & Departure		Ports of Call			BEFORE				AFTER							
					FY2016				FY2017				FY2018			
		1	2	3	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
North China	Tianjin	Japan														1
		Japan	Japan													4
East China	Qingdao	Japan														1
	Shanghai	Korea	Japan		19	14	13	6								
		Korea				3	6	2								
		Korea	Korea		1	2										
		Korea	Korea	Japan	1	1										
		Korea	Japan	Japan		1		2								
		Japan			2		5	4	21	19	20	10	5	8	9	3
		Japan	Japan					2	1	3	2	6	8	10	11	7
		Japan	Japan	Japan								2	1	1		
Total number of itineraries					23	21	24	16	22	22	22	18	14	19	20	16

Figure 2-7 Ship movement (COSTA SERENA)

b) GLORY SEA

The GLORY SEA goes to two ports in Japan and Korea from Shanghai and Qingdao ports in China in FY2016. However, from FY2017 to FY2018, the GLORY SEA's arrival and departure ports change to Qingdao and Dalian, and after that, she operates ocean-only itineraries with no ports of call and shift to Lianyungang. According to Seatrade Cruise News (2019) on March 16, 2019, "the Glory Sea, owned by Diamond Cruise International Co., Limited, was placed under arrest by Shanghai Maritime Court due to unpaid crew wages". Following this news, her service has remained suspended. The lower row of the chart showing the number of arrival and departure for this ship each quarter cannot be analyzed due to variations in the numbers.

▼THAAD *Number of Itineraries*

Arrival & Departure		Ports of Call			BEFORE				AFTER							
					FY2016				FY2017				FY2018			
		1	2	3	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
North China	Dalian	Japan							5	6	1					
		Japan	Japan						2		2					
		(At sea)								1						
	Tianjin	Japan									1					
East China	Qingdao	Korea						1								
		Korea	Japan				3	4								
		Korea	Korea	Japan				1								
		Japan				1		3	5	4	5		4	1		
		Japan	Japan						1							
		(At sea)												1		
	Lianyungang	Japan											8	9		
		(At sea)												4		
	Shanghai	Korea	Japan			3	11	7								
		Japan				5			2	3					1	
		Japan	China							1			1			
		China													1	
	Ningbo	Japan								2						
		Japan	Japan								1					
		(At sea)									1					
	Wenzhou	Japan												2	1	
South China	Haikou	(At sea)										12	3			
		(Outside Northeast Asia)									3	17	2			
Total number of itineraries					0	9	14	16	15	17	14	29	18	17	3	0

Figure 2-8 Ship movement (GLORY SEA)

c) COSTA ATLANTICA

The COSTA ATLANTICA goes to two ports in Japan and Korea from Tianjin port in FY2016. However, in FY2017, the arrival and departure port shifted from Tianjin port to Shanghai port and then back to Tianjin port for a short time, but soon shift to Shekou and Xiamen ports in southern China in FY2018. The bottom line of the chart shows the number of arrivals and departures per quarter. Although the number of arrival and departure increased in the first quarter immediately after the THAAD event, there was no significant change from FY2016 to FY2018, indicating that the sailing days does not change.

▼THAAD — Number of Itineraries

Arrival & Departure		Ports of Call 1	2	3	4	BEFORE FY2016 Q1	Q2	Q3	Q4	AFTER FY2017 Q1	Q2	Q3	Q4	FY2018 Q1	Q2	Q3	Q4
North China	Tianjin	Korea					3	2									
		Korea	Japan			12	13	7	5								
		Korea	Japan	Japan	Japan			1									
		Korea	Korea				1										
		Korea	Korea	Japan				1									
		Korea	Korea	Korea			1										
		Japan							4			9					
		Japan	Japan									8					
East China	Shanghai	Korea				1											
		Korea	Japan			5			1								
		Japan							5	19	11	1					
		Japan	Japan							3	1						
		Japan	Japan	Japan	China						1						
		(At sea)									1						
South China	Xiamen	Japan														6	
		Japan	Japan													1	
		(At sea)														4	
		(Outside Northeast Asia)														3	
	Shekou	Japan												1	2		1
		Japan	Japan								2		5	5	4	2	6
		HongKong									1			1			1
		(At sea)											6	6	3		11
		(Outside Northeast Asia)											1	6	10	5	
Taiwan	Keelung	Japan	Korea	Japan													1
Total number of itineraries						18	18	11	15	22	17	18	12	19	19	21	20

Figure 2-9 Ship movement (COSTA ATLANTICA)

d) SKYSEA GOLDEN ERA

The SKYSEA GOLDEN ERA goes to two ports in Japan and Korea from the Shanghai port in FY2016. However, in FY2017, along the way, she shifts to Xiamen and Shekou ports, but she keeps the arrivals and departures from Shanghai port and shifts her port of call to one of Japan's ports. The bottom line shows the number of arrival and departure per quarter. No significant change from FY2016 to FY2018, indicating that the sailing days do not change. According to Cruise Industry News (2018), "Royal Caribbean Cruises and Ctrip announced that they were ending the SkySea Cruise Line joint venture, which had carried well over 200,000 Chinese passengers since launching its service in 2015. TUI AG's Marella Cruises agreed to purchase the SKYSEA GOLDEN ERA, with delivery expected in December 2018. After the sale of her, it is expected that SkySea will wind down its business operations before the end of 2018."

▼THAAD *Number of Itineraries*

Arrival & Departure		Ports of Call			BEFORE				AFTER							
					FY2016				FY2017				FY2018			
		1	2	3	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
East China	Qingdao	Japan							2	2						
		Japan	Japan							1						
	Shanghai	Korea				1	1									
		Korea	Japan		11	8	10	11								
		Korea	Korea	Japan	5	1	3	1								
		Korea	Japan	Japan	3	4	5	2								
		Japan			1	1		3	6	7		14	8	13		
		Japan	Japan			1	2	3	3	5		5	3			
		Japan	Japan	Japan		1										
		(At sea)								1		1	1	2		
	Ningbo	Japan									2					
South China	Xiamen	Japan							4	1			4			
		Japan	Japan						1	1			2			
		(Outside Northeast Asia)								1			2			
	Shekou	Japan									5					
		(At sea)									3					
Korea	Busan	Japan	Japan						1							
Total number of itineraries					20	17	21	20	17	19	10	20	20	15	0	0

Figure 2-10 Ship movement (SKYSEA GOLDEN ERA)

e) CHINESE TAISHAN

The CHINESE TAISHAN sails from many ports to wander in FY2016, and her ports of call at that time are two ports in Japan and Korea. However, in the first half of 2017, she fixes Xiamen port as an arrival and departure port, but one year later, she shifts to Dalian, Qingdao, Tianjin, Yantai, and Weihai ports in FY2018. During this time, her port of call is only one port in Japan. The bottom line of the chart shows the number of arrivals and departures per quarter. Although the number of arrival and departure increased in the first quarter immediately after the THAAD event, there is no significant change from FY2016 to FY2018, indicating that the sailing days does not change.

▼THAAD *Number of Itineraries*

Arrival & Departure		Ports of Call			BEFORE				AFTER							
					FY2016				FY2017				FY2018			
		1	2	3	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
North China	Dalian	Korea			1											
		Korea	Japan		5	1	4									
		Korea	Japan	Japan	2											
		Japan					1						11	5		
		Japan	Japan				1						1			
		(At sea)												3		
	Tianjin	Japan													1	1
		Japan	Japan												12	10
East China	Yantai	Korea	Korea		2											
		Korea	Japan		1											
		Japan											1		1	
	Weihai	Japan												3		
	Qingdao	Korea				2										
		Korea	Japan		2	11	2									
		Korea	Korea	Japan	2											
		Russia	Korea	Japan		1										
		Japan											1	5		4
		Japan	Japan													1
		(At sea)				1	1							2		
	Ningbo	Korea	Japan				6									
		Korea	Japan	Japan			1									
		Japan					4									
South China	Xiamen	Japan							15	7						
		Japan	Japan						5	8						
		(At sea)						1	2							
		China							1							
	Haikou	(At sea)						19								
Total number of itineraries					15	16	20	20	23	15	0	0	14	18	14	16

Figure 2-11 Ship movement (CHINESE TAISHAN)

Thus, it is found that the port selection behavior is significantly different for each cruise ship. The COSTA SERENA and the SKYSEA GOLDEN ERA have a fixed itinerary both before and after the THAAD event at Shanghai port. On the other hand, the GLORY SEA and the CHINESE TAISHAN have unfixed itineraries both before and after the THAAD event. The COSTA ATLANTICA is easy to understand as cruise line’s port selection behavior. Before the THAAD event, she is visiting Japan and Korea from Tianjin port. However, as soon as the itinerary for Korea cannot be organized, the port shifts from Tianjin port to Shanghai port. After arriving and departing from Shanghai port for more than half a year, she moves further south to the Shekou and Xiamen ports. In some cases, the number of sailing days is temporarily shortened immediately after the interruption, and in some cases, it is extended more than one year after the interruption. However, in general, there is no change before and after the THAAD event.

2.4.3. Analysis of the recovery curve

Figure 2-12 shows the sum of the movements of these five cruise ships. In FY2016, the year before the THAAD event, most of the itineraries visit two ports, Japan and Korea. In the first quarter of FY2016, 72% of all itineraries for the five ships call at two ports in Japan and Korea. 63% in the second quarter and 62% in the third quarter call at two ports, Japan and Korea. However, in the first quarter of FY2017, 81% of all itineraries were called at only one port in Japan. Since then, 70% in the second quarter and 69% in the third quarter called at only one port in Japan. While the fourth quarter of Northeast Asia is in winter, the numbers fluctuate as the cruise ship temporarily moves south, but in the first quarter of 2018, still, 52% are in the second quarter. Even in the period, 55% called at one port in Japan.

The change occurs in the third quarter of FY2018. In the third quarter of 2018, a year and a half has passed since the THAAD event stopped cruise ship calls from China to Korea. Calls to two Japanese ports exceed the number of calls to one Japanese port. 46% of all itineraries call at two ports in Japan. And in the fourth quarter, 56% called at two ports in Japan. In the previous chapter, the operating level for a cruise line was defined as one that offers both high profitability and high passenger satisfaction. In the Northeast Asian cruise market, where most first cruisers are located, it is more attractive to have more ports of call than a cruise package that has fewer ports of call per itinerary.

▼THAAD *Percentage of calls*

Arrival & Departure	***Port of call patterns***	***Ports of Call***				***BEFORE***				***AFTER***							
						FY2016				***FY2017***				***FY2018***			
		1	***2***	***3***	***4***	***Q1***	***Q2***	***Q3***	***Q4***	***Q1***	***Q2***	***Q3***	***Q4***	***Q1***	***Q2***	***Q3***	***Q4***
China	*Korea*	*Korea*				*3%*	*11%*	*10%*	*3%*								
		Korea	*Korea*			*4%*	*4%*										
		Korea	*Korea*	*Korea*			*1%*										
	Japan & Korea	*Korea*	*Korea*	*Japan*		*11%*	*3%*	*4%*	*2%*								
		Korea	*Japan*	*Japan*	*Japan*			*1%*									
		Korea	*Japan*	*Japan*		*7%*	*6%*	*7%*	*5%*								
		Korea	*Japan*			*72%*	*63%*	*62%*	*39%*								
	Japan	*Japan*				*4%*	*9%*	*11%*	*22%*	*81%*	*70%*	*69%*	*30%*	*52%*	*55%*	*33%*	*22%*
		Japan	*Japan*				*1%*	*3%*	*6%*	*16%*	*24%*	*20%*	*20%*	*23%*	*16%*	*46%*	*56%*
		Japan	*Japan*	*Japan*			*1%*				*1%*		*3%*	*1%*	*1%*		
	Others	*(At sea)*					*1%*	*1%*	*23%*	*2%*	*3%*	*6%*	*24%*	*12%*	*17%*	*7%*	*22%*
		(Outside Northeast Asia)									*1%*	*5%*	*23%*	*12%*	*11%*	*14%*	
Total						*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*

Figure 2-12 Five ship movements

Figure 2-13 shows changes in the best three itineraries for each of the five cruise ships. Before the THAAD event, all cruise ships call at Jeju port in FY2016 and have another itinerary at a Japanese port. The COSTA SERENA departs from Shanghai port for the itinerary in FY2016, calling at Jeju port first, and then calling at a single port in Japan (Hakata port, Nagasaki port, Kagoshima port). However, in FY2017 after THAAD, it does not call at Jeju Port, but only at one port in Japan, and in FY2018 it changes to an itinerary calling at two ports, Hakata Port and Nagasaki Port. The GLORY SEA also calls at another port in Japan (Sasebo port, Shimonoseki port) based on Jeju port in FY2016, but since FY2017 after THAAD, it is re-arranged to call at only one port in Japan. The COSTA ATLANTICA also calls at another port in Japan (Hakata port, Nagasaki port) based on Jeju Port in FY2016, but since FY2017 after THAAD, it is changed to an itinerary that calls only at one port in Japan. In FY2018, the port of call is switched to the Okinawa archipelago in the southern part of Japan (Naha port, Hirara port). The SKYSEA GOLDEN ERA is also located at Jeju port before THAAD and calls at another Japanese port (Hakata port, Sasebo port). However, after THAAD, it skips Jeju port and returns to one of the Japanese ports (Hakata port and Sasebo port, Naha port). Before the THAAD event, the CHINESE TAISHAN is also an itinerary calling at Jeju port and one of the Japanese ports (Sasebo port, Hakata port).

In other words, before the THAAD event, Jeju port is a marquee port for cruise ships from China that can call Japan and Korea. However, no itinerary can be completed only at Jeju port. It can be said that the pattern of calling at Jeju port plus another Japanese port is a typical itinerary in Northeast Asia. However, after the THAAD event, it is found that they cannot call at Jeju port, so they choose a single port in Japan and gradually shift to an itinerary to call at two ports in Japan. And it turns out that the marquee ports in Japan are Hakata port, Nagasaki port, Sasebo port, and so on.

Ship Name	Top	FY2016			FY2017			FY2018		
		Arrival and Departure	Ports of Call	Itinerary %	Arrival and Departure	Ports of Call	Itinerary %	Arrival and Departure	Ports of Call	Itinerary %
COSTA SERENA	1	Shanghai	Jeju / Hakata	28%	Shanghai	Hakata	29%	Shanghai	Nagasaki / Hakata	9%
	2	Shanghai	Jeju / Nagasaki	13%	Shanghai	Nagasaki	19%	Shanghai	Nagasaki	7%
	3	Shanghai	Jeju / Kagoshima	10%	Shanghai	Kagoshima	15%	Shanghai	Hakata	5%
GLORY SEA	1	Shanghai	Jeju / Sasebo	31%	Haikou	(Out of Northeast Asia)	25%	Lianyungang	Sasebo	21%
	2	Shanghai	Jeju / Shimonoseki	15%	Qingdao	Sasebo	17%	Lianyungang	Nagasaki	13%
	3	Qingdao	Jeju / Sasebo	15%	Haikou	(At sea)	16%	Lianyungang	(At sea)	11%
COSTA ATLANTICA	1	Tianjin	Jeju / Hakata	42%	Shanghai	Hakata	17%	Shekou	(Out of Northeast Asia)	27%
	2	Tianjin	Jeju / Nagasaki	13%	Shanghai	Nagasaki	13%	Shekou	(At sea)	24%
	3	Shanghai	Jeju / Hakata	10%	Shanghai	Kagoshima	10%	Shekou	Naha / Hirara	20%
SKYSEA GOLDEN ERA	1	Shanghai	Jeju / Hakata	24%	Shanghai	Sasebo	24%	Shanghai	Sasebo	23%
	2	Shanghai	Jeju / Sasebo	13%	Shanghai	Hakata	8%	Shanghai	Hakata	23%
	3	Shanghai	Jeju / Kagoshima / Nagasaki	10%	Xiamen	Naha	8%	Xiamen	Naha	9%
CHINESE TAISHAN	1	Haikou	(At sea)	27%	Xiamen	Hirara	55%	Qingdao	Hakata	15%
	2	Qingdao	Jeju / Sasebo	10%	Xiamen	Naha / Hirara	18%	Tianjin	Sasebo / Hakata	15%
	3	Qingdao	Jeju / Hakata	8%	Xiamen	Nakagusuku / Hirara	16%	Dalian	Hakata	13%

Figure 2-13 Top 3 trends in itinerary patterns by ship

Figure 2-14 shows the average number of sailing days for each itinerary for five ships. Although there is a slight change in Q3 of FY2017, there is no significant change before and after the THAAD event. The average number of sailing days over three years is 5.3 days (4.3 nights). According to Sun (2014), the average cruise duration in the Chinese market is 4.5 nights. The analysis in the previous section shows that the number of ports of call is reduced from a few ports to a single port immediately after the THAAD event. Reducing the number of ports of call without changing the sailing days puts the highest priority on keeping the schedule.

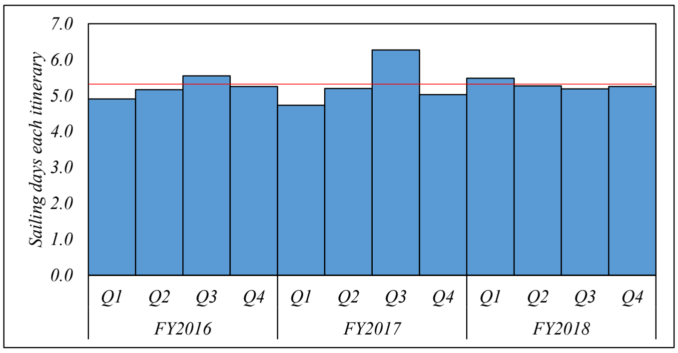

Figure 2-14 Trends in the average number of sailing days each itinerary

Figure 2-15 shows the operating level, as measured by the percentage of itineraries calling at multiple ports including the “At sea” itinerary where the cruise ship itself is the destination. Before the THAAD event, this percentage is about 80% in FY2016. However, it decreases to less than 20% immediately after the THAAD event. After that, it increases gradually, more than half in the third quarter of FY2018, and it exceeds 70% in the fourth quarter. In other words, it takes one and a half years to recover from the situation before the THAAD event.

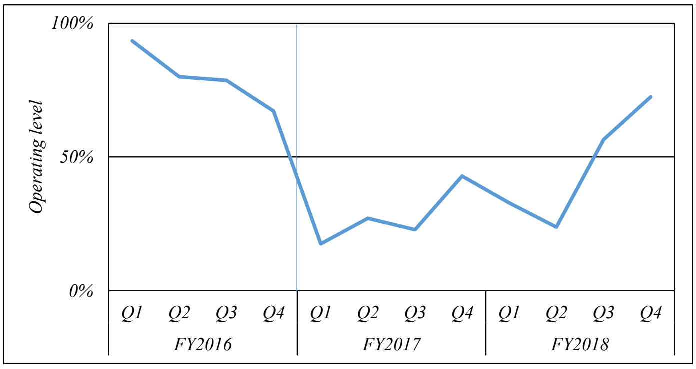

Figure 2-15 Trends in the percentage of itineraries calling at multiple ports

Our research question is “When cruise lines cannot visit desired ports due to some trouble, what are their priorities, and how do they recover? How does cruise line’s port selection behavior under these risks change over time?” In particular, three questions are focused on in this chapter. (1) Immediately after the THAAD event, what is the priority of the cruise line to keep their cruise business? (2) How long does it take to recover to the original operating level? (3) How does the cruise market in Northeast Asia change because of the THAAD event?

Consequently, (1) immediately after the trouble, cruise lines prioritized reducing the number of ports of call and keeping schedules. In other words, this prioritizes keeping sailing days. During this period, it maintained its itinerary to call one of the marquee ports (Hakata port, Nagasaki port, or Sasebo port) from Shanghai port. (2) Subsequently, gradually adding new ports to their itinerary, based on the marquee ports, was piloted. It took nearly a year and a half to finally create the next best itinerary. (3) Due to the THAAD event, the centers of the cruise market in Northeast Asia shifted from Shanghai port in eastern China to Shekou port and Xiamen port in southern China, Keelung port in Taiwan, and Tokyo/Yokohama ports in Japan. With this shift, the centers of call shifted to the Okinawa archipelago (Naha port, Hirara port, Ishigaki port) in southern Japan and out of Northeast Asia (Southeast Asia, etc.).

According to Henry (2012), from a cruise ship company's perspective, planning takes place some 2-3 years before an actual voyage. In this chapter, the next good itinerary takes about one and a half years. Keeping the schedule is one of the most important things in the cruise business (Bagis and Dooms, 2014). This chapter also concludes that many cruise lines reduce port calls and kept sailing days shortly after the THAAD event. In addition, an operating level for a cruise line is a combination of a marquee port that is popular with passengers and a discovery port that expects discoveries (Rodrigue et al., 2013a). This time, just after the THAAD event, there was only a single port, but a two-port itinerary was being made gradually. When cruise lines consider port selection, they do not think about the port of call but about the itinerary (Rodrigue and Notteboom, 2013b). In this chapter, itinerary units shifted from Shanghai port in eastern China to areas such as southern China (Shekou, Xiamen), Taiwan (Keelung), and Japan (Tokyo, Yokohama).

There are three limitations of this chapter. One limitation is that this chapter targets the top five ships booked at Jeju Port, but it is necessary to analyze more ships in the future. Second, this chapter uses three years from FY2016 to FY2018 to draw the recovery curve, but the line stops during recovery. In the future, it is necessary to extend the analysis a little longer. Third, the chapter chose the number of ports of call as an indicator of the operating level for drawing a recovery curve. However, an operating level cannot be defined solely by the number of ports of call. For example, various indicators such as port distance and ship speed for cost minimization, ticket prices and pre- and post-tour fees for maximizing revenue, and attractiveness of tourist destinations for customer satisfaction can be adopted. In the future, it is necessary to draw a recovery curve using these various indicators.

2.5. Chapter conclusion

In this chapter, the movement of the cruise ship before and after the THAAD event was analyzed using AIS data for the period from FY2016 to FY2018. The target cruise ships were the top five ships with the highest number of berth bookings at Jeju port during the year 2017.

Consequently, immediately after the THAAD event, to keep the sailing days, that is, to adhere to the schedule strictly, the number of ports of call was reduced to a single port, which is a marquee port, and the number of port calls was reduced and the ship continued to operate. Then, while gradually testing discovery ports, itinerary patterns were increased, and after one and a half years, the next best itinerary was created. Due to the THAAD event, the centers of the cruise market in Northeast Asia shifted from Shanghai port in eastern China to Shekou and Xiamen ports in southern China, Keelung port in Taiwan, and Tokyo/Yokohama ports in Japan. With this shift, the centers of call shifted to the Okinawa archipelago in southern Japan and out of Northeast Asia (Southeast Asia, etc.).

Chinese cruise passengers have driven the growth of the Northeast Asian cruise market. Its main itinerary from China involves two countries, Japan and Korea. Jeju port in Korea, located very close to Shanghai port, has extremely high geographic potential. The itinerary that cannot visit Jeju port gradually moved south and shifted to Japan. According to Cruise Industry News, “Royal Caribbean Cruises and Ctrip announced that SkySea will wind down its business operations before the end of 2018.” In addition, according to Seatrade Cruise News (2018), “In April 2019, the NORWEGIAN JOY will reposition from China to Seattle to offer seven-day voyages to Alaska.” Consequently, the market in Northeast Asia has shrunk.

While our writing this report, a new difficulty emerged: the new Coronavirus. According to the World Health Organization (WHO, 2020a), “The Chinese authorities identified a new type of coronavirus (novel coronavirus, nCoV (After this statement, it is named COVID-19.)), which was isolated on 7 January 2020. According to information conveyed to the WHO by Chinese authorities on 11 and 12 January, 41 cases of novel coronavirus infection have been preliminarily diagnosed in Wuhan City. Symptom onset of the 41 confirmed nCoV cases ranges from 8 December 2019 to 2 January 2020." Namely, COVID-19 occurred in 2019, just two years after the THAAD event in 2017. Yet again, the following year, the cruise ship from China stopped.

This chapter focused on the THAAD event. The disruption of popular ports of call, such as Jeju port, caused cruise lines to struggle to create itineraries, causing the cruise market to move south and shrink. The recovery curve for the operating level confirmed that THAAD affected 70% of the itinerary of the five ships and that the original itinerary took one and a half years. In the future, the Business Continuity Planning (BCP) measures should be considered to shift this recovery curve upward (minimally damaging) and to the left (early recovery).

3. THE CRUISE INDUSTRY AND THE COVID-19 OUTBREAK

3.1. Introduction

Cruise ship movements can be a major trigger of the COVID-19 outbreaks. In Australia, the cruise ship, the Ruby Princess became the largest COVID-19 epicenter. When the Ruby Princess arrived at the Port of Sydney in New South Wales on March 19, 2020, approximately 2,700 passengers disembarked. On arrival, 130 passengers and crew members with flu-like symptoms were tested for the new virus. However, the officials of New South Wales allowed the other passengers to disembark before the test results were available. The next day, four people tested positive. The infection continued, however, among the passengers who had disembarked, and the number rose to 162 by March 27 (Reuters, 2020).

Signs that cruise ships may become a source of infection had already appeared in early February. The largest cluster of COVID-19 cases outside mainland China occurred on board the Diamond Princess, which was quarantined in the port of Yokohama, Japan on February 3 (WHO, 2020b). On March 6, cases of COVID-19 were identified on the Grand Princess off the coast of California; the ship was subsequently quarantined. By March 17, confirmed cases of COVID-19 had been associated with at least 25 additional cruise ships (CDC, 2020b). The two cruise ships mentioned above were reportedly successful in isolating the infected individuals on board, to prevent transmission to local communities.

The cruise industry has been suspended due to infectious diseases such as norovirus, SARS, and MERS (McCarter, 2009; Vivancos *et al.*, 2010; Seatrade Cruise News, 2015; Fisher *et al.*, 2018). Frequent outages due to infectious diseases may cause problems such as reduced economic effects and loss of employment not only on cruise lines but also around ports. Analyzing the link between the cruise industry and COVID-19 is important for the resumption of safe cruise operations in the future. The purpose of this chapter is to analyze the relationship between the cruise industry and the COVID-19 outbreak.

An analysis is attempted from two perspectives. The first analysis focuses on the relationship between the estimated number of cruise passengers landing and the number of COVID-19 cases. The second analysis focuses on the characteristics of cruise ships infected with COVID-19. For the first analysis, the global movement of ocean cruise ships is tracked using AIS data, in service from January to March 2020, and estimate the number of cruise passengers landing in each country. Then, the number of cruise passengers landing and the number of COVID-19 cases are compared, and the relationship between the movement of cruise ships and the COVID-19 outbreak is analyzed. In the second analysis, characteristics of ship size, onboard services, and itineraries are compared from a list of cruise ships infected with CDC's COVID-19. With this, the characteristics of cruise ships infected with COVID-19 are analyzed.

COVID-19 is said to be transmitted by human-to-human contact. The transportation industry is not limited to cruise ships but includes airplanes, railroads, buses, and other ships too. Thus, cruise ships are not the only source of COVID-19 transmission. Using AIS data to track cruise ships, the number of cruise passengers landing in each country is estimated. The estimates differ from the actual figures based on the capacity of the ships (occupancy rate 100%).

The rest of this chapter is organized as follows. Section 3.2 outlines methodologies such as AIS data. Section 3.3 presents the results and discussion of the chapter. Finally, Section 3.4 provides conclusions.

3.2. Methodology

Using AIS data, the global movement of ocean cruise ships in service from January to March is tracked. All ocean cruise ships registered as “Passenger/Cruise” on the ship registration database IHS Maritime Sea-web (2020) are identified. A total of 392 ocean cruise ships were in operation. The movement data are based on the date and time when the cruise ship enters the port. After obtaining movement data of the cruise ships at each port, the data is divided into ten cruise areas (Appendix 1). Next, using ship data from the IHS Maritime (2020), ship sizes and itinerary characteristics are compared from the CDC's list of cruise ships infected with COVID-19. With this, the characteristics of cruise ships infected with COVID-19 are analyzed.

The first analysis focuses on the relationship between the estimated number of cruise passengers landing and the number of COVID-19 cases. AIS data is used to track the global movement of ocean cruise ships in service from January to March and estimate the number of cruise passengers landing in each country. All ocean cruise ships registered as “Passenger/Cruise” on the ship registration database are identified, IHS Maritime Sea-web (2020). A total of 392 ocean cruise ships were in operation from January to March 2020. Data is obtained using the International Maritime Organization (IMO) ship identification number allotted by the IMO. Using three months of AIS data, the time and location of the ocean cruise ship deployments are extracted. The purpose of the AIS is to enhance safety at sea, improve navigation efficiency, and protect marine environments. The International Convention for Safety of Life at Sea (SOLAS) requires AIS to be fitted on board all international voyaging ships above 299 gross tonnages (GT).

After obtaining movement data of the cruise ships at each port, the data is divided into ten main regions (Figure 3-1): North America, Caribbean, South America, Pacific Ocean, Oceania, Asia, Middle East, and South Asia, Mediterranean, Northern Europe, and Africa. In this way, the number of deployments for all cruise ships in each region is counted. The movement data are based on the date and time when the cruise ship enters the port. The subsequent movement data, which is unintended for passenger transportation, are removed from this analysis: movements within the port; same-day movements; movements to refuel from the refueling ships; transportation of only crew members; transport to change used berths; transfer to shipyards; and voyage in domestic waters.

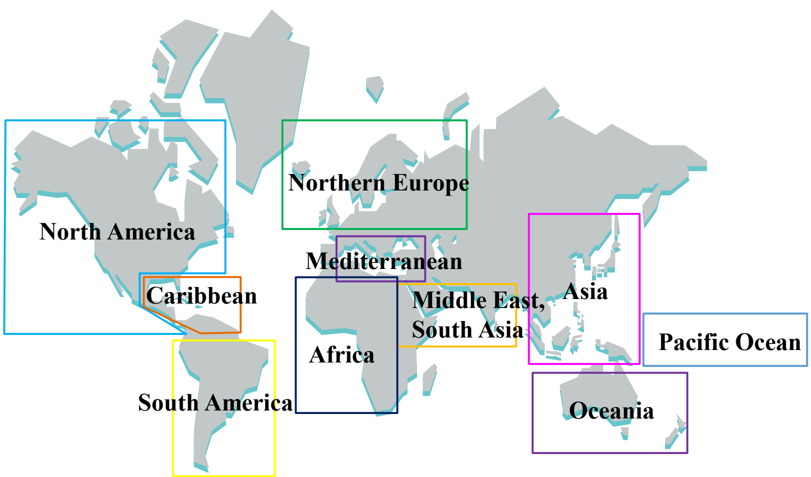

Figure 3-1 Cruise area classification

The second analysis focuses on the characteristics of cruise ships infected with COVID-

19. Using ship data from the IHS Maritime (2020), ship sizes, onboard services, and itinerary characteristics are compared to the CDC's list of cruise ships infected with COVID-19. With this, the characteristics of cruise ships infected with COVID-19 are analyzed.

3.3. Results and discussion

3.3.1. Cruise passenger landing and the COVID-19 outbreak

Figure 3-2 shows the total number of calls per week for each cruising area. The Caribbean has the largest number, followed by Oceania, South America, and North America. In terms of the number of port calls, the Caribbean Sea is 400 to 450 times a week from January to February, 300 times in the second week of March, and approximately 50 times from the third week in March.

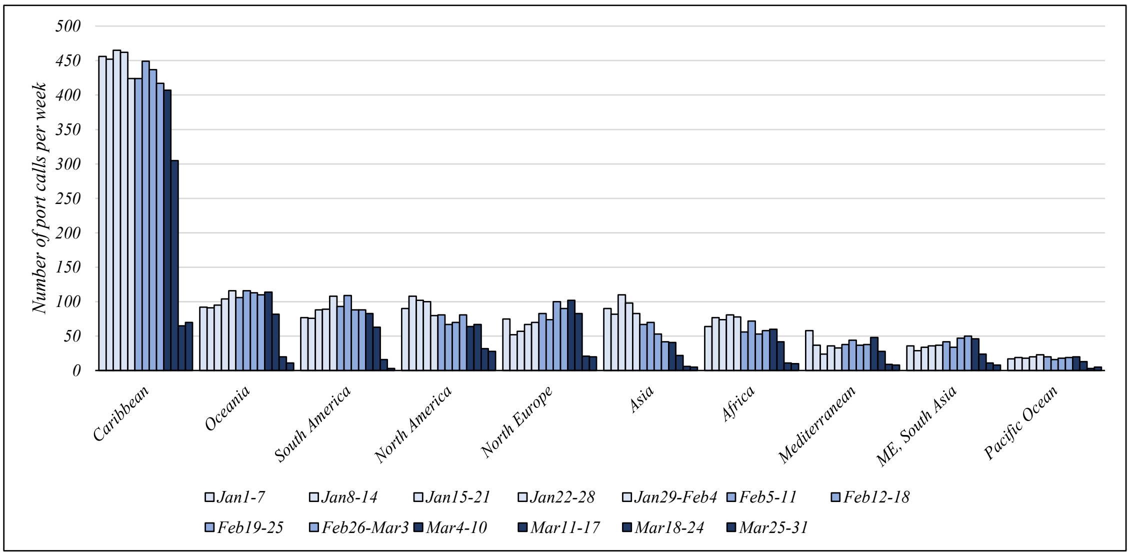

Figure 3-2 Number of port calls per week by cruise area

To observe the relationship between the number of cruise passengers landing and COVID-19 transmission, the former is calculated using Equation (1).

$$L^i = \sum_{p \in P^i} \sum_{r \in R} x_{p,r} \, N_r \, C_r \qquad (1)$$

L^i represents the number of passengers landing in the country i. P^i is a port in the country i. R is all services for cruise products. N_r is the number of port calls for service r (number of calls). C_r is the capacity of service r (the number of cruise ship passengers put into service r). $x_{p,r}$ is 1 if service r calls at port p, and 0 otherwise. The number of cruise passengers landing by country from January to March 2020 and the number of COVID-19 cases by country from December 2019 to April 15, 2020, are calculated as shown in Table 3-1. This chapter uses the capacity of cruise ships instead of actual passengers of cruise ships due to data unavailability.

From January to March, the US had the largest number of cruise passengers (4.71 million), followed by Mexico (2.06 million), Bahamas (1.90 million), Australia (990,197), and the Canary Islands (906,978), New Zealand has 828,170, and Brazil has 800,283. Note that the number of cruise passengers landing is counted as three when one passenger calls at three ports. Note also that this is not the net number of cruise passengers. Table 3-1 shows the top 50 countries with the largest number of cruise passengers landing from January to March. AIS data confirms cruise passengers landing in 129 countries.

Table 3-1 Estimated number of cruise passengers landing and COVID-19 cases

	Countries and territories	Passengers landing[a]	COVID cases[b]		Countries and territories	Passengers landing[a]	COVID cases[b]		Countries and territories	Passengers landing[a]	COVID cases[b]		Countries and territories	Passengers landing[a]	COVID Cases[b]
1	United States of America	4,709,671	609,516	36	China	192,293	83,352	71	Mauritius	37,022	324	106	Senegal	2485	299
2	Mexico	2,066,815	5399	37	Madeira	181,981	N/A	72	Greece	36,794	2170	107	Ireland	2426	11,479
3	Bahamas	1,898,830	49	38	Colombia	181,875	2979	73	Cambodia	35,527	122	108	Ukraine	2310	3372
4	Australia	990,197	6416	39	Norway	181,156	6566	74	French Polynesia	34,680	55	109	Kenya	1844	216
5	Canary Islands	906,978	N/A	40	Guadeloupe	175,440	N/A	75	Seychelles	33,220	11	110	Monaco	1826	93
6	New Zealand	828,170	1078	41	South Africa	171,240	2415	76	Nicaragua	33,173	12	111	Faeroe Islands	1794	184
7	Brazil	800,283	25,262	42	Grenada	170,039	14	77	Namibia	31,449	16	112	Iceland	1794	1720
8	United Arab Emirates	738,397	4933	43	Costa Rica	147,621	618	78	Morocco	31,205	1888	113	Brunei Darussalam	1582	136
9	Puerto Rico	552,538	923	44	Sweden	135,060	11,445	79	Azores	29,081	N/A	114	Solomon Islands	1400	N/A
10	Italy	544,543	162,488	45	United Kingdom	134,451	93,873	80	Cape Verde Islands	27,096	11	115	St Helena Island	1200	N/A
11	Cayman Islands	542,079	54	46	Dominica	134,426	16	81	Turks & Caicos Islands	26,507	10	116	Gambia	1197	9
12	Spain	514,549	172,541	47	Finland	129,600	3161	82	Netherlands	25,053	27,419	117	Guam	1010	135
13	St Maarten	505,762	52	48	Vietnam	122,696	274	83	Indonesia	23,070	4839	118	Marshall Islands	1010	N/A
14	Virgin Islands (US)	496,695	N/A	49	Thailand	112,445	2643	84	Egypt	22,189	2350	119	Samoa	1000	N/A
15	Panama	471,607	3574	50	New Caledonia	112,187	18	85	Papua New Guinea	18,394	2	120	El Salvador	702	159
16	Barbados	439,705	73	51	Qatar	109,429	3428	86	Ecuador	17,714	7603	121	St-Martin	565	N/A
17	Argentina	357,881	2432	52	France	102,854	103,573	87	Cyprus	17,313	695	122	Isle of Man	530	242
18	St Lucia	334,828	15	53	Hong Kong	102,458	N/A	88	Israel	16,264	12,046	123	Angola	462	19
19	Malaysia	329,002	4987	54	St Vincent	99,916	12	89	Belgium	15,967	31,119	124	Cote d'Ivoire	462	626
20	Singapore	324,471	3252	55	India	92,717	11,438	90	Gibraltar	15,628	129	125	Ghana	462	636
21	Jamaica	316,344	105	56	Germany	83,264	127,584	91	Bermuda	14,848	57	126	Denmark	432	6511
22	Antigua	294,678	23	57	Philippines	76,473	5223	92	Cuba	13,314	766	127	Montserrat	286	11
23	Aruba	288,998	92	58	Vanuatu	72,502	N/A	93	Korea (South)	12,644	10,591	128	Palau	144	N/A
24	Curacao	287,688	14	59	Portugal	66,018	17,448	94	Russia	11,412	21,102	129	Timor-Leste	120	6
25	Dominican Republic	281,210	3286	60	Bahrain	59,661	1528	95	Jordan	5086	397		Total	26,471,816	1,757,368
26	St Kitts & Nevis	276,311	14	61	Taiwan	57,836	395	96	Falkland Islands	5060	11				
27	Honduras	270,339	419	62	Fiji	57,190	16	97	Croatia	5036	1704				
28	Uruguay	255,931	533	63	Guatemala	52,974	180	98	Mozambique	4615	28				
29	Japan	251,677	8100	64	Trinidad & Tobago	52,056	113	99	Tanzania	4025	N/A				
30	Martinique	250,879	N/A	65	Madagascar	50,682	108	100	Tonga	3716	N/A				
31	Virgin Islands (British)	248,096	N/A	66	Haiti	50,490	40	101	Cook Islands	3246	N/A				
32	Belize	246,921	18	67	Malta	46,237	393	102	Canada	3197	27,046				
33	Chile	212,779	7917	68	Peru	42,583	10,303	103	American Samoa	3000	N/A				
34	Bonaire	207,577	4	69	Reunion	42,328	N/A	104	Turkey	2995	65,111				
35	Oman	199,333	910	70	Sri Lanka	37,861	233	105	Northern Mariana Islands	2680	13				

Source: European Centre for Disease Prevention and Control (2020)

a. The number of cruise passengers landing is from January 1, 2020, to March 31, 2020.

b. The number of COVID-19 cases is from December 2019 to April 15, 2020.

The US, which had a large number of cruise passengers landing, also had the largest number of COVID-19 cases at 609,516. However, Mexico has the second largest number of cruise passengers with 5,399 COVID-19 cases, while the Bahamas, with the third largest, has only 49. In addition, Italy, which has a large number of COVID-19 cases, has the 10th largest number of cruise passengers, while Spain ranks 12th and the UK ranks 45th. In other words, countries with the highest number of cruise passengers did not necessarily have the highest number of COVID-19 cases.

In general, cruise passengers stay in the port city for a few days before boarding or disembarking the ship. On the other hand, the passengers spend only a few hours at the port of call. According to Henry (2012), cruise passengers generally prefer to arrive at a port by 8 am and leave before 6 pm (in the early evening). This allows maximum daylight hours ashore and an opportunity to leave after breakfast and return for an evening meal. In other words, the time spent by cruise passengers at the arrival and departure ports tends to be longer than the time spent at the port of call. Therefore, the infection rate of COVID-19 in countries with arrival and departure ports and the infection rate of COVID-19 in countries with only ports of call were analyzed separately.

Unfortunately, AIS data can track ship movements, but not passenger movements. Therefore, the Expedia cruise product search website (2020) was used. However, it should be noted that this website does not include cruise products directly sold by some cruise lines and travel agencies. Since our search was conducted in April, the results were different from the ports where ships arrived and departed from January to March. In particular, more countries in the Northern Hemisphere, which have the best season for cruises from April, were included in the search results than countries in the Southern Hemisphere. As of April 10, 18,501 items of ocean cruise products were sold. Using this site, all cruise products are sorted by port of departure and arrival and by country, as shown in Appendix 2. The US accounted for 43%, followed by Italy, Spain, Canada, France, and Australia. In this analysis, these 30 countries as those with ports of arrival and departure are defined.

The data in Table 3-1 are divided into two groups: one for countries with arrival and departure ports and those without ports. Then, the following two indicators are used for comparison between the port of arrival and departure and the port of call. The first indicator is the number of COVID-19 cases relative to the number of cruise passengers landing. The results are shown in Table 3-2. For the country of arrival and departure, the figure was 12.85% and for the country, only at the port of call, it was 1.50%. It was found that the number of COVID-19 cases against the number of cruise passengers landing at the country of arrival and departure was 11.36% points higher. The second indicator is the COVID-19 infection rate to express the number of COVID-19 cases per population. The COVID-19 infection rate in the country of arrival and departure was 0.057%, while that in the country of the port of call was 0.006%. It was found that the COVID-19 infection rate in the country of arrival and departure tended to be 0.051% points higher.

Table 3-2 COVID-19 infection rates between countries with arrival and departure ports and countries with only ports of call

	Cruise passengers landing[a]	Population	COVID-19 cases[b]	COVID-19 cases/passengers landing	COVID-19 infection rate
	a	*b*	*c*	$d = c/a$	$e = c/b$
(A) Country of arrival and departure	12,314,032	2,788,910,590	1582,558	12.85%	0.057%
(B) Country only at port of call	11,689,288	3,023,378,663	174,810	1.50%	0.006%
(A) - (B)	624,744	−234,468,073	1,407,748	11.35%pt	0.051%pt

a. The number of cruise passengers landing is from January 1, 2020, to March 31, 2020.

b. The number of COVID-19 cases is from December 2019 to April 15, 2020.

Lekakou et al. (2009) proposed that the convenience of an international airport is a necessary condition for cities with arrival and departure ports. Based on an analysis of cruise home ports, Castillo-Manzano et al. (2014) suggested that the likelihood of having cruise traffic was linked to the location of the port in populous areas and being close to large airports. In other words, cities with ports of arrival and departure are characterized by proximity to an international airport. Therefore, it should be noted that many tourists are not passengers because of the international airport nearby.

There may be some relationship between the timing of the port call and the timing of the COVID-19 outbreak expansion. Figure 3-3 shows the number of port calls by day for the top 30 ports from January to March. A dark color-filled box indicates a day with many port calls, while white means no port calls in a day. Most of the top 30 ports accepted cruise ships until mid-March when CLIA announced that the cruise ships had stopped operating (CLIA, 2020g). In particular, Caribbean ports such as Cozumel

(Mexico), Miami (US), and Nassau (Bahamas) continued to accept cruise ships.

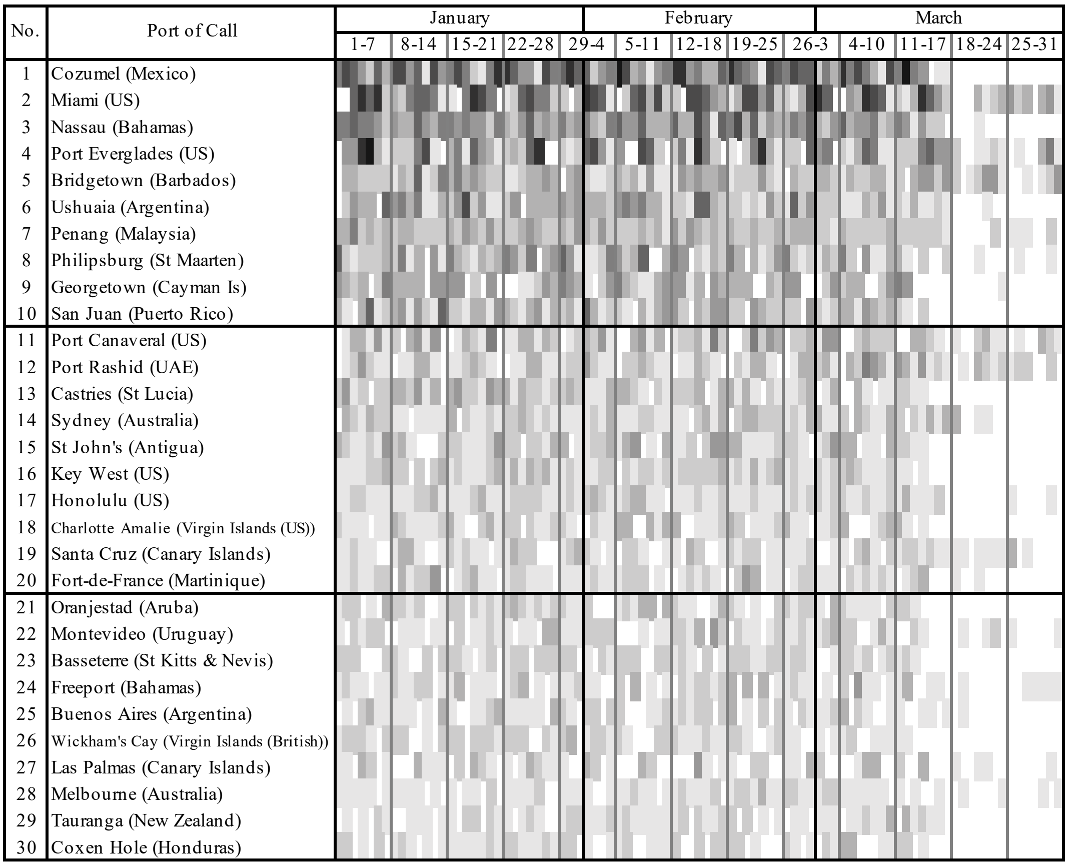

Figure 3-3 Number of port calls for each port from January to March

Source: IHS Maritime (2020)

*Darker color indicates a higher number of port calls.

Given the 14-day incubation period, the number of COVID-19 cases in mid-April is suspected to be related to the acceptance of cruise ships in March. Therefore, COVID-19 infection rates among countries that had reduced the acceptance of cruise ships in March and those that did not are compared. In the 129 countries in Table 1 where cruise ships called from January to March, the number of cruise passengers landing in March was arranged in descending order. These countries are then divided into two groups for analysis. The top half of countries are defined as the group that continued to accept cruise ships in March. On the other hand, the lower half of countries are defined as the group that had reduced the acceptance of cruise ships in March.

As a result, Figure 3-4 shows the COVID-19 infection rate of the former group was 0% in January-February but increased to 0.016% in March. By mid-April, it has increased to 0.028%. Conversely, the COVID-19 infection rate of the latter group was flat at

0.003% in February, 0.002% in March, and 0.006% in mid-April. The results show that the COVID-19 infection rate in countries that had reduced the acceptance of cruise ships in March was lower than that of the countries that continued to accept cruise ships in March.

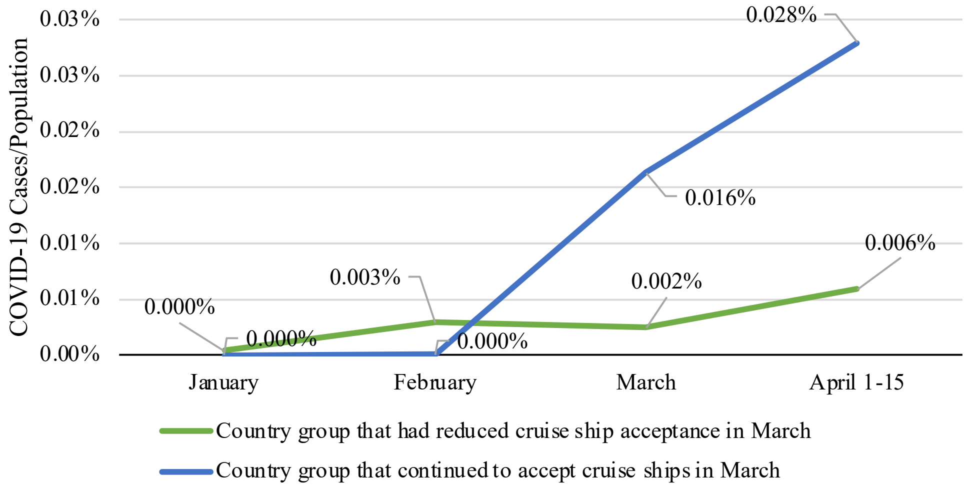

Figure 3-4 COVID-19 infection rate for groups accepting and reducing ships in March

As shown in Figure 3-4, major cruise ports continued to accept cruise ships even until mid-March. This indicates that the decision of stopping a cruise operation cannot be made by each cruise line alone. Similarly, the suspension of port operations also cannot be decided by each port individually. The following viewpoints can offer some reasons.

According to Bagis and Dooms (2014), the purpose of the cruise business is to maximize profits by using ships with huge investments. Suspension of cruise ships will lead to reduced profits and, in the worst case, bankruptcy. According to Henry (2012), general itinerary planning by a cruise line takes place some 2-3 years before an actual voyage. If one port is closed, a cruise line cannot immediately call at another port. Due to these circumstances, even if the risk of infection from a cruise ship is increasing, it is not easy for a cruise line to take a management decision to suspend cruise operations.

Table 3-3 identifies areas where cruise travel was stopped following the stopping of cruises to and from China on January 25 to prevent the spread of COVID-19 infection in Wuhan, China. The events that occurred subsequently are summarized in Table 3-2.

Table 3-3 Major events stopping the movement of cruise ships

Date	Event
January 25	Cruise ports closed in China (Cruise Industry News, 2020a)
February 3	Refusal to accept cruise ships in Saint Lucia and Dominica (The Australian, 2020)
February 6-11	Cruise ports closed in Taiwan. Refusal to accept cruise ships in Japan and Thailand (Cruise Industry News, 2020b, c, d)
February 27	Refusal to accept cruise ships in Jamaica and Grand Cayman (TIME, 2020)
March 8	Cruise Lines International Association (CLIA) announces on March 8 "the adoption of additional enhanced screening measures in response to COVID-19" (CLIA, 2020h)
March 13	CLIA ocean-going cruise lines decide to voluntarily and temporarily suspend cruise ship operations from US ports of call for 30 days as public health officials and the US Government continue to address COVID-19. The temporary suspension takes effect at midnight EDT on March 14, 2020. (CLIA, 2020g)
March 14-15	Cruise ports closed in the US, Canada, Australia, and New Zealand (Cruise Industry News, 2020e)

Source: Cruise Industry News, 2020a; The Australian, 2020; Cruise Industry News, 2020b, 2020c, 2020d, 2020e; TIME, 2020; CLIA, 2020h; CLIA, 2020g

Even for the port, closing the port is also a difficult decision. One of the reasons for this is the fierce competition between neighboring ports. Recently, the bargaining power on the port side becomes weaker than that of the cruise line. Port closures could lead to the elimination of future port calls. According to Pallis *et al*. (2018), investment in ports by cruise lines is accelerating. In recent years, cruise lines have invested in ports and have exclusive cruise terminals for their ships. The trend of privatization leads to a decrease in interest in cruises on the port side. There is concern that the lack of interest in the cruise business on the part of the port led to the delay in the decision to close the port.

3.3.2. Characteristics of cruise ships with an infection on board and the COVID-19 outbreak

According to the "Cruise ships affected in the US by COVID-19" (CDC, 2020b), the cruise ships listed in Appendix 3 made voyages discovered to be infected with COVID-19. The characteristics of these cruise ships infected with COVID-19 from two perspectives: the ship size and ship operation schedule, were analyzed.

Figure 3-5 shows the passenger capacities of cruise ships that were in operation between January and March, which are arranged in order of size of the ship. A total of 594 ships were analyzed, including river cruises. The median and average for all cruise ships are 312 and 1,238 passengers, respectively. The passenger capacity of all infected cruise ships was above the median and average. Cruise ships infected with COVID-19 are large ships.

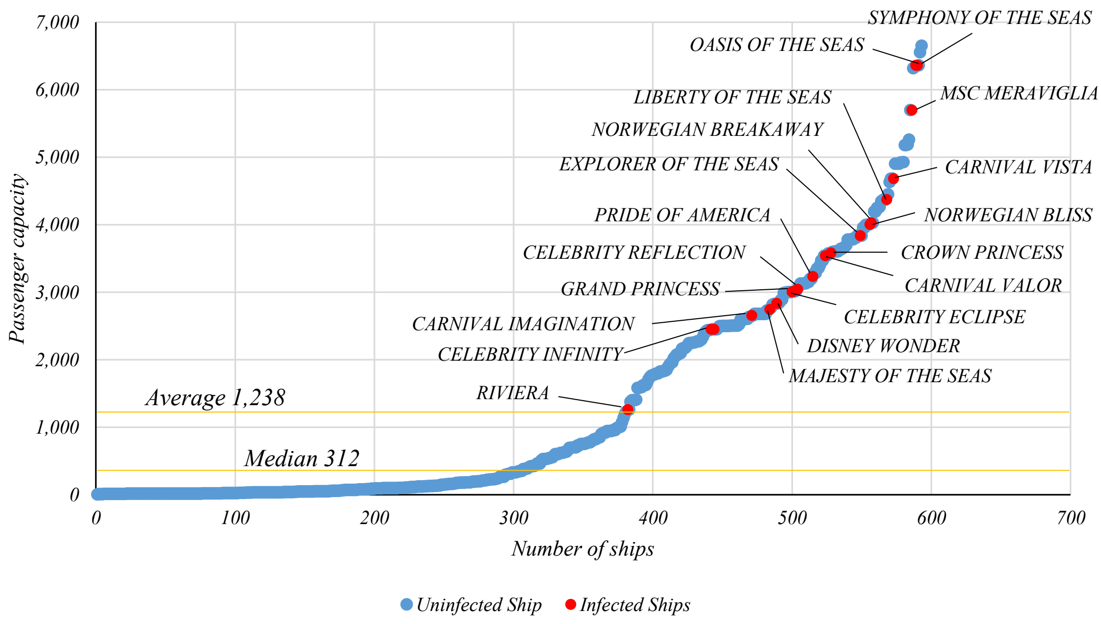

Figure 3-5 Passenger capacity of cruise ships infected with COVID-19

The second indicator is a ship operation schedule (itinerary). Table 3-4 shows the itinerary of eight large cruise ships before the COVID-19 infection was confirmed. These itineraries had several characteristics. The first is an itinerary that repeats one week for seven nights and eight days. Second is the itinerary, where the arrival and departure port (home port) is fixed. Third, the port of call as a destination is also fixed. These itineraries include private islands owned by each cruise line as ports of call.

Table 3-4 Itinerary of cruise ships infected with COVID-19

SYMPHONY OF THE SEAS

Day1	2/15	Miami	US
Day3	2/17	Coxen Hole	Honduras
Day4	2/18	Puerto Coasta Maya	Mexico
Day5	2/19	Cozumel	Mexico
Day7	2/21	Slaughter Harbour	Bahamas
Day8	2/22	Miami	US
Day1	2/22	Miami	US
Day4	2/25	Philipsburg	St Maarten
Day5	2/26	San Juan	Puerto Rico
Day7	2/28	Slaughter Harbour	Bahamas
Day8	2/29	Miami	US
Day1	2/29	Miami	US
Day3	3/2	Coxen Hole	Honduras
Day4	3/3	Puerto Coasta Maya	Mexico
Day5	3/4	Cozumel	Mexico
Day7	3/6	Coco Cay	Bahamas
Day8	3/7	Miami	US
Day1	3/7	Miami	US
Day4	3/10	Basseterre	St Kitts & Nevis
Day5	3/11	St Thomas	Virgin Islands (US)
Day7	3/13	Coco Cay	Bahamas
Day8	3/14	Miami	US

OASIS OF THE SEAS

Day1	2/9	Miami	US
Day4	2/12	Falmouth Port	Jamaica
Day6	2/14	Cozumel	Mexico
Day8	2/16	Miami	US
Day1	2/16	Miami	US
Day3	2/18	Labadee	Haiti
Day4	2/19	San Juan	Puerto Rico
Day5	2/20	St Thomas	Virgin Islands (US)
Day8	2/23	Miami	US
Day1	2/23	Miami	US
Day6	2/28	Cozumel	Mexico
Day8	3/1	Miami	US
Day1	3/2	Miami	US
Day3	3/4	Philipsburg	St Maarten
Day4	3/5	San Juan	Puerto Rico
Day7	3/8	Miami	US
Day1	3/8	Miami	US
Day6	3/13	Cozumel	Mexico
Day8	3/15	Miami	US

MSC MERAVIGLIA

Day1	2/9	Miami	US
Day3	2/11	Ocho Rios	Jamaica
Day4	2/12	Georgetown	Cayman Islands
Day5	2/13	Cozumel	Mexico
Day7	2/15	Ocean Cay	Bahamas
Day8	2/16	Miami	US
Day1	2/16	Miami	US
Day3	2/18	Coxen Hole	Honduras
Day4	2/19	Belize City	Belize
Day5	2/20	Puerto Coasta Maya	Mexico
Day8	2/23	Miami	US
Day1	2/23	Miami	US
Day3	2/25	Ocho Rios	Jamaica
Day5	2/27	Cozumel	Mexico
Day8	3/1	Miami	US
Day1	3/1	Miami	US
Day4	3/4	Belize City	Belize
Day5	3/5	Coxen Hole	Honduras
Day8	3/8	Miami	US

CARNIVAL VISTA

Day1	2/1	Galveston	US
Day3	2/3	Cozumel	Mexico
Day4	2/4	Belize City	Belize
Day8	2/8	Galveston	US
Day1	2/8	Galveston	US
Day3	2/10	Cozumel	Mexico
Day4	2/11	Georgetown	Cayman Islands
Day5	2/12	Ocho Rios	Jamaica
Day8	2/15	Galveston	US
Day1	2/15	Galveston	US
Day3	2/17	Cozumel	Mexico
Day4	2/18	Belize City	Belize
Day8	2/22	Galveston	US
Day1	2/22	Galveston	US
Day3	2/24	Cozumel	Mexico
Day4	2/25	Georgetown	Cayman Islands
Day5	2/26	Ocho Rios	Jamaica
Day8	2/29	Galveston	US
Day1	2/29	Galveston	US
Day5	3/4	Belize City	Belize
Day6	3/5	Cozumel	Mexico
Day8	3/7	Galveston	US

LIBERTY OF THE SEAS

Day1	2/23	Galveston	US
Day3	2/25	Cozumel	Mexico
Day4	2/26	Georgetown	Cayman Islands
Day8	3/1	Galveston	US
Day1	3/1	Galveston	US
Day4	3/4	Coxen Hole	Honduras
Day6	3/6	Cozumel	Mexico
Day8	3/8	Galveston	US
Day1	3/8	Galveston	US
Day3	3/10	Cozumel	Mexico
Day4	3/11	Georgetown	Cayman Islands
Day5	3/12	Falmouth Port	Jamaica
Day8	3/15	Galveston	US
Day1	3/15	Galveston	US
Day7	3/21	South Sabine Point STS	US
Day8	3/22	Galveston	US
Day1	3/22	Galveston	US
Day6	3/27	South Sabine Point STS	US
Day8	3/29	Galveston	US

NORWEGIAN BREAKAWAY

Day1	2/8	Port Canaveral	US
Day4	2/11	Wickham's Cay	Virgin Islands (British)
Day5	2/12	San Juan	Puerto Rico
Day7	2/14	Slaughter Harbour	Bahamas
Day8	2/15	Port Canaveral	US
Day1	2/15	Port Canaveral	US
Day5	2/19	Georgetown	Cayman Islands
Day6	2/20	Cozumel	Mexico
Day8	2/22	Port Canaveral	US
Day1	2/22	Port Canaveral	US
Day4	2/25	Wickham's Cay	Virgin Islands (British)
Day5	2/26	Charlotte Amalie	Virgin Islands (US)
Day8	2/29	Port Canaveral	US
Day1	2/29	Port Canaveral	US
Day4	3/3	Falmouth Port	Jamaica
Day5	3/4	Georgetown	Cayman Islands
Day6	3/5	Cozumel	Mexico
Day8	3/7	Port Canaveral	US
Day1	3/7	Port Canaveral	US
Day6	3/12	Cozumel	Mexico
Day8	3/14	Port Canaveral	US

NORWEGIAN BLISS

Day1	2/18	Port Canaveral	US
Day3	2/20	Nassau	Bahamas
Day6	2/23	New York & New Jersey	US
Day8	2/25	Port Canaveral	US
Day1	2/25	Port Canaveral	US
Day2	2/26	Slaughter Harbour	Bahamas
Day3	2/27	Nassau	Bahamas
Day6	3/1	New York & New Jersey	US
Day8	3/3	Port Canaveral	US
Day1	3/3	Port Canaveral	US
Day2	3/4	Great Stirrup Cay	Bahamas
Day3	3/5	Nassau	Bahamas
Day6	3/8	New York & New Jersey	US
Day8	3/10	Port Canaveral	US
Day1	3/10	Port Canaveral	US
Day2	3/11	Great Stirrup Cay	Bahamas
Day3	3/12	Nassau	Bahamas
Day6	3/15	New York & New Jersey	US
Day11	3/20	Miami	US

EXPLORER OF THE SEAS

Day1	2/16	Miami	US
Day3	2/18	Nassau	Bahamas
Day5	2/20	Nassau	Bahamas
Day6	2/21	Miami	US
Day1	2/21	Miami	US
Day5	2/25	Oranjestad (Aruba)	Aruba
Day6	2/26	Kralendijk	Bonaire
Day7	2/27	Willemstad West Bank	Curacao
Day10	3/1	Miami	US
Day1	3/1	Miami	US
Day4	3/4	San Juan	Puerto Rico
Day5	3/5	St Thomas	Virgin Islands (US)
Day7	3/7	Freeport (Bahamas)	Bahamas
Day8	3/8	Miami	US
Day1	3/8	Miami	US
Day3	3/10	San Juan	Puerto Rico
Day4	3/11	Charlotte Amalie	Virgin Islands (US)
Day8	3/15	Miami	US

Source: IHS maritime (2020)

*Darker color indicates an itinerary infected with COVID-19.

The risk of infection on board a ship increases proportionately as the number of passengers increases. Cruise ships with an unspecified number of cruise passengers replaced in a week have a higher infection rate than ships that do not have passengers replaced for several weeks. In the case of a large cruise ship with many passengers aboard, due to the limited number of persons in charge of inspection, there is a possibility that health inspection cannot be strict.

3.4. Chapter conclusion

The purpose of this chapter is to analyze the relationship between the cruise industry and the COVID-19 outbreak. This from two perspectives is analyzed.

The first analysis focused on the relationship between the cruise ship movement and the COVID-19 outbreak. Consequently, it was found that COVID-19 infection rates in countries that have ports of arrival and departure are higher than in countries with only ports of call. In addition, COVID-19 infection rates in countries that continued to accept cruise ships until March were higher than those in countries that did not. However, estimates of the number of cruise passengers landing in each country by AIS data were used to track cruise ships. The estimated figures differ from the actual ones; thus, it is necessary to get the actual data from the cruise lines. The second analysis focused on the characteristics of cruise ships infected with COVID-19. From the CDC's list of cruise ships infected with COVID-19, ship sizes and itinerary characteristics were compared. The cruise ships infected with COVID-19 tended to be large. In addition, most cruise ships were sailing from the same home port to the same port of call in a week. It should be noted that, as mentioned earlier, the spread of COVID-19 infection is not only caused by cruise ships, but also by differences in infection control measures in each country and the effects of other modes of transportation such as airplanes.

The emergence of the modern cruise industry began in the late 1960s and early 1970s (Garin, 2005). The cruise industry has shown remarkable resilience in the face of economic, social-political, and other crises. The global financial crisis of 2008-2009 had a serious impact on the maritime cargo shipping industry. However, the cruise industry has continued to grow steadily. When the Costa Concordia loss (2012) created a period of negative publicity for the cruise industry, the industry cruised “through the perfect storm” (Peisley, 2012) and continued to generate more demand in large part due to the successful marketing strategies developed by the cruise lines (Pallis, 2018). Vogel and Oschmann (2012) explained that cruise demand has always been “supply-led” starting with the invention of leisure cruising by passenger shipping lines whose scheduled transatlantic services were losing passengers to the airlines. Similarly, Rodrigue and Notteboom (2013) analyzed that the cruise industry works in a “supply push mechanism” as cruise lines aim to generate demand for cruises by providing new products with a larger and more diversified range of ships. The impact of COVID-19 on the cruise industry will be much stronger than any of the past difficulties. However, the cruise industry will grow again with a new supply-driven strategy as overcoming difficulties in the past. The results of this chapter will be useful not only for academic researchers but also for executives of the cruise industry and port officials.

4. SPATIAL AND TEMPORAL CHANGES IN THE CRUISE NETWORK STRUCTURE IN NORTHEAST ASIA

4.1. Introduction

Cruise demand has the characteristic of being supply-driven. In other words, supply-side initiatives such as port development are undertaken first, followed by the emergence of demand in the form of cruise ships and passengers. Conversely, supply-driven port development does not lead to success in all ports. Some ports have experienced problems with cruise ships not coming after the passenger terminals and other facilities have been put into service. The cruise industry has proliferated since the 1990s. The world cruise population increased from 3.8 million in 1990 to 29.7 million in 2019 (CLIA, 2011; CLIA, 2019a). The average annual growth rate for the last 30 years is 7.37%. Furthermore, the global cruise industry has created huge economic benefits. The cruise industry generated $72.0 billion in total direct expenditures and $154.5 billion in total output contributions worldwide over the year 2019. A vast number of employment opportunities were also created, with a total income contribution of $50.5 billion and a total employment contribution of 1.16 million people, making it a huge industry (CLIA, 2020a).

While the accommodation of cruise ships at a port can be expected to generate economic benefits, it also requires a huge investment to construct the berth and improve the passenger terminal. Therefore, understanding the port selection behavior of cruise lines is important to avoid wasting investment in port improvements and consequently, cruise ships not coming to the ports. In our view, the problem in the supply-driven cruise industry is that there is not enough information available to decide on whether to invest in port development. In other words, the problem is that ports are required to make decisions on port development under conditions of uncertain future cruise demand. In the cruise industry, which is characterized as supply-driven, reducing the uncertainty of future demand may prevent unnecessary port investments. Reducing uncertainty about future demand requires an understanding of the principles of demand-side cruise line port selection behavior.

The port selection behavior of cruise lines is influenced by various factors such as the preferences of their target customers, quality of service, and size of their ships. The quality of a cruise line's service is classified into "cruise segments." Cruise segment classifications differ among evaluation agencies, and there are no uniform standards. Bjornsen (2003) gives examples of the differences in cruise duration, ticket price, and ship sizes in different categories. Contemporary is an itinerary of 3 to 7 days, 100-200 USD per day per person, operating mega- and large-size ships. Premium is an itinerary of 7 to 14 days, 150-500 USD per day per person, operating large- and mid-size ships. Luxury is an itinerary of 7 days and upwards, 600-3,000 USD per day per person, operating mid- and small-size ships (Gibson, 2012). Thus, small-size cruise ships typically offer better service and higher ticket prices. In particular, the size of the cruise ship may be a limiting factor in port selection. In practical terms, the first step in developing a cruise port is to determine the size of the cruise ships to be anchored. In the case of mega-size ships, there are many restrictions. For example, they need to be based at a turnaround port that can handle large volumes of passengers quickly and efficiently. Additionally, they require ports that can physically handle such large ships and where there are no impediments to berthing (Henry, 2012).

A network diagram can be depicted by tracking the movement of cruise ships as they navigate between ports. The network describes the number and location of ports (nodes) that make up the cruise network and their connections (edges) due to cruise ship movements. Network structures can be measured using various network science methods, which is a powerful way to understand the structure of various networks of different types, such as technological, information, social, and biological networks (Newman, 2018). Barabási (2015) revealed that the architectures of networks that emerge in different domains of science, nature, and technology are similar and are based on the same organizational principles. If so, some network science methods may be able to analyze cruise networks to understand their port selection behavior.

This chapter aims to understand the spatial and temporal changes in the structure of the cruise network in Northeast Asia. To this end, the movements of cruise ships are tracked by AIS data, and the aggregated data are viewed as a network to understand t the spatial and temporal changes in the structure of the cruise network based on the actual situation of the number of ports and routes in a particular sea area, the existence of hub ports, connections between ports. AIS data (https://maritime.ihs.com) is used to track the movement of cruise ships in Northeast Asia by size.

4.2. Literature review

Several previous studies have focused on cruise lines' port selection behavior. Marti (1990) suggests that the geographic concepts of "site" and "situation" can contribute to a greater understanding of the cruise-ship port selection process. "Site," a physical factor, holds great significance in the origin and evolution of cruise ports. "Situation" is a notion that can comprise either physical or cultural qualities. Manning (2006) explains that the main influencing factors for port selection include the key natural and cultural assets of the port, port facilities, location access to other destinations and the homeport, security, infrastructure, provisioning, port costs, and marketing. Gui and Russo (2011) show that cruise lines' requirements include a wide range of dedicated infrastructure and services, as well as port area infrastructure, airports, taxi fleets, coach services, and shore excursions and shopping areas. Wang *et al*. (2014) analyze the factors that affect cruise lines' port selections using the fuzzy-AHP method. The results show that "tourism attractions" are the most significant issue taken into consideration when a cruise ship is selecting a port of call location. Castillo-Manzano *et al*. (2014) conclude that the likelihood of having cruise traffic is linked to ports located in populous areas and closer to large airports.

Few studies have analyzed cruise ship networks using network science techniques. Tsiotas et al. (2018) show the double role of the cruise network, which is composed of the profit-driven strategies of cruise companies and port authorities, using data from the 2013 itineraries of Costa Cruises and MSC Cruises in the Mediterranean cruise market. Jeon et al. (2019) investigate the centrality of cruise ports in the Asian cruise shipping market while proposing the hubs and authorities centrality (HACC) metric as a directional synthesis of the hubs centrality and authorities centrality to explore cyclical and directional features of centrality in the cruise shipping network. In a recent cruise network study, Kanrak and Nguyen (2021) reveal that the cruise shipping network is scale-free using itinerary data from Asian and Australian cruise network websites. Lopez Rodriguez et al. (2021) suggest that Caribbean ports are the most important concerning hub and authority centrality, using 2018 itineraries for each cruise line from the sites for 902 ports in the Caribbean and Northern Europe. To the best of our knowledge, there are no cases of structural changes in cruise networks using network science methods.

Moreover, few studies have used AIS data for analysis in cruise shipping. Tichavska and

Tovar (2015) use AIS data to measure the pollution status of exhaust gas from cruise ships calling at the Las Palmas Port in the Canary Islands. Vicente-Cera *et al*. (2019, 2020a) arrange the cruise ship's operating hours, repair times, and berthing times, estimated seawater pollution status by cruise ships, and assess environmental pressures related to global cruise traffic along their paths based on AIS data. Vicente-Cera *et al*. (2020b) use AIS data to aggregate cruise ship calling patterns at European ports and evaluated the diversity of cruise ship calls at each port. Ito *et al*. (2020) organize the port call patterns before and after the suspension of cruise ship operations by COVID-19 and analyze the relationship between cruise ship operations and the spread of infection at the port of call using AIS data. However, there are no studies of network analysis focusing on the structural changes of cruise networks using AIS data for cruise ships for a longer period.

4.3. Methodology

4.3.1. Data

The Northeast Asian cruise area, which has expanded rapidly in recent years, was chosen as a case study. The CLIA officially began collecting data on the Northeast Asian cruise population in 2012. The cruise population in Northeast Asia in 2012 was approximately 450,000, reaching 2.84 million by 2019 (CLIA Asia, 2013; 2020). China is a source of demand for the fast-growing Northeast Asian cruise market. In 2006, the first year of the Chinese cruise market, the cruise population was 20,000 (Wang, 2017). In 2016, the number reached 2.1 million, and China became the world's second-largest cruise market, following the United States (CLIA, 2016).

Data from international cruise itineraries (excluding domestic cruise itineraries) calling at ports in Northeast Asian countries (Japan, China, Hong Kong, Taiwan, and South Korea) from 2014 to 2019 were used. Since some ports are not equipped with AIS data receivers and itineraries for which AIS data cannot be obtained, the itineraries were supplemented with brochures and other information from each cruise line. The division by the size of the cruise ship followed the classification criteria of CLIA Asia (2019). The classification criteria are as follows. Information on cruise operators, based on ship size, is provided in Appendix 4.

- Mega-size: Lower berth capacity of 3,500 or more OR GRT over 150,000
- Large-size: Lower berth capacity of 2,000 to 3,500 AND GRT over 75,000
- Mid-size: Lower berth capacity of 750 to 2,000 passengers
- Small-size: Lower berth capacity under 750 passengers (*including Expedition ships)

The locations of the ports targeted in this chapter are shown in Figure 4-1.

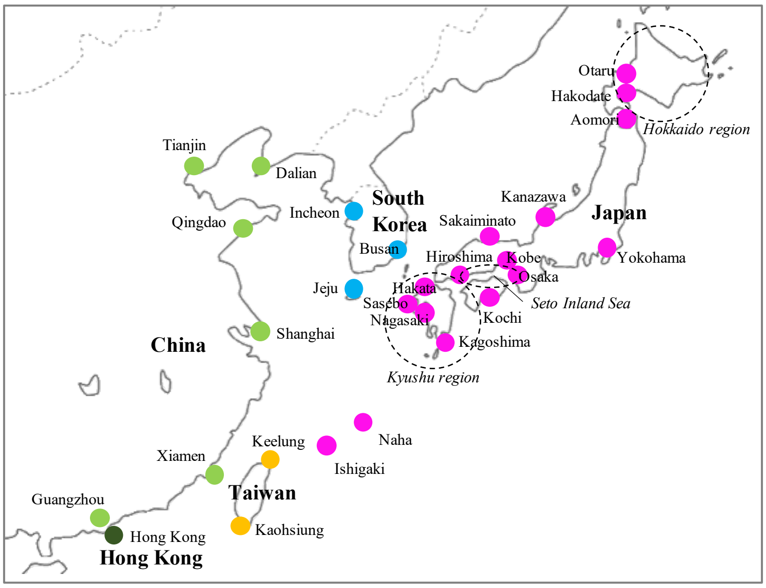

Figure 4-1 Location of ports

4.3.2. Measurements of network structure

The cruise passengers depart from the generating region, stop at each port of call to look around, and finally arrive at the destination region, which can be the same as the generating region. In the case of these looped routes, whether the order of port calls is clockwise or counterclockwise is of little significance. Kanrak and Nguyen (2021) reported that the degree distributions for in-degree and out-degree were similar observations. Therefore, the network was analyzed in an undirected graph. In addition, since this chapter aims to understand the spatial and temporal changes in the structure of the cruise network, it focuses on the connections between ports rather than the number of port calls, so it is analyzed in an unweighted graph. Network analysis and visualization were conducted using Gephi (the open graph Viz platform).

The maximum number of edges in a network is limited by the number of possible different connections between nodes in the cruise network. The maximum number of edges is therefore given by the number of pairs of nodes. A network with the maximum number of edges, in which all possible pairs of nodes are connected by edges, is called a complete network (Menczer *et al.*, 2020). The density is the ratio of the actual number of edges to the number of all possible edges in a graph. It is used to analyze the network's connectivity level. If the number of nodes is n and the number of edges is m, the network density d is given as follows:

$$d = \frac{2m}{n(n-1)} \tag{1}$$

The clustering coefficient of a node is the fraction of pairs of neighbors of the node connected. The clustering coefficient C_i of node i is defined as follows: $\tau(i)$ is the number of triangles involved in i. The maximum possible number of triangles for i is the number of pairs formed by its k_i neighbors. C_i is defined only if the degree $k_i > 1$ because of the terms k_i and $k_i - 1$ in the denominator. A node must have at least two neighbors for any triangle to be possible.

$$C_i = \frac{2\tau(i)}{k_i(k_i-1)} \tag{2}$$

The clustering coefficient of the entire network is the average clustering coefficient C, which is used to understand the formation of the triangular route. The formula is as follows:

$$C = \frac{1}{n}\sum_{i=1}^{n} C_i \tag{3}$$

The average shortest path length is the average of the shortest network distances in the network that can reach the other ports. The average shortest path length $\langle l \rangle$ is as follows: l_{ij} is the shortest path length between nodes i and j. The sum is over all pairs of nodes, and it is divided by the number of pairs to compute the average.

$$\langle l \rangle = \frac{\sum_{i,j} l_{ij}}{\binom{n}{2}} = \frac{2\sum_{i,j} l_{ij}}{n(n-1)} \tag{4}$$

The diameter l_{max} of a network is the maximum shortest-path length across all pairs of nodes (i.e., the length of the longest shortest path in the network). The formula is as follows:

$$l_{max} = \max_{i,j} l_{ij} \tag{5}$$

Degree centrality k_i is assumed to be centered on a node with a higher degree among the nodes in the network. Hub ports are detected with degree centrality. The degree of node i by k_i is denoted. If the adjacency matrix of a network with n nodes is a_{ij}, then degree centrality can be formulated as follows:

$$k_i = \sum_{j=1}^{n} a_{ij} = \sum_{j=1}^{n} a_{ji} \tag{6}$$

Degree centralization C_D measures are based on a normalized variance in the degree centrality to compare distinct networks based on their highest degree centralization scores (Freeman, 1979; Krnc and Škrekovski, 2020). It can measure whether the degree is biased toward a high node in the network. k_{max} is the highest degree centrality in the network. k_i denotes the degree of node i. The more concentrated the network, the less homogeneous it is:

$$C_D = \frac{\sum_{i=1}^{n}(k_{max} - k_i)}{\max \sum_{i=1}^{n}(k_{max} - k_i)} \tag{7}$$

In network science, a community is defined as a group of nodes belonging to one group and connected with a higher probability than the nodes belonging to other groups. Community detection was performed using modularity optimization. Modularity is a measure of the quality of the community partitioning results. Modularity Q is defined as follows: L_c is the number of internal edges in community c, and k_c is the total degree of nodes in community c. L is the number of edges in the network.

$$Q = \frac{1}{L}\sum_{c}\left(L_c - \frac{k_c^2}{4L}\right) \tag{8}$$

In this chapter, the Louvain algorithm for modularity optimization was used (Blondel *et al*., 2008). The Louvain algorithm is a heuristic algorithm for approximately maximizing modularity over divisions of a network into any number of communities. This is an agglomerative algorithm, which works by taking single nodes and joining them into groups, then joining groups with other groups, and so forth, to find the configuration with the highest modularity (Newman, 2018). Calculated using Gephi.

Table 4-1 Interpretation of network indicators from the cruise industry perspective

Indicators	Meaning of indicators	Network characteristics	Cruise lines' port selection behavior
Number of nodes	Number of ports where cruise ships have called	The higher the number of nodes, the more developed and diversified the network of ports of call.	A higher number of nodes indicates characteristics that promote the development of new ports.
Number of edges	Number of cruise ship routes navigated between ports	The higher the number of edges, the more developed (multidirectional) the route is in the network.	A high edge number indicates characteristics that promote the creation of a new route.
Density	The ratio of the actual number of shipping routes to the number of possible connections between ports	The higher the density, the higher the percentage of development of shipping routes is in the network. If the development of shipping routes is more advanced than the development of ports, density will be higher. (Progress in the development of new shipping routes by shipping lines)	If the density is high, new ports may not be developed and itineraries (combinations of ports of call) may become rutted.
Average clustering coefficient	The ratio of ports that have shipping routes to and from one port to another.	The higher the average cluster coefficient, the more triangular the network (i.e., a product consisting of an arrival and departure port and two ports of call), or a network with many routes that are not connected but are triangulated.	Characteristics of (changes in) shipping routes in a given network, such as whether a shipper's itinerary is open or closed, longer or shorter in days, etc.
Average shortest path length	The shortest path on the network between one port and another	Not considering connections on direct itineraries, the longer the average shortest path length, the longer the connections (paths) between ports on the closest route, and the sparser the network.	Characteristics of (changes in) shipping routes in a given network, such as whether a shipper's itinerary is open or closed, longer or shorter in days, etc.
Diameter	The longest path on the network between one port and another	It does not consider connections on direct itineraries; the longer the diameter, the longer the connection (path) between ports on the longest route, and the sparser the network.	Characteristics of (changes in) shipping routes in a given network, such as whether a shipper's itinerary is open or closed, longer or shorter in days, etc.
Degree centrality	Number of shipping routes connecting to the port	Ports with a higher degree centrality have more shipping connections with neighboring ports. The port is a hub port with multimodal shipping routes.	It shows which ports the shipping lines operate out of. Degree centrality can also understand the strategies of the shipping companies, such as whether or not they are promoting hubs in

			certain ports.
Degree centralization	The ratio of degrees biased toward the port with the highest degree	Networks with a higher degree centralization are more heterogeneous and biased toward the port with the highest degree (hub port).	The network as a whole can understand strategies such as whether or not a group of carriers participating in a given network is converting to a hub.
Modularity	Quality of community (inter-port connections) division	The higher the modularity, the higher the quality of the network in terms of the division (boundaries) of communities (groups of ports) that are connected among ports.	From the perspective of which ports and which ports belong to the same community, modularity can understand the characteristics of the port selection behavior of cruise lines.

Source: Author

4.4. Results

4.4.1. Network structure

The changes in the number of nodes and edges over time were analyzed to examine changes in the number of ports and routes by ship size in Figure 4-2 (a) and (b). The number of nodes and edges was highest for the small-size ships and lowest for the mega-size ships. The changing trend was an increasing number of nodes and edges for small- and mega-size ships, whereas that of large- and mid-size ships decreased around 2017–2018. This indicates that small- and mega-size ships were driving growth in the Northeast Asian cruise market. In Figure 4-2 (c) and (d), observations were made using density and average clustering coefficients to understand changes in network density and the presence of triangular connection patterns. As a result, small-size ships had sparse networks and low triangular connectivity. The network of mega-size ships around 2014 was dense, but it tended to become sparse over time. It can be said that mega-size ships were dense in the early years of the market, but they gradually became sparse as the choice of ports of call increased. Furthermore, changes in network size were analyzed using the average shortest path length and diameter indicators in Figure 4-2 (e) and (f). The network of small-size ships was longer than that of other sizes, both in average shortest path length and diameter. In particular, the diameter of small ships has become increasingly longer since 2018.

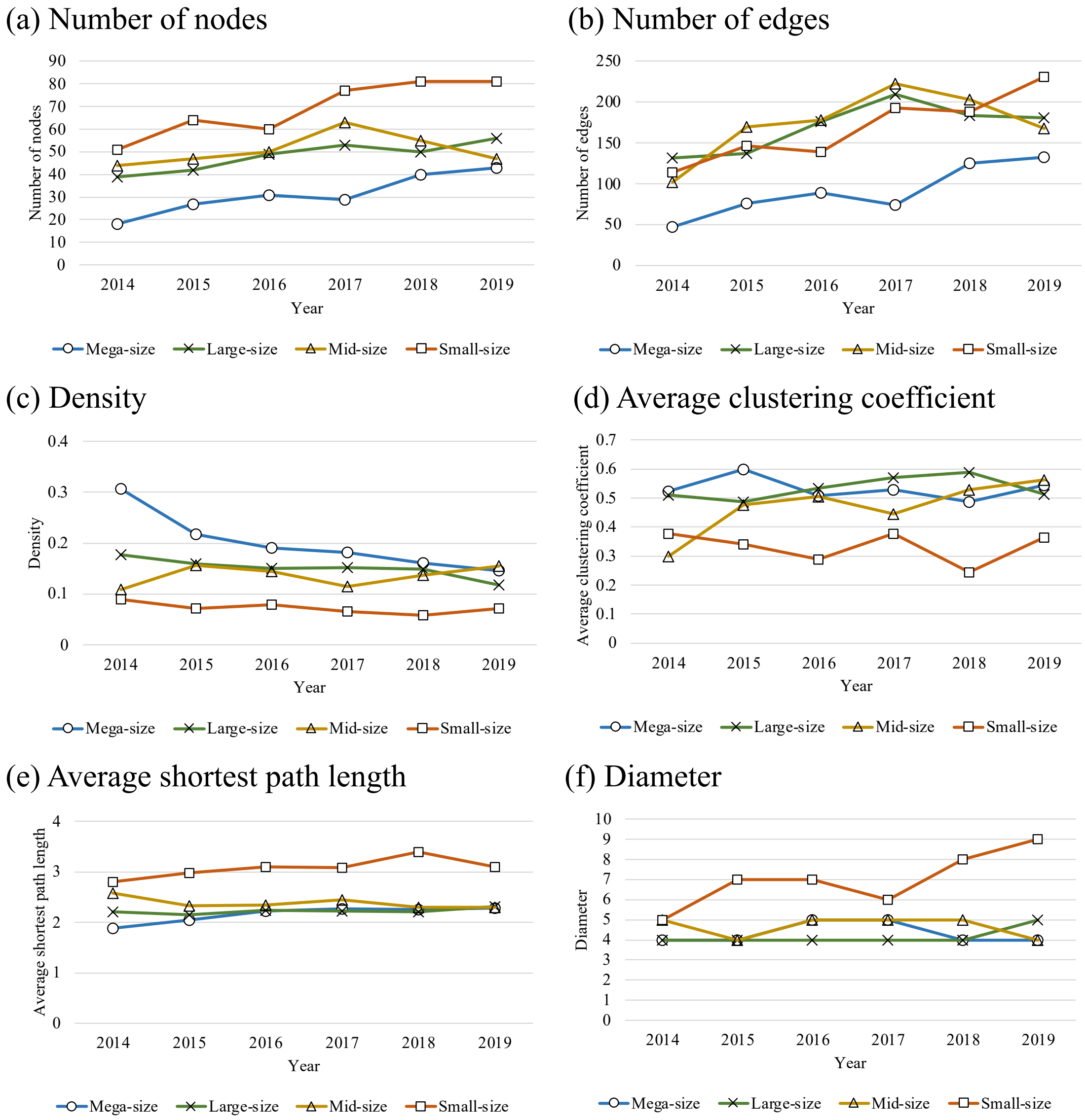

Figure 4-2 Network structure

4.4.2. Degree centrality

Hub ports by ship size were detected from Figure 4-3 to Figure 4–6 using degree centrality to understand changes in the center of the Northeast Asian cruise network. The nodes of the same color belong to the same country. The size of each node represents its degree. The mega-sized network has grown with Shanghai, Japan's Kyushu region, and South Korea's ports as hubs (Figure 4-3). In 2014, there were still few ports with mega-size ships calling. Then, in 2015, the number of degrees in Shanghai, Nagasaki, Hakata, and Jeju increased. In 2016, these ports were joined by Hong Kong and Busan. From 2017, the number of degrees in Naha gradually increased. In 2018, Shanghai's degrees increased even more, as did the degree of the Kyushu region in Japan, such as Kagoshima, Nagasaki, and Hakata. Additionally, Jeju disappeared from the network this year. In 2019, Busan, Keelung, and Naha grew as hub ports. Thus, the group of hub ports where mega-size ships call had grown into a hub port with Shanghai as the center, together with the surrounding port groups in Japan, Korea, Taiwan, and Hong Kong. However, there are few operations in the northern part of Japan (Hokkaido region), and they are not extensive.

Figure 4-4 shows the growth of the large-size network with Yokohama and Busan as hub ports. In 2014, the degree increased in Yokohama, Kobe, Busan, Jeju, and Shanghai. There were also cruise ship calls to the Hokkaido region, located in northern Japan. In 2015, the degree in Shanghai, Yokohama, and Busan increased. In 2016, in addition to these port groups, the degree of Jeju, Keelung, Nagasaki, and Kagoshima increased. In 2017, the degree of Busan, Shanghai, and Keelung increased further, as well as for many Japanese ports (including Yokohama, Nagasaki, Kagoshima, Kobe, Kochi, and Naha). In 2018, Tianjin's degree increased, and in 2019, Yokohama and Busan grew into huge hubs while Shanghai declined. Thus, the network of large-size ships consisted of Yokohama and Busan as hub ports, with multiple ports of call scattered around them. Ports of call were widely spread throughout Northeast Asia, with some as far north as Japan. The situation was not as Shanghai-centric as the mega-size network.

The mid-size network had grown with Shanghai and Jeju as hub ports until 2017, after which the hub ports shifted to Keelung in Taiwan, Busan in South Korea, and Kyushu region in Japan (Figure 4-5). In 2014, Yokohama and Shanghai were the hub ports, but both still had low degree numbers. In 2015, several hub ports had emerged, mainly Shanghai, and Jeju, Hakata, Kobe, and Keelung had also increased their degree. In 2016, Yokohama and Busan joined this hub port group. In 2017, Shanghai grew into an even more massive hub port. Other ports such as Kobe, Hakata, Sasebo, and Naha also increased. However, the situation changed in 2018. While Shanghai, Tianjin, and Jeju declined, Hakata and Sasebo increased, and Keelung emerged as a hub port. In 2019, the degree shrank at many ports. Thus, the mid-size network was on a downward trend, as the trend toward expansion from 2014 to 2017 changed dramatically in 2018. The decline in the position of Shanghai and Jeju was noticeable.

In the small-size network, the development of Hiroshima and Kobe as hub ports can be seen in Figure 4-6. No major hub ports were found in 2014, but the following were relatively high: Kobe, Otaru, Busan, Jeju, Shanghai, Keelung, and Hong Kong. Several hub ports have emerged around Japan since 2015. These hub ports are Hiroshima, Kobe, and Nagasaki. In 2016, Hiroshima and Kobe formed a huge hub port among these ports, followed by Jeju, Shanghai, and Keelung, which were gradually increasing. In 2017, in addition to Hiroshima and Kobe, Nagasaki, Busan, and Hong Kong were growing hub ports. It is also evident that cruise ship calls were operating over a wide area from the Hokkaido region in northern Japan to southern China. In 2018, Hiroshima emerged as a huge hub port. Moreover, numerous ports had emerged around Hiroshima. Furthermore, by 2019, an extremely large number of ports would emerge around Hiroshima, as well as Kobe, Osaka, and Nagasaki, while Hakodate would be next in line in northern Japan. Thus, it can be seen that the small-size network has grown with Hiroshima as its hub port in Japan, with several sub-hub ports in the vicinity working in tandem with each other. In the northern part of Japan, there were also signs of a hub port cluster forming around Hakodate.

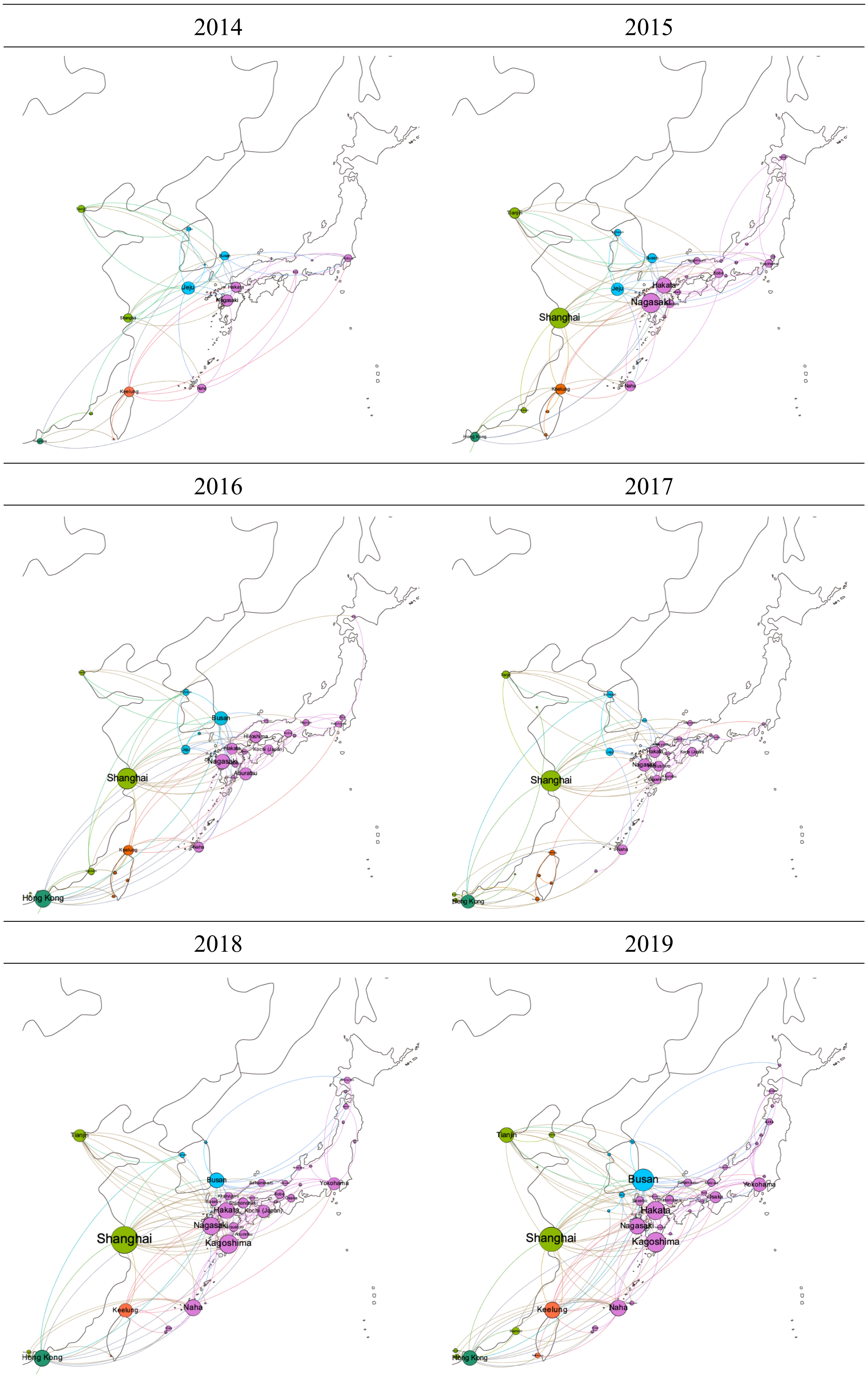

Figure 4-3 Mega-size ship network

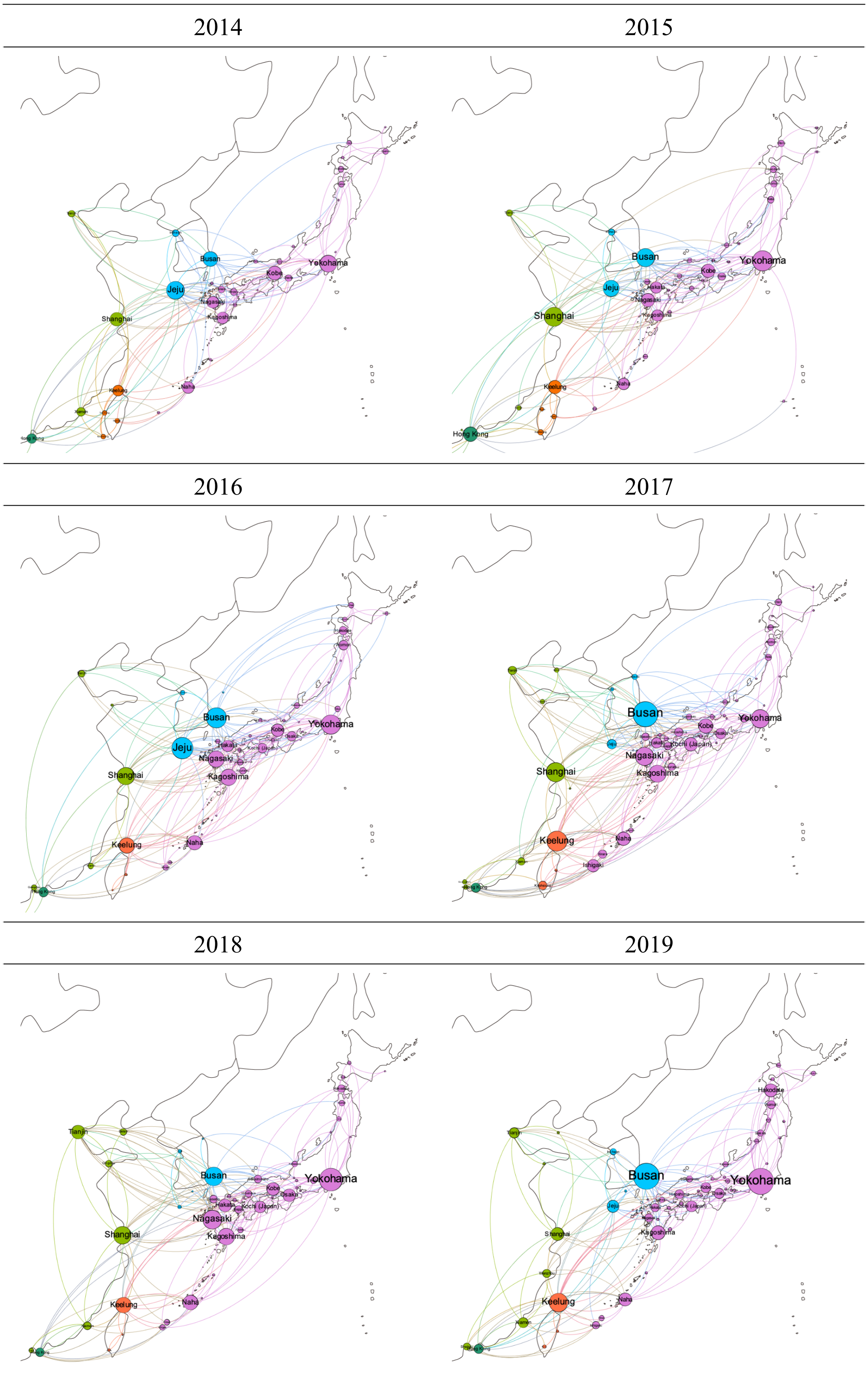

Figure 4-4 Large-size ship network

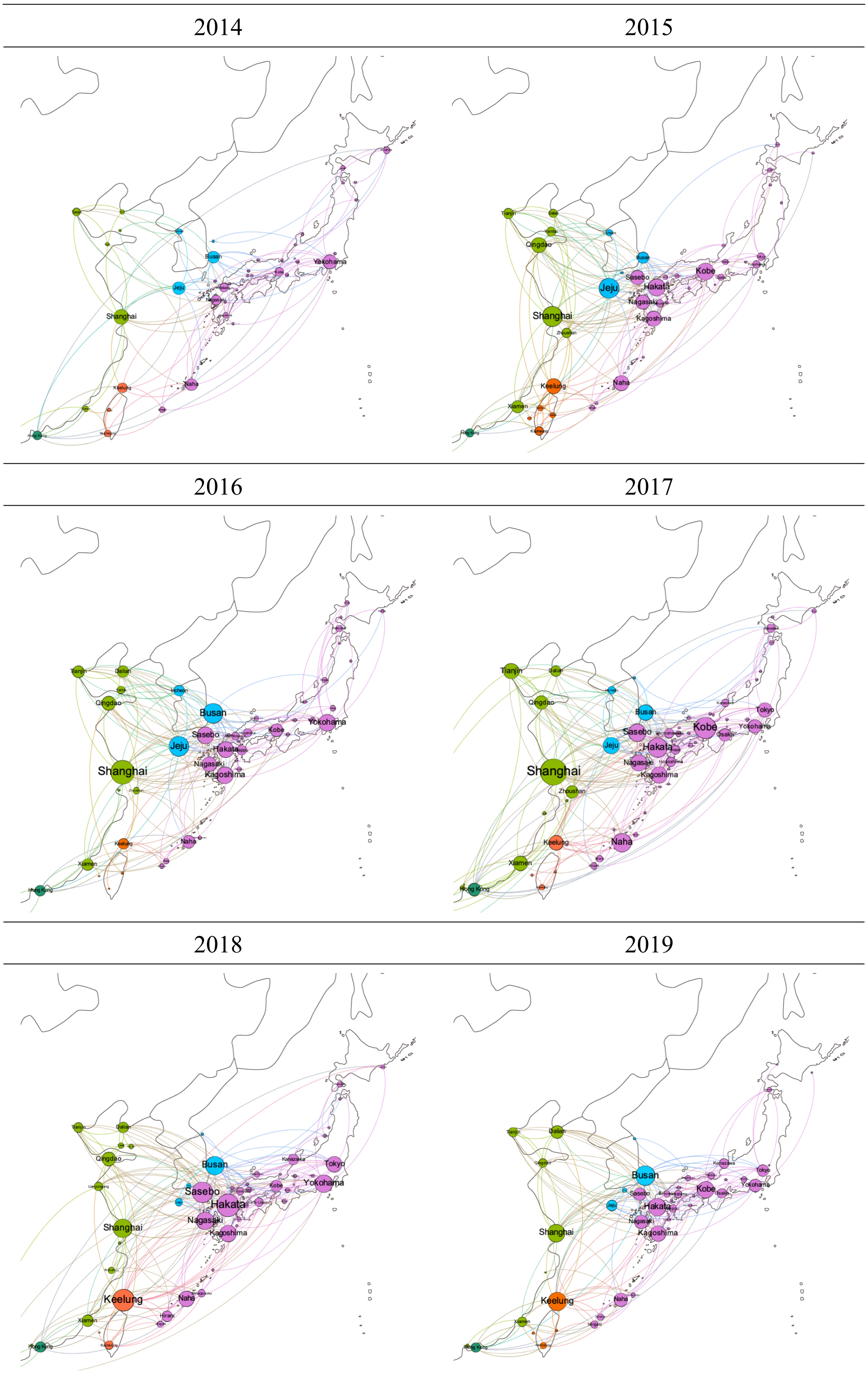

Figure 4-5 Mid-size ship network

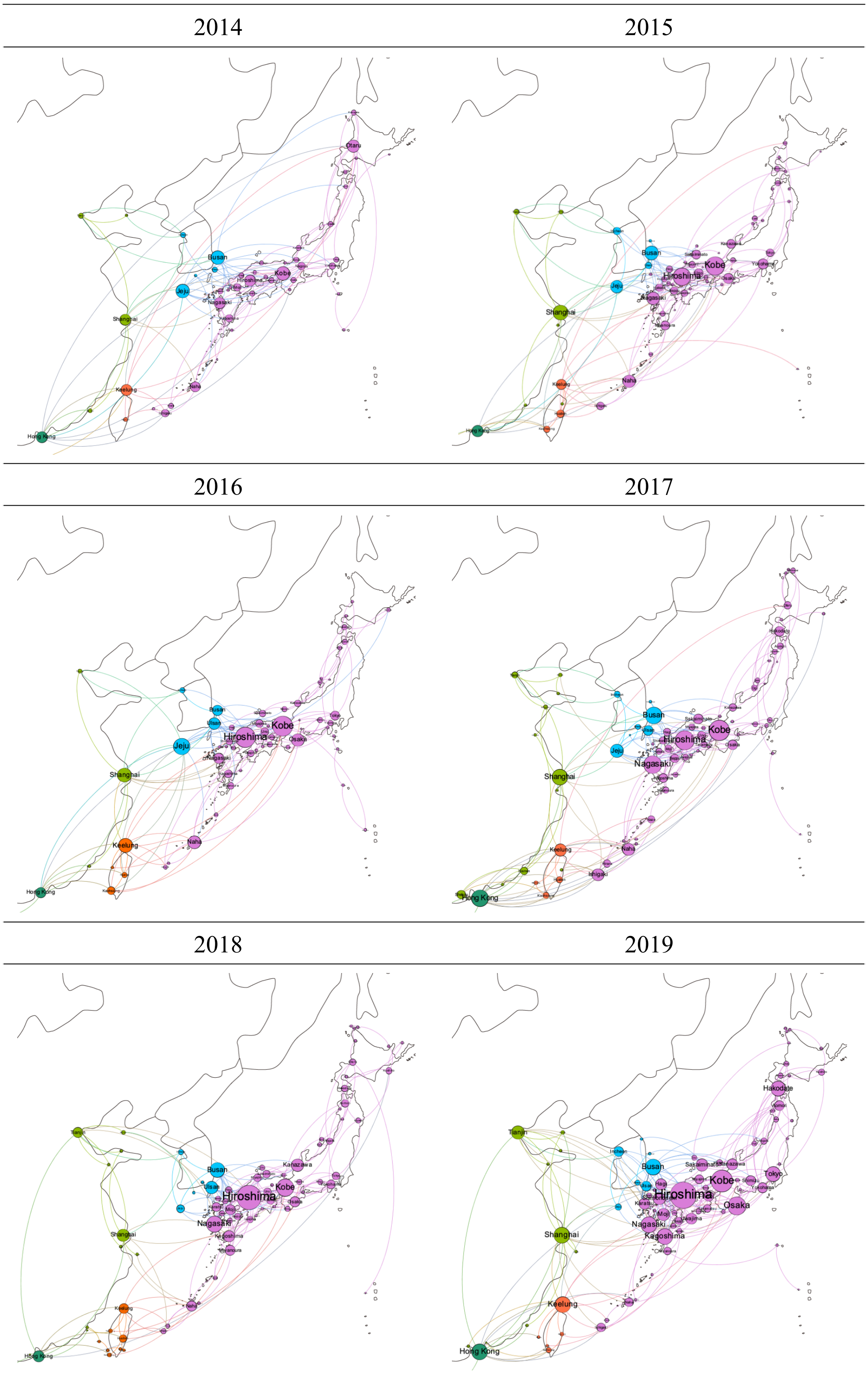

Figure 4-6 Small-size ship network

Figure 4-7 shows the degree by the port to observe changes in the hub ports by ship size. The legend lists the top 10 ports in 2019. Each country has a different color line. Pink, light green, light blue, green, and orange colors represent Japan, China, South Korea, Hong Kong, and Taiwan, respectively. The gray lines represent the degree of ports ranked 11th and lower in 2019. The mega- and small-size ship's hubs remain unchanged, while the large- and mid-size ship's hubs were gradually replaced. The transition of hub ports by ship size is described below.

Since 2015, the mega-size network was continuously highest in Shanghai, indicating that the hub port was fixed in only Shanghai. In 2019, Shanghai, Busan, and Kagoshima were higher. There was a temporary drop in the overall degree in 2017. It also shows that Shanghai, Kagoshima, and Hakata have changed at the same time since 2017. Large-size frequently swapped places in the rankings. Jeju was the highest in 2014 and 2016, Yokohama in 2015 and 2018, and Busan in 2017 and 2019. In 2019, Busan was the highest, followed by Yokohama and Keelung. For the mid-size, after the upward trend from 2014 to 2017, a downward trend was evident from 2018 onwards. Shanghai remained at a high level through 2017 but then fell sharply in 2018. This led to higher degrees in 2019 for Busan, Keelung, and Hakata, but none of these ports had been on an upward trend in recent years and remained flat. In terms of the small-size network, Hiroshima and Kobe have continuously had high degrees since 2015. In particular, Hiroshima's degree was high since 2018, indicating that the port was present as a hub port. In 2019, Japanese ports such as Hiroshima, Kobe, and Osaka ranked high. It also shows that the number of ports in the grey lines with a degree of 10 or less was high and densely populated.

The degree distribution is organized in Figure 4-8 to examine changes in the degree by ship size. In this bar chart, the white bars represent 2014, the black bars represent 2019, and the rest represent the degree distribution for each year. The red line in the figure depicts the 2019 figures. The distribution bar charts for all sizes also had a shape with a long tail to the right-hand side, with the highest bar around degree two. The bar then shifts to the right-hand side over time. The mega-size was mostly degrees 2 and 4. The number of degrees after 13 increased over time, indicating that the trend was toward becoming a hub. Large-size was mostly in the range from 2 to 5, followed by degrees 10 and 13. In addition, ports with a higher degree of 27 were present. Mid-size had similar levels of degrees with a wide range of degrees from 2 to 9. This is in contrast to a large number of degrees 2 in the other sizes. The number of ports with higher degrees decreased over time. Small-size had higher degrees 2 and 4, followed by degrees 8 and 13. Compared with the other sizes, the tails on the right-hand side were shorter, indicating less obvious hub ports.

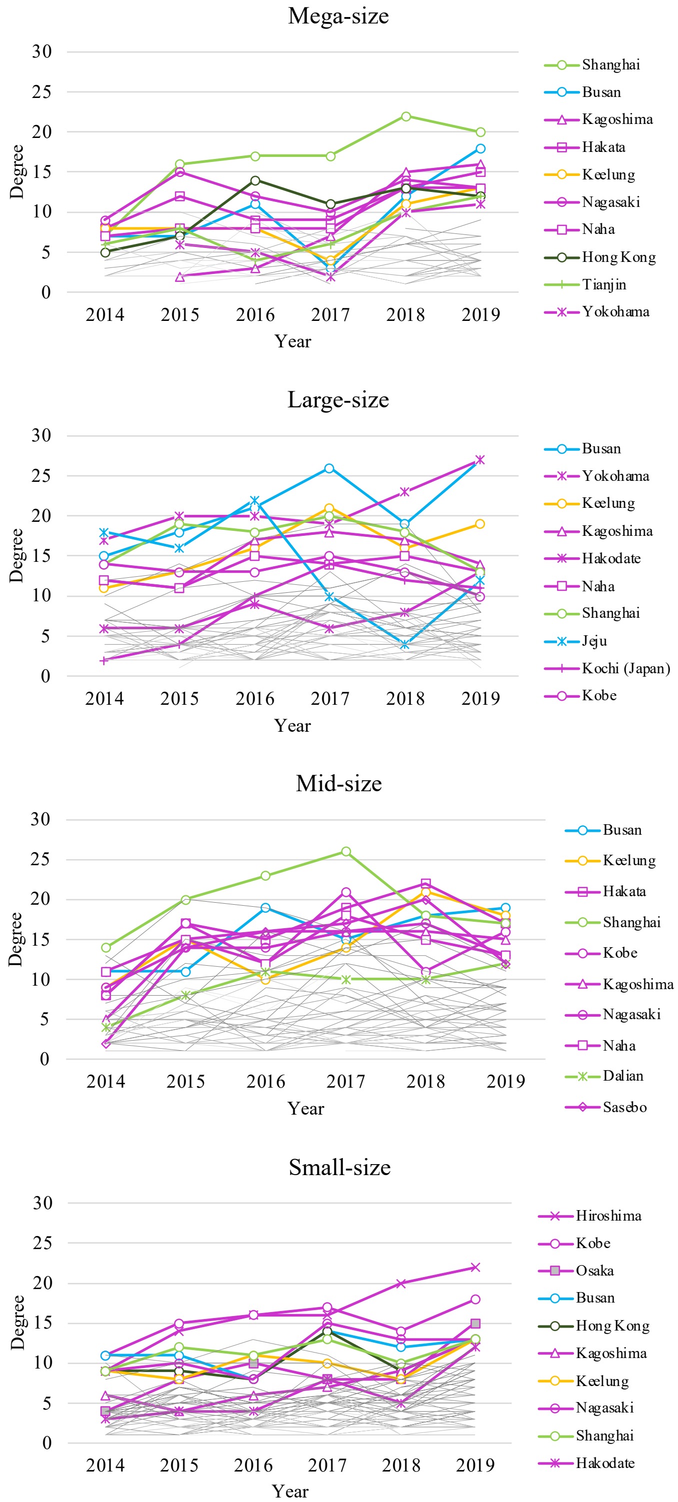

Figure 4-7 Degree centrality

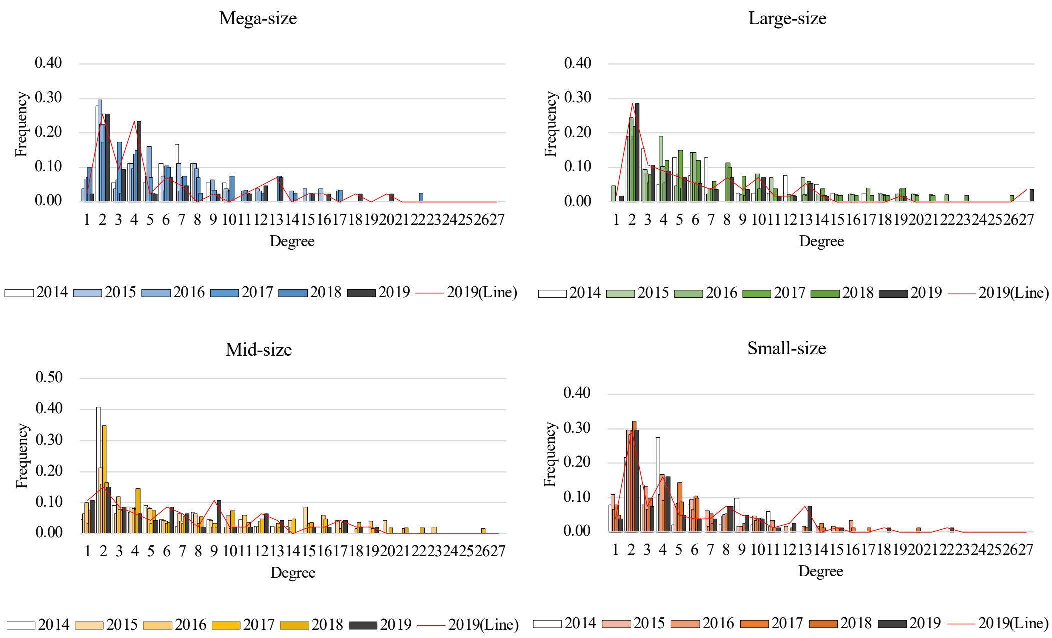

Figure 4-8 Degree distribution

Figure 4-9 using a measure of degree centralization examines changes in network uniformity (i.e., the relative impact of higher degree hub ports) with ship size. From 2014 to 2018, the mega-size network was the highest. This is because the mega-size network means a heterogeneous network with some huge hub ports versus some that were not. The large-size network was on a gradual but upward trend. However, it declined from 2018 onward, with large-size having the highest values in 2019. Mid-size was on an upward trend until 2016, and it had been declining since 2017. The small-size network was at much lower levels indicating that it was more homogeneous than the other sizes.

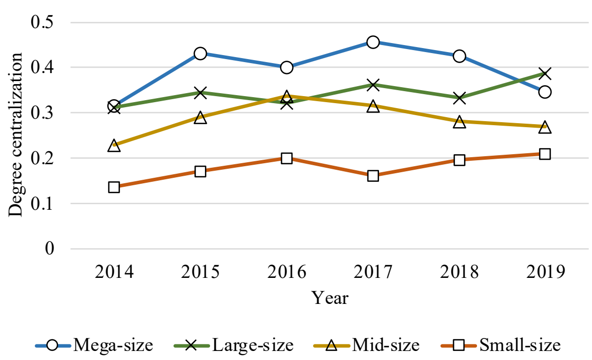

Figure 4-9 Degree centralization

4.4.3. Community detection

Using a method of community detection based on modularity optimization, spatial and temporal changes in the number of communities and geographic locations created by connections between ports by ship size were observed (Figure 4-10). The mega-size network witnessed a rapid increase in the number of communities from two to five from 2014–2019. The mega-size network had two communities in 2014, one in northern China, Japan, and Korea, and the other in southern China, Taiwan, and eastern Japan. There were four communities in 2015–2016. The community in northern Japan disappeared in 2017, reducing the number of communities to three. The community in northern Japan community again emerged in 2018, bringing the number of communities back to four. Further, Tianjin and Kyushu regions in Japan formed a separate community from Shanghai in 2018. Another community emerged in the Hong Kong and Guangzhou areas in 2019, bringing the number of communities to five.

The large-size network remained stable with four to five communities from 2014–2019. The large-size already had five communities in 2014. Unlike the mega-sized communities of the same year, these communities were geographically widespread, including northern Japan. From 2015 to 2017, the community was fixed in four communities: "northern China, western Japan, and South Korea," "southern China, Hong Kong, Taiwan, and southern Japan," "northern Japan," and "eastern Japan." However, the community in the central part of Japan split in 2018, and since then, five communities have emerged.

The mid-size, like the large-size, remained stable with four to five communities from 2014 to 2019. The location of the boundaries dividing the mid-size communities was also similar to that of the large-size. The similarity was also evident in 2018 when Jeju, located near Shanghai, left the northern Chinese community and joined the Japanese community. However, there were some differences between the mid- and large-size communities. The mid-size had more nodes in northern China (near Dalian and Qingdao), fewer nodes in northern Japan, and a new community emerged in southern China from 2016 to 2017.

The small-size community had a different structural evolution from other sized communities. The four main differences between the small size and the other sizes were the number of communities, geographic spread of nodes in the same community, location of the community boundaries, and areas where the nodes were concentrated.

First, the number of small-size communities was already five in 2014, with seven emerging in 2015. Even in 2019, there were six communities. Second, several nodes located far away from each other were connected within the same community. For example, one of the communities in 2014 (in orange) was characterized by the geographic breadth of the community, with a node in northern Japan and a node in southern China belonging to the same community. Third, other than the small size network, there were two distinct communities, one centered in Shanghai and the other in Keelung. However, because of their small size, Shanghai and Keelung belonged to the same community in 2016, 2018, and 2019. Finally, many nodes have been continuously concentrated in the Seto Inland Sea in western Japan since 2014.

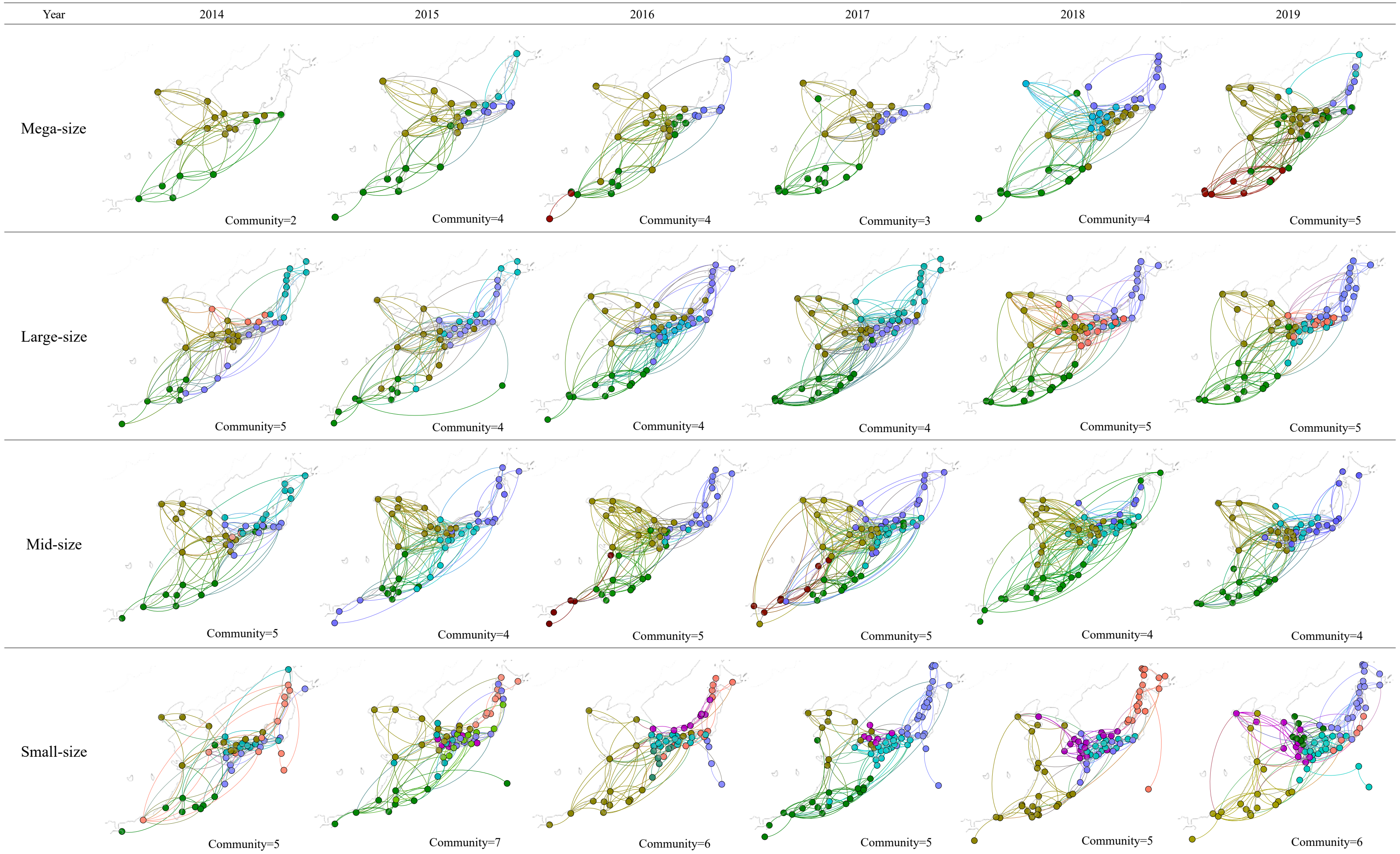

Figure 4-10 Community detection

Note: Nodes of the same color belong to the same community.

Further analysis visualizes the differences in the way ports are connected by ship size (Figure 4-11). Nodes of the same color belong to the same community. The size of each node represents its degree. The network of mega-, large-, and mid-size ships had several high-degree hubs with several smaller nodes around them, forming a “hub and spoke” structure in each community, as well as connected edges across communities. Conversely, the network of small-size ships tended to be homogeneous in the degree of each node and had the smallest value of degree centralization. The appearance of some nodes being connected with some detours between them was also consistent with the longer average shortest path lengths and diameters. In other words, the small-size network was constructed by connecting ports “side by side.”

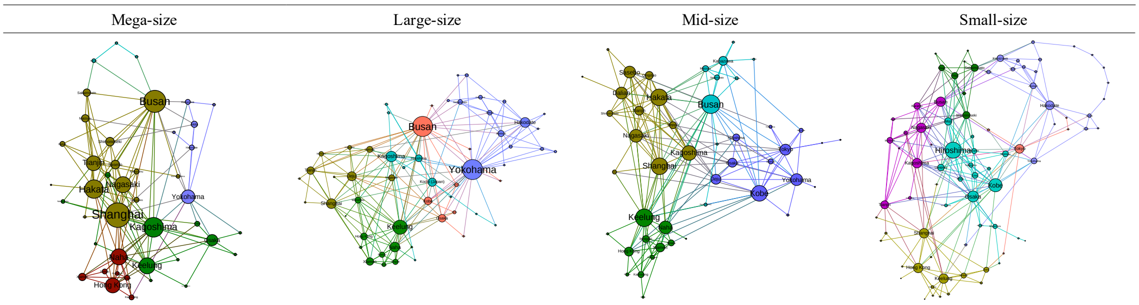

Figure 4-11 Visualizing the 2019 Northeast Asian cruise network

The quality of the network’s community partitioning by ship size was analyzed using the measure of modularity, which is shown in Figure 4-12. This implies that the cruise network increases the quality of community division over time. In addition, the modularity of the small-ship network was the highest compared with other sizes, although it has been declining since 2018. However, the lowest was the modularity of mega-ships.

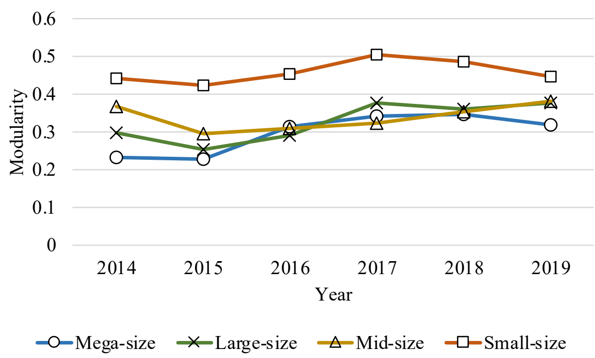

Figure 4-12 Modularity

4.5. Discussion

This chapter aimed to understand the spatial and temporal changes in the structure of the cruise network in Northeast Asia. The spatial and temporal changes in the structure of the cruise network varied with ship size. In particular, five key findings were found.

First, the number of nodes and edges in the mega- and small-sizes were growing faster than those in the other sizes in Northeast Asia. The small-size network had the highest number of nodes and edges. Generally, small ships are operated by luxury cruise lines, which target wealthy customers. Barron and Greenwood (2006) and Han and Hyun (2018) stated that the development of luxury cruise itineraries is critical to customer satisfaction. Hwang and Han (2014) and Lee and Kim (2019) stated that luxury cruise lines need to constantly offer new cruise products. As pointed out in these studies, small ships are always looking for new ports and routes, which leads to a large number of nodes and edges. Bagis and Dooms (2014) also noted that the itineraries of larger ships tend to be more fixed than those of smaller ships. The mega-sized network in this chapter may have the lowest number of nodes and edges, given the limited number of ports that can be called. Interestingly, however, the number of nodes and edges for mega- and small-size networks has been on the rise in recent years. In other words, the growth of the cruise market in Northeast Asia in recent years was accomplished by two ship sizes: mega- and small-size.

Second, the growth pattern of the small-size network differed from that of the other sizes. Specifically, the small size grew uniquely, with low network density and an average clustering coefficient but a high average shortest path length and diameter. The low density is due to the rapid increase in the number of nodes. Also, the low average clustering coefficient is due to longer duration itineraries than other ship sizes, which results in fewer triangular routes. Furthermore, the high average shortest path length and diameter may be because there are fewer “hub and spoke” connections, and there are many patterns in which ports are connected “side by side” compared with other ship sizes.

Third, hub ports differed depending on the size of the ship. In 2019, the mega-size hub was Shanghai; the large-size ones were Busan and Yokohama; the mid-size ones were Busan and Keelung; the small-size ones were Hiroshima and Kobe. The mega- and small-size ship’s hubs remain unchanged, while the large- and mid-size ship’s hubs were gradually replaced. In terms of port calls to peripheral ports, mainly hub ports, the mega-, and mid-size networks were mainly to ports in the vicinity of Shanghai, Busan, and Keelung, which are closer together. Meanwhile, the large- and small-size networks were growing, with cruise ships operating over a wide area from northern Japan to southern China. Furthermore, as for the homogeneity of the network for hub ports, the small-size network was growing in a more homogeneous state than those of other sizes.

Fourth, Shanghai was a mega-size hub port. Shanghai was a hub port for large- and mid-size networks until 2017; however, since 2018, Shanghai was no longer a hub port due to its rapidly decreasing degree centrality. At the time, many of the major cruise lines were the first to deploy their new mega-ships to Shanghai to target the rapidly growing number of Chinese cruise passengers. This resulted in the existing large- and mid-size ships in Shanghai being displaced by the new mega-size ships and shifted to Keelung, Hong Kong, Yokohama, and other ports. In the case of Princess Cruises, the deployment of the mega-size ship MAJESTIC PRINCESS to Shanghai in 2017 shifted the existing large-size ship, SAPPHIRE PRINCESS, from Shanghai to Keelung. As a result, Shanghai was a hub port in the mega-ship network, but it significantly reduced the number of degrees for large- and mid-size ships. This reflects the cruise lines' port selection behavior of launching large- or mid-size ships in the early stages of the cruise market and then replacing them with mega-size ships when they are convinced that there is sufficient passenger demand in that port.

Finally, modularity increased for all sizes, which indicates that the community structure has become clearer over time. Moreover, the small-ship network had more communities and different boundaries than the other sizes. The number of mega-, large-, and mid-size ship communities was approximately four to five. On the contrary, only the small-ship network had seven communities in 2015 and six in 2019. Many communities were located in Japan, and the boundaries between the communities differed from other ship sizes. Unlike other sizes, in 2016, 2018, and 2019, small-ship networks had Shanghai in the same community as Hong Kong and Keelung, and many ports were concentrated around the Seto Inland Sea in Japan.

Our findings allow for a deeper analysis to clarify the structural changes in the cruise network by considering the following data limitations. First, AIS data show the movement of cruise ships but do not distinguish between arrival/departure ports and ports of call. Therefore, this chapter could not analyze the data on an itinerary basis.

Second, AIS data do not provide the number of cruise passengers per route (edge). Ideally, if a network diagram could depict not only the movement of cruise ships but also the movement of cruise passengers, the process of evolution of the relationship between supply and demand could be analyzed.

4.6. Chapter conclusion

In summary, by using AIS data and some network science methods, the spatial and temporal structure of the cruise network were determined through observations of changes over time by ship size. The results from these data highlight the spatial and temporal structure of the cruise network by ship size.

The mega-size ships choose Shanghai as their hub port and connect with nearby ports. Over time, they formed a network of "hub and spoke." The number of nodes and edges is small compared with other ship sizes, but that number has been growing rapidly in recent years. This indicates that the development of ports in Northeast Asia has eliminated restrictions on port facilities, passenger handling, and other factors. Cruises, one of the tourism products, are supply-driven (Vogel and Oschmann, 2012; Rodrigue and Notteboom, 2013). Future development of the cruise market for mega-ships in Northeast Asia will require synchronization of port development and deployment of cruise ships by cruise lines.

Conversely, large-size ships used to have Shanghai and Jeju as their hub ports. However, since 2017, they have shifted to Busan and Yokohama, which is characterized by frequent changes in hub ports. Large-size ships operate over a wider area throughout Northeast Asia than mega-size ships. Similarly, mid-size ships were characterized by a shift from Shanghai and Jeju as hub ports to Busan and Keelung after 2017. To add, the impact of the deployment of new mega-size ships in Shanghai led to the replacement of hub ports within each network as existing large and mid-size ships were pushed out. This indicates that countries and ports need to closely monitor cruise ship deployment behavior by major cruise lines such as Royal Caribbean Cruises, Costa Cruises, MSC Cruises, and Princess Cruise Lines, which own three sizes of ships: mega-, large-, and mid-size ships.

Small-size ships have unique operational and commercial port selection characteristics. In the network of small-size ships, the Japanese ports of Hiroshima and Kobe became hub ports and grew higher over time. In addition, the number of nodes and edges in the small-size network is higher than for other ship sizes and has been increasing in recent years. This indicates that luxury cruise lines operating small ships are successfully developing new ports and routes to improve customer satisfaction. Furthermore, small-size cruise ships operate on a side-by-side rather than the hub-and-spoke connection found on other ship sizes.

More specifically, the increasing trend in the number of nodes and edges was observed not only for small-size ships but also for mega-size ships, which indicates that the cruise market in Northeast Asia has been diversifying in recent years. Further development of ports where small-size ships can call at ports of call and tourist attractions should be further promoted, especially in Japan. Furthermore, it is necessary to create a market where not only small-size ships but also mega-, large-, and mid-size ships operate. This situation will help customers with diverse needs to choose their favorite cruise ship category. The government, ports, and cruise lines need to work together to diversify the cruise market.

Moreover, one characteristic of all ship sizes is the sudden disappearance of Jeju from the network in 2018. This phenomenon might be related to the Terminal High Altitude Area Defense missile (THAAD) event in March 2017. China banned group travel to South Korea in retaliation for the planned deployment of THAAD by US forces in South Korea’s territory. This event hugely impacted the entire Korean cruise tourism industry (Park, 2019). Since then, all cruise ships from China to South Korea have stopped. This suggests that the cruise network is fragile and is affected by a variety of factors. Given such vulnerability, governments need to actively promote cross-border cooperation among ports. Specifically, ports must be prepared in advance to provide backup in the event of an emergency, and a system must be established to ensure that cruise ship operations do not come to a halt in the event of an emergency.

There are three challenges for future studies. The first is to expand the target cruise area from Northeast Asia to the world to clarify the geographical differences in the structural changes of the cruise network. The second is to conduct a more detailed analysis of units (e.g., monthly and quarterly) to show the seasonal differences in the structural changes of the network structure over time. The third is to understand the structure of connections between nodes based on their spatial characteristics, analyze the evolution process of cruise networks, and apply it to future prediction models.

5. CHANGES IN THE GLOBAL CRUISE NETWORK DUE TO SEASONALITY

5.1. Introduction

Seasonality plays a key role in the cruise industry (Charlier, 1999; Charlier and McCalla, 2006). The characteristic of frequent changes in cruise ship deployment based on seasonality may not be seen in other transports. In the case of air and container transport, hubs are fixed throughout the year, based on the operator's business strategy. Conversely, because demand for tourist destinations changes with the seasons, the cruise industry may also frequently change hub ports from season to season.

Seasonality is beneficial to both the cruise line and the tourist destination. For the cruise lines, customer satisfaction will be enhanced because they can introduce their passengers to tourist destinations at the time of year when the weather is most favorable for them. The understanding of attractive tourism resources on a global scale due to seasonality also has the advantage that strategies can be drawn to further expand the cruise market. For destinations, this will also improve the image of the destination to visiting cruise passengers, who will be more likely to return for a longer stay the next time they visit.

However, seasonality is not always desirable for ports. The varying number of cruise ship calls per season exposes taxpayers to criticism for passenger terminals that are not used during off-season periods. It also creates job instability for employees in the cruise industry, as they may need to find other work during off-season periods. Understanding the spatial and temporal changes in the structure of the cruise network on a global scale will be necessary for the stability of underutilized passenger terminals and employment during off-peak periods.

A network diagram can be depicted by tracking the movement of cruise ships as they navigate between ports. The network describes the number and location of ports (nodes) that make up the cruise network and their connections (edges) due to cruise ship movements. Network structures can be measured using various network science methods, which is a powerful way to understand the structure of various networks of different types, such as technological, information, social, and biological networks (Newman, 2018). Barabási (2015) revealed that the architectures of networks that emerge in different domains of science, nature, and technology are similar and are based on the same organizational principles. If so, some network science methods could be used to analyze changes in hub port and cruise network structure due to seasonality.

The purpose of this chapter is to understand how seasonality changes in the structure of the cruise network. A case study is the global cruise network in 2019. To do so, track seasonal movements of all cruise ships in the world with AIS data (https://maritime.ihs.com) and set up network data. The spatial and temporal changes in the structure of the cruise network are measured using the number of nodes and edges, average degree, average clustering coefficient, density, and degree centralization. The number of nodes and edges indicates the number of ports and routes where the cruise ship sails. The average degree is the average number of routes (directions) at each port, and the average clustering coefficient indicates the percentage of connected partner ports that are connected. And density indicates the percentage of direct route connections to the complete graph. Furthermore, degree centralization indicates the homogeneity of the network. The change in the hub port is measured by a measure of degree centrality.

The rest of this chapter is organized as follows. Section 5-2 presents a literature review. Section 5-3 outlines methodologies such as AIS data and network structure measurement. Section 5-4 presents the results of the chapter, which is discussed in Section 5-5. Finally, the conclusions of the chapter are presented in Section 5-6.

5.2. Literature review

Several previous studies exist that have analyzed the impact of seasonality on the cruise industry. Seasonality plays a key role in the cruise industry (Charlier, 1999; Charlier and McCalla, 2006). Cruise lines are attempting to optimize the utilization of their assets year-round by repositioning to take advantage of the seasonality of cruise markets. The Caribbean is dominantly serviced during the winter while the Mediterranean experiences a summer peak season. The two markets are not functioning independently but are interconnected operationally, particularly through the repositioning of ship units to cope with variations in seasonal demand among the geographical markets. The seasonality of Alaska, Bermuda, and Canada/ New England is also evident (Rodrigue and Notteboom, 2012). The seasonality pattern of cruise destinations is not only conditioned by both weather and market demand constraints, but also by the seasonality patterns of other neighboring destination regions (Esteve-Perez and Garcia-Sanchez, 2019). The cruise ship tends to voyage in a stable temperature range of 10°C–20°C, flee the winter and catch up with the summer and spring, and mainly stay in the temperature maritime climate zone, the subtropical monsoon humid climate zone, and the Mediterranean climate zone to form several branch networks (Li *et al*., 2021).

Few studies have analyzed cruise ship networks using network science techniques. Tsiotas *et al*. (2018) showed the double role of the cruise network, which is composed of the profit-driven strategies of cruise companies and port authorities, using data from the 2013 itineraries of Costa Cruises and Mediterranean Shipping Company (MSC) Cruises in the Mediterranean cruise market. Jeon *et al*. (2019) investigated the centrality of cruise ports in the Asian cruise shipping market while proposing the hub and authority centrality metric as a directional synthesis of the hub centrality and authority centrality to explore cyclical and directional features of centrality in the cruise shipping network. In a recent cruise network study, Kanrak and Nguyen (2021) revealed that the cruise shipping network is scale-free using itinerary data from Asian and Australian cruise network websites. Lopez Rodriguez *et al*. (2021) suggested that Caribbean ports are the most important for hub and authority centrality, using 2018 itineraries for each cruise line from the sites of 902 ports in the Caribbean and Northern Europe.

Moreover, few studies have used AIS data for analysis in cruise shipping. Tichavska and Tovar (2015) used AIS data to measure the pollution status of exhaust gas from cruise ships calling at the Las Palmas Port in the Canary Islands. Vicente-Cera *et al*. (2019, 2020a) arranged the cruise ship's operating hours, repair times, and berthing times, estimated seawater pollution status by cruise ships, and assessed environmental pressures related to global cruise traffic along their paths based on AIS data. Vicente-Cera *et al*. (2020b) used AIS data to aggregate cruise ship calling patterns at European ports and evaluated the diversity of cruise ship calls at each port. Ito *et al*. (2020) organized the port call patterns before and after the suspension of cruise ship operations owing to the coronavirus disease 2019 pandemic and analyzed the relationship between cruise ship operations and the spread of infection at the port of call using AIS data.

To the best of our knowledge, no network science approach using AIS data has elucidated the spatial and temporal changes in the structure of the cruise network over the seasons. In particular, no previous studies have focused on markets around the world, not just major markets such as the Caribbean and Mediterranean, or changes in hub ports, network structure, and cruise ship travel distances.

5.3. Methodology

5.3.1. Data

AIS data on ports of arrival for all cruise ships worldwide in 2019 is used. The division by the size of the cruise ship followed the classification criteria of CLIA Asia (2019). The classification criteria are as follows.

- Mega-size: Lower berth capacity of 3,500 or more OR GRT over 150,000
- Large-size: Lower berth capacity of 2,000 to 3500 AND GRT over 75,000
- Mid-size: Lower berth capacity of 750 to 2,000 passengers
- Small-size: Lower berth capacity under 750 passengers (*including Expedition ships)

5.3.2. Network structure measurement

The network is analyzed with an undirected graph and an unweighted graph. Network analysis and visualization were conducted using Gephi (the open graph Viz platform).

A network is made up of components called nodes and direct connections between them called edges. An average degree is denoted by $\langle k \rangle$. An average degree is a number obtained by dividing the total degree k_i of node $i$by the number of nodes n.

$$\langle k \rangle = \frac{1}{n}\sum_{i=1}^{n} k_i \tag{1}$$

The clustering coefficient of a node is the fraction of pairs of neighbors of the node connected. The clustering coefficient C_i of node i is defined as follows: $\tau(i)$ is the number of triangles involved in i. The maximum possible number of triangles for i is the number of pairs formed by its k_i neighbors. C_i is defined only if the degree $k_i > 1$ because of the terms k_i and $k_i - 1$ in the denominator. A node must have at least two neighbors for any triangle to be possible.

$$C_i = \frac{2\tau(i)}{k_i(k_i - 1)} \tag{2}$$

The clustering coefficient of the entire network is the average clustering coefficient C, which is used to understand the formation of the triangular route. The formula is as follows:

$$C = \frac{1}{n}\sum_{i=1}^{n} C_i \tag{3}$$

The density is the ratio of the actual number of edges to the number of all possible edges in a graph. It is used to analyze the network's connectivity level. If the number of nodes is n and the number of edges is m, the network density d is given as follows:

$$d = \frac{2m}{n(n-1)} \tag{4}$$

Degree centralization C_D measures are based on a normalized variance in the degree centrality to compare distinct networks based on their highest degree centralization scores (Freeman, 1979; Krnc and Škrekovski, 2020). It can measure whether the degree is biased toward a high node in the network. k_{max} is the highest degree centrality in the network. k_i denotes the degree of node i. The more concentrated the network, the less homogeneous it is:

$$C_D = \frac{\sum_{i=1}^{n}(k_{max} - k_i)}{\max \sum_{i=1}^{n}(k_{max} - k_i)} \tag{5}$$

Degree centrality k_i is assumed to be centered on a node with a higher degree among the nodes in the network. Hub ports are detected with degree centrality. the degree of node i by k_i is denoted. If the adjacency matrix of a network with n nodes is a_{ij}, then degree centrality can be formulated as follows:

$$k_i = \sum_{j=1}^{n} a_{ij} = \sum_{j=1}^{n} a_{ji} \tag{6}$$

Table 5-1 Interpretation of network indicators from the cruise industry perspective

Indicators	Meaning of indicators	Network characteristics	Cruise lines' port selection behavior
Number of nodes	Number of ports where cruise ships have called	The higher the number of nodes, the more developed and diversified the network of ports of call.	A higher number of nodes indicates characteristics that promote the development of new ports.
Number of edges	Number of cruise ship routes navigated between ports	The higher the number of edges, the more developed (multidirectional) the route is in the network.	A high edge number indicates characteristics that promote the creation of a new route.
Average degree	Number of shipping routes per port (number of directions)	The higher the average degree, the more routes are served per port and the denser the network. (multidirectional shipping routes)	A high average degree indicates the characteristic of developing routes to various directions with the base port as the axis.
Average clustering coefficient	The ratio of ports that have shipping routes to and from one port to another.	The higher the average cluster coefficient, the more triangular the network (i.e., a product consisting of an arrival and departure port and two ports of call), or a network with many routes that are not connected but are triangulated.	Characteristics of (changes in) shipping routes in a given network, such as whether a shipper's itinerary is open or closed, longer or shorter in days, etc.
Density	The ratio of the actual number of shipping routes to the number of possible connections between ports	The higher the density, the higher the percentage of development of shipping routes is in the network. If the development of shipping routes is more advanced than the development of ports, density will be higher. (Progress in the development of new shipping routes by shipping lines)	If the density is high, new ports may not be developed and itineraries (combinations of ports of call) may become rutted.
Degree centralization	The ratio of degrees biased toward the port with the highest degree	Networks with a higher degree centralization are more heterogeneous and biased toward the port with the highest degree (hub port).	The network as a whole can understand strategies such as whether or not a group of carriers participating in a given network is converting to a hub.
Degree centrality	Number of shipping routes connecting to the port	Ports with a higher degree centrality have more shipping connections with neighboring ports. The port is a hub port with multimodal shipping routes.	It shows which ports the shipping lines operate out of. Degree centrality can also understand the strategies of the shipping companies, such as whether or not they are promoting hubs in certain ports.

Source: Author

5.4. Results

5.4.1. Network structure

As shown in Figure 5-1, the number of nodes tended to be higher for smaller ships. The small-size ships with the highest number of nodes had an increase in the number of nodes at two different times: from April to May and from September to October. The small-size ships were positioning themselves to change areas from south to north and from north to south during these two periods. The timing of these changes in the number of nodes was generally similar for the other sizes.

Conversely, the change in the number of edges was different from the change in the number of nodes. The number of edges was higher for small-size ships in May-June and September-October, but higher for mid-size ships in July-August. July-August, when the edge numbers for mid-size ships were high, was the right time to be deployed to Alaska. The size with the lowest number of edges was the network of mega-size ships, as was the number of nodes. In summary, the number of edges was high from May to October and low from November to April, a trend common to all sizes.

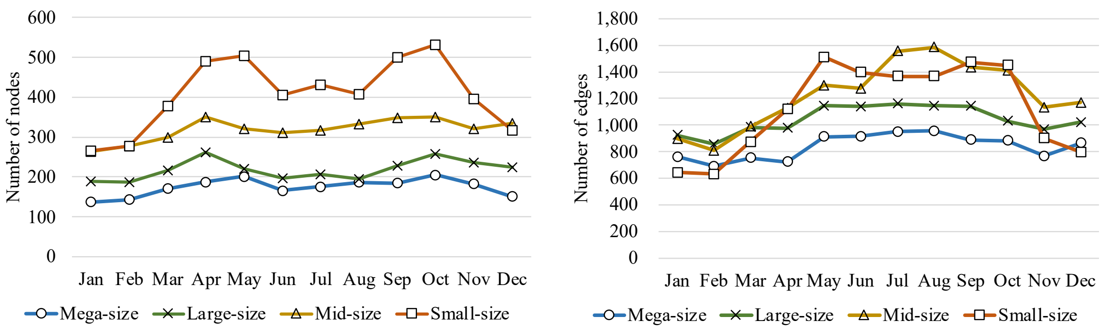

Figure 5-1 Number of nodes and edges

The average degree in Figure 5-2 was highest for mega- and large-size ships and lowest for small-size ships. This result was opposite to the number of nodes and edges. The trend of change was similar for mega- and large-size ships and similar for mid- and small-size ships. Mega- and large-size ships were lower from March to April and from October to November. During this period, they were deployed in the Caribbean and Mediterranean. Mid- and small-size ships remained high from May to around August but did not increase after December.

The average clustering coefficient was also high for mega- and large-size ships, as was the average degree. In particular, it was above 0.5 from December to January for mega-size ships. Mega-size ships were deployed only in the Caribbean during this period. Overall, the trend was high around June through September and falling around April and November.

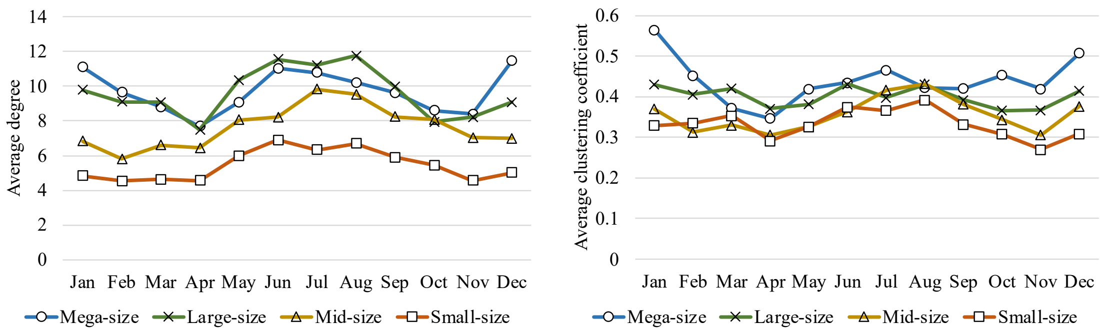

Figure 5-2 Average degree and average clustering coefficient

Similar to an average degree, density in Figure 5-3 also showed similar trends for mega- and large-size ships and similar trends for mid- and small-size ships. Mega-size ships had higher densities from December to January and June to July. Large-size ships had higher densities in January or February and June to August. From December to February, when the density of mega- and large-size ships was high, they were deployed only in the Caribbean. In addition, the density of these sizes increased again from June to August because they were deployed intensively in Alaska, the Mediterranean, and Northern Europe.

Degree centralization was higher for mega- and large-size ships and lower for mid- and small-size ships, the same as average degree, average clustering coefficient, and density, but differed in that the mega-size ship did not increase around June to August. It should be noted that the figures for mega-size ships increased from December to January and for large-size ships from May to September. The timing of the higher degree centralization for these two sizes is exactly the opposite. Degree centralization for mega-size ships was high from December to February because of the concentration of deployments in Cozumel, Miami, and Nassau. Also, degree centralization for large-size ships was high from May to September because of the concentration of deployments in Alaska.

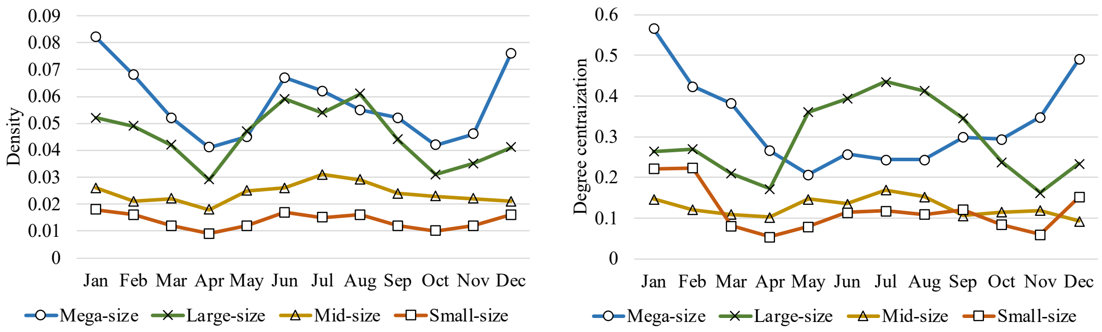

Figure 5-3 Density and degree centralization

5.4.2. Degree centrality

Figure 5-4 plots the degree centrality of mega-size ships on a world map. Ports with larger node circles indicate ports with a higher degree centrality. In other words, these ports are called hub ports. One of the characteristics of the mega-ship network is that the Caribbean has a high concentration of hub ports throughout the year. The mega-size ships were deployed in the Caribbean and South America from December to March, only in the Caribbean and Mediterranean in April, in Alaska and Northeast Asia from May, and back to only the Caribbean and the Mediterranean again in October. No cruise ships were crossing the Atlantic between June and August.

Large ships changed their deployment areas seasonally compared to mega ships (Figure 5-5). The network of large-size ships is characterized by a large variation in Caribbean degree. Caribbean degree centrality was high from November to April but contracted the rest of the year. The Mediterranean showed an increase in degree centrality from April, the Nordic and Baltic Sea were also higher from May, and then shrank from November. Another characteristic of the large-size ship network is the movement around Alaska. Alaska's degree centrality was high only during the five months from May to September. In addition, degree centrality around Sydney, Australia, and New Zealand was high for six months from November to April. Large ships were moving east to west from March to April and October. No cruise ships were crossing the Atlantic between June and September.

The mid-size network tended to have a higher degree around Northern Europe, such as the Baltic Sea, the Scandinavian, and the Mediterranean Sea (Figure 5-6). These regions were highly degree-centric for the nine months from April to December. Conversely, the Caribbean had a high degree centrality for the six months from October to March, the opposite of the Mediterranean. From June to September, degree centrality around Alaska also increased, but the numbers were lower than those for large-size ships. Another characteristic is that the smaller degrees are scattered over a wider area than those of mega- and large-size ships. For example, numerous small degrees can be found in South America, Africa, Australia, and Asia. Mid-size ships were moving east to west from February to March and November to December. The north-south movement was in January and November-December. No ships were crossing the Atlantic in July and August.

The network of small-size ships changed their deployment areas significantly depending on the season (Figure 5-7). The highest degree centrality ports were concentrated in Northern Europe, such as the Mediterranean, the Baltic Sea, and the Scandinavian. Although these areas have degrees all year round, degree centrality was high during the eight months from April to November. In particular, around Scandinavia, despite the cooler temperatures in the region, the degree was also present in the winter months of December through March. The characteristic of the small-size ship network is the high number of degrees in the Panama Canal during the five months from November to March. Since the Panama Canal is intended for crossings between the Pacific and Atlantic Oceans, many small cruise ships are likely engaging in what is known as positioning, changing their deployment areas during this period. Another characteristic of the small-size ship network is the movement of ships from October to November. Several edges can be seen crossing from north to south in October. Then, in November, a sudden high degree centrality appeared around Ushuaia (for Antarctic cruises), Argentina, and the tip of South America. In both time and region, there was a high degree centrality in Australia from December to March, followed by a shift in the center of degree centrality to around Southeast Asia in March. Furthermore, from April to May thereafter, the degree centrality in Northeast Asia around Japan increased. This means that the small ship group was gradually moving northward during the period from December to May. East-west movements of small-size ships were from February to March, while north-south movements were from April and from October to December.

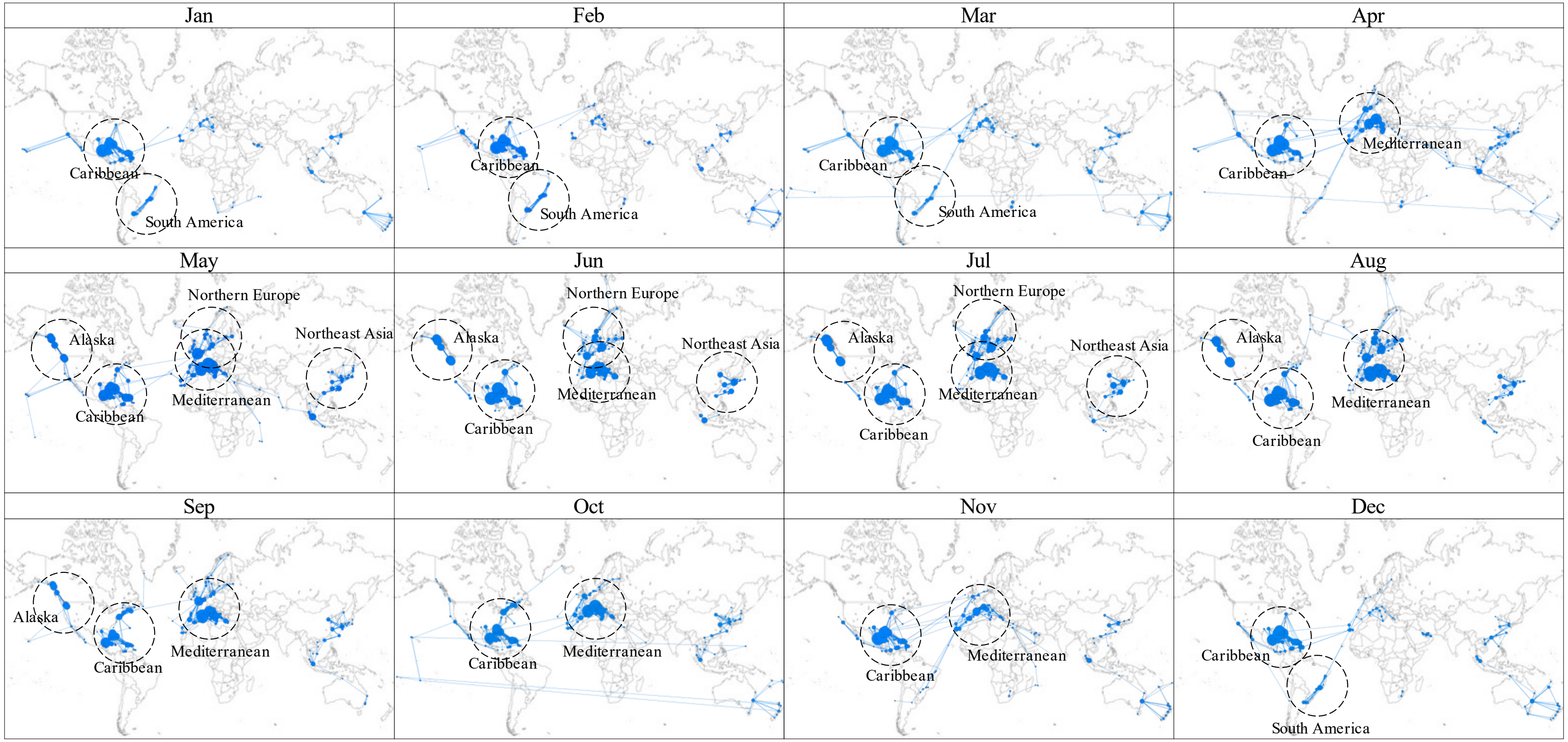

Figure 5-4 Degree centrality (Mega-size)

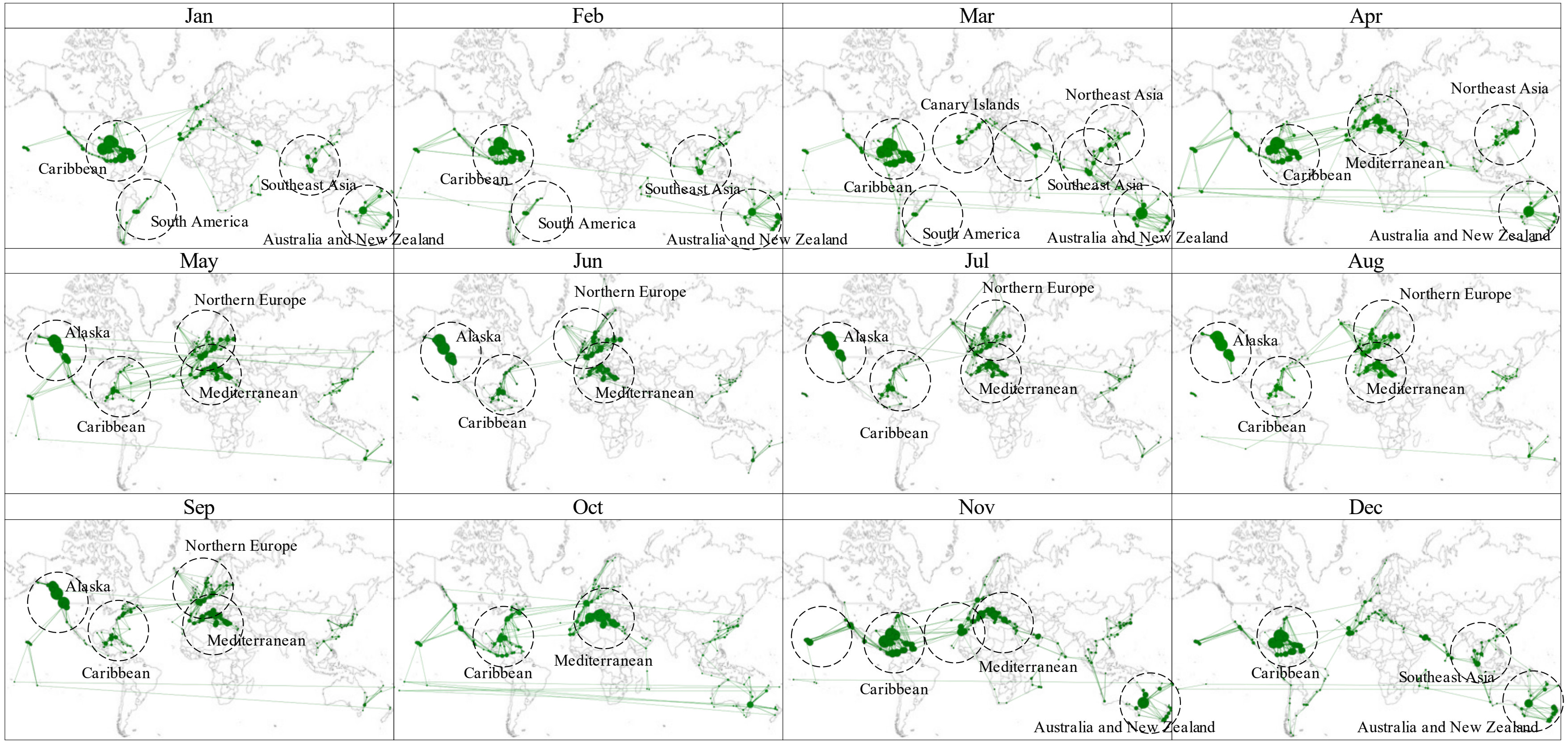

Figure 5-5 Degree centrality (Large-size)

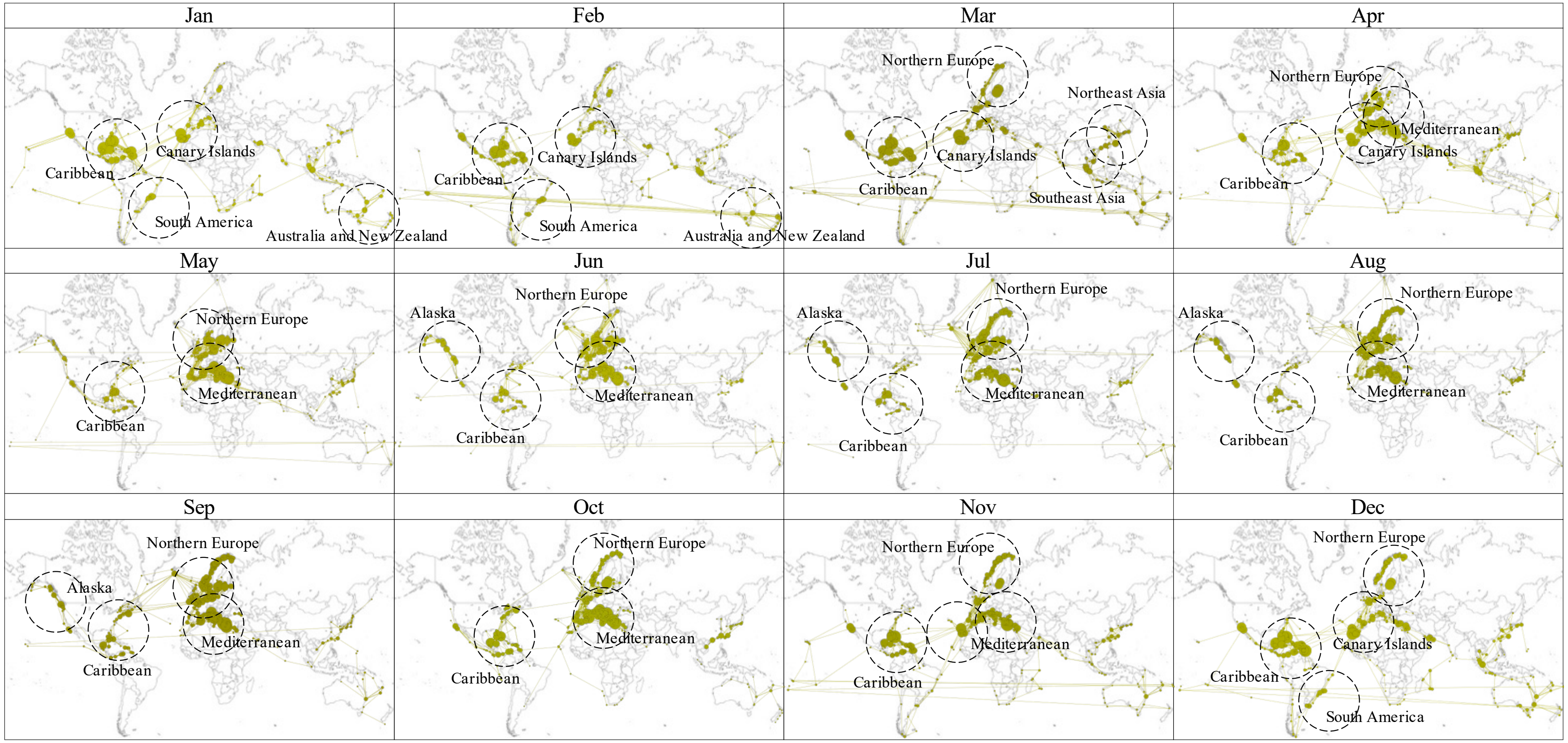

Figure 5-6 Degree centrality (Mid-size)

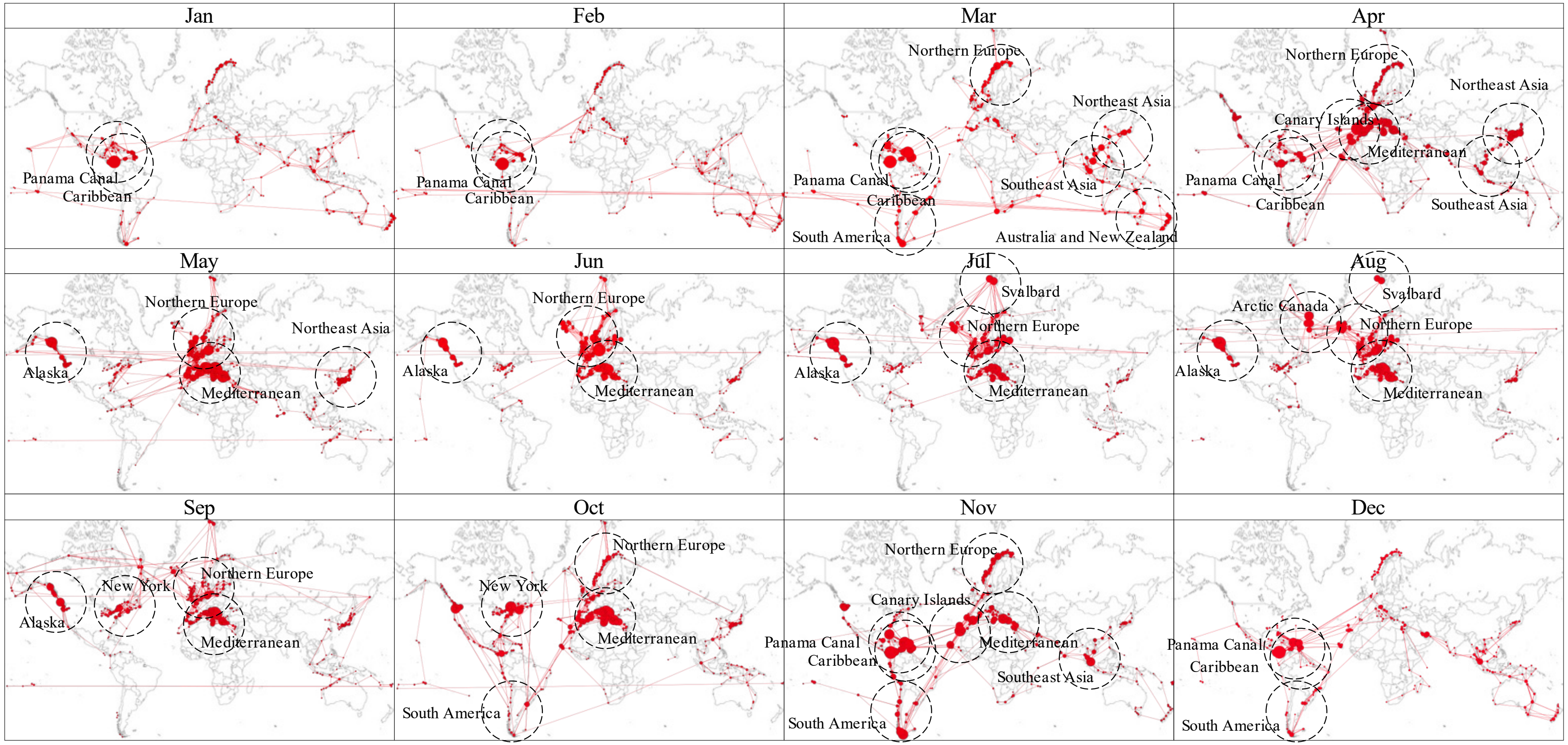

Figure 5-7 Degree centrality (Small-size)

5.4.3. Seasonal variation in the degree

Seasonality could lead to frequent changes in hub ports. Figure 5-8 shows the 50 ports with the highest annual total number of monthly degrees by ship size. The darker colored areas indicate periods of high degree, and the white areas indicate periods of no port calls. Most of the top ports for mega-size ships tended to have high degrees throughout the year, and mid-size ships tended to be similar. Conversely, the top-ranked ports for large- and small-size ships had low degrees or no port calls at certain times of the year. In other words, these networks vary widely with seasonality.

Hub ports for the mega-size network were mainly Caribbean ports such as Cozumel, Miami, Nassau, Port Canaveral, Port Everglades, Philipsburg, and San Juan, and Mediterranean ports such as Barcelona, Genoa, and Civitavecchia. These ports continued to operate cruise ships throughout the year, but the Caribbean ports had higher degrees from November through March, while the Mediterranean ports had higher degrees from April through October.

Hub ports for the large-size network were also Caribbean ports such as Nassau, Miami, Cozumel, Key West, Port Everglades, and Alaskan ports such as Ketchikan, Juneau, Skagway, and Campbell River (Canada). Sydney (Australia) was also a hub port with cruise ship calls year-round. While these Caribbean ports had cruise ship calls year-round, the Alaskan ports only had cruise ship calls for six months, from May to October.

Hub ports for the mid-size network were Stockholm in the Baltic Sea; Piraeus, Mykonos, and Heraklion in the Aegean Sea; Barcelona and Palma in the Mediterranean Sea; Cozumel, Freeport (Bahamas), Nassau, and Miami in the Caribbean Sea. The mid-size network was similar to the mega-size with many ports with cruise ship calls all year round. Characteristically, Aegean hub ports such as Piraeus, Mykonos, and Heraklion had high degrees around April to November.

Hub ports for the small-sized network were extensive, including Split and Dubrovnik on the Adriatic, the Panama Canal, Piraeus on the Aegean, Juneau in Alaska, Civitavecchia, and Valletta in the Mediterranean, and Kiel and Tromso in Northern Europe. Split and Dubrovnik in the Adriatic and Piraeus in the Aegean, Civitavecchia, and Valletta in the Mediterranean from April to October, the Panama Canal from October to April, Juneau in Alaska and Kiel and Tromso from May to September had a higher degree. The small-size network was characterized by many ports with large seasonal degree fluctuations.

#	Port	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	Cozumel	87	69	73	56	43	53	50	55	50	56	71	75	738
2	Miami	65	58	51	52	46	43	50	48	42	43	66	84	648
3	Nassau	59	49	64	57	44	48	48	52	35	39	36	72	603
4	Port Canaveral	50	43	59	52	30	52	42	39	35	46	32	63	543
5	Barcelona	17	15	22	45	50	42	43	55	64	65	42	14	474
6	Genoa	13	12	23	50	49	39	39	37	54	68	32	11	427
7	Civitavecchia		6	9	22	50	41	53	54	45	52	24	11	367
8	Port Everglades	43	38	45	30	20	19	17	10	11	20	45	64	362
9	Philipsburg	45	43	37	18	29	27	27	23	13	23	26	32	343
10	San Juan	15	19	23	23	31	36	31	37	24	37	25	40	341
11	Georgetown (Cayman Is)	42	35	29	27	22	28	23	27	20	28	31	27	339
12	St Thomas	35	34	23	22	30	25	24	19	16	32	28	41	329
13	Palma	8	8	9	24	36	40	42	52	46	39	16	2	322
14	Savona-Vado	12	12	15	32	36	27	23	23	35	40	23	5	283
15	Southampton	1	5	10	24	45	31	35	39	44	25	16	6	281
16	Singapore	22	20	22	23	26	22	14	16	19	17	24	20	245
17	New York & New Jersey	11	12	18	20	18	24	19	23	29	32	20	16	242
18	Naples	3		4	24	32	31	37	32	32	36	8		239
19	Marseille	9	7	11	24	23	25	25	25	20	8	14	5	196
20	Shanghai	23	16	7	10	13	19	25	18	17	20	18	10	196
21	Basseterre	32	29	29	12	13	10	7	6	5	9	11	24	187
22	Long Beach	20	26	21	19	10	8	8	7	6	14	16	20	175
23	Belize City	27	19	10	13	15	14	16	11	9	11	14	15	174
24	Hakata	12	11	12	10	13	26	23	20	18	11	11	6	173
25	Juneau				2	30	34	41	32	33	1			173
26	Palermo	16	14	14	16	14	16	20	17	17	16	5	8	173
27	New Orleans	21	16	16	8	12	14	11	11	13	15	18	17	172
28	Skagway				1	27	35	39	37	31	2			172
29	Victoria (Canada)					27	34	32	38	30	4			165
30	Willemstad	25	15	12	11	13	10	11	10	8	9	19	22	165
31	Seattle				2	26	33	35	35	30	3			164
32	La Spezia				6	22	22	28	25	23	18	4	3	151
33	Oranjestad (Aruba)	23	13	13	11	10	7	10	9	7	9	20	18	150
34	St John's (Antigua)	36	23	25	4	2	4	4	2	4	8	13	22	147
35	Naha	6	7	7	10	20	20	20	16	11	10	9	9	145
36	Copenhagen				2	17	33	36	31	16	7			142
37	Piraeus				2	11	24	20	26	22	18	14	3	140
38	Ketchikan				2	24	27	28	27	23	2			133
39	Castries	23	13	16	5	4	4	4	4	4	8	18	27	130
40	Valletta	8	8	10	20	16	8	9	9	9	17	7	7	128
41	Sydney (Australia)	18	20	19	6					6	12	21	25	127
42	Bridgetown	23	17	15	6	3	4	4	4	4	6	15	25	126
43	Hong Kong	4	4	12	13	12	10	10	12	13	9	9	18	126
44	Johor	10	9	9	12	14	11	9	11	11	9	14	7	126
45	Nagasaki	12	5	12	11	6	21	10	7	5	10	14	11	124
46	Puerto Progreso	14	9	7	9	7	8	11	8	9	14	12	14	122
47	Great Stirrup Cay	4	8	5	8	7	10	12	10	8	6	24	17	119
48	Santa Cruz de Tenerife	10	8	14	17	6		2	2	8	10	23	16	116
49	Tianjin		2	9	7	2	20	16	18	16	14	9	1	114
50	Livorno				2	14	17	14	21	18	21	6		113

#	Port	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	Nassau	48	47	46	39	20	37	40	33	23	29	39	52	453
2	Miami	54	46	43	52	29	28	25	20	25	32	34	53	441
3	Ketchikan					75	88	95	91	88	2			439
4	Juneau					89	76	100	85	71	4			425
5	Cozumel	56	46	51	38	20	21	25	25	27	16	46	53	424
6	Skagway					71	85	82	85	59	2			384
7	Key West	45	42	36	42	20	23	24	23	29	32	29	34	379
8	Port Everglades	59	59	54	45	2	9	9	8	7	16	46	61	375
9	Sydney (Australia)	36	36	51	44	21	20	8	16	16	33	42	39	362
10	Campbell River					49	75	72	72	82	4			354
11	Civitavecchia				25	50	34	42	48	47	69	32	6	353
12	Barcelona	14	10	15	26	37	23	26	26	33	54	31	8	303
13	Piraeus	4			26	36	27	32	35	37	40	22	9	268
14	Southampton	12			12	32	33	32	39	43	33	18	13	267
15	Victoria (Canada)				3	45	55	50	50	43	9			255
16	Georgetown (Cayman Is)	31	30	36	22	10	12	13	15	10	5	25	40	249
17	Venice	2		3	24	33	31	41	32	36	29	11	5	247
18	Valletta	3			22	31	29	27	36	33	32	8		221
19	Dubrovnik			4	21	27	30	28	26	29	31	12	6	214
20	Vancouver (Canada)				3	37	36	35	30	47	19	2		209
21	Seattle				2	31	41	44	43	36	6			203
22	Thira				7	24	32	30	34	35	32	3	1	198
23	Port Canaveral	17	14	19	23	19	17	22	20	8	16	10	12	197
24	San Juan	33	32	30	28	1	4	2	4	4	5	21	28	192
25	Naples			2	14	22	21	21	17	21	36	28	5	187
26	Cartagena (Colombia)	25	27	34	25						18	28	25	182
27	Augusta				17	24	25	20	21	31	34	7		179
28	Palma	6	4	9	12	19	19	21	20	27	20	11	6	174
29	Copenhagen				3	36	34	33	35	26	2		2	171
30	Bari	3		4	18	20	24	21	22	27	18	8	5	170
31	Willemstad	36	24	23	23		2	2		2	5	21	32	170
32	Oranjestad (Aruba)	38	26	21	21			2		2	10	20	28	168
33	Zeebrugge	8	1			43	27	18	18	31	9	7	5	167
34	Mykonos				6	28	28	17	27	25	23	7		161
35	Kralendijk	32	28	24	18					3	7	17	28	157
36	Philipsburg	29	22	33	23	4				2	8	13	23	157
37	New York & New Jersey	4	3	7	6	14	17	20	16	18	26	13	9	153
38	Hilo	10	10	10	15	16	8	9	9	13	16	23	13	152
39	Castries	30	22	32	21					1	5	22	18	151
40	Yakutat					25	34	32	36	21				148
41	Honolulu	8	14	10	13	12	9	8	9	14	17	18	14	146
42	Livorno			1	6	24	14	25	16	17	25	13	3	144
43	St John's (Antigua)	29	32	26	13	2					2	18	22	144
44	St Petersburg				2	27	34	26	39	13	2			143
45	Tallinn				2	31	34	23	37	13	3			143
46	Long Beach	15	8	19	17	8	2	3		4	26	22	16	140
47	Panama Canal	14	19	27	14		1	3			17	28	17	140
48	St Thomas	21	22	14	22	1	4	4	4	4	7	14	21	138
49	Genoa			5	12	13	13	12	13	17	26	20	4	135
50	Bridgetown	24	23	26	17						2	17	25	134

#	Port	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	Stockholm	15	15	31	10	46	37	51	46	34	38	27	27	377
2	Piraeus		6	14	42	55	37	46	40	45	47	26	13	371
3	Mykonos			8	28	54	50	63	60	45	35	16	2	361
4	Cozumel	45	39	31	18	23	24	30	30	25	32	28	34	359
5	Heraklion		2	16	33	34	39	38	39	42	41	45	13	342
6	Freeport (Bahamas)	43	26	39	38	35	23	37	24	5	19	23	23	335
7	Barcelona	14	14	20	40	37	26	27	29	25	45	33	15	325
8	Nassau	27	22	17	16	15	23	26	19	18	36	44	38	301
9	Palma	17	13	11	19	29	31	31	34	30	39	24	15	293
10	Miami	35	21	22	21	22	18	25	23	20	24	29	27	287
11	Palm Beach	31	14	27	29	27	15	31	16	4	27	31	32	284
12	Bergen	1	6	12	15	25	37	53	56	37	22	9	8	281
13	Civitavecchia			7	33	31	28	32	29	30	48	24	15	277
14	Mariehamn	13	15	31	8	26	20	27	27	24	31	27	27	276
15	Dubrovnik		2	4	22	47	39	26	43	26	45	17	4	275
16	Long Beach	30	22	24	21	21	12	22	25	16	20	25	27	265
17	Venice			2	22	43	38	25	38	37	36	16	1	258
18	Thira			4	17	34	37	42	38	34	28	16	2	252
19	Livorno	11	8	16	23	25	19	24	27	22	42	14	12	243
20	Southampton	7	5	20	29	18	27	19	31	12	20	28	21	237
21	Ensenada	25	17	22	20	15	12	22	25	11	16	23	21	229
22	Georgetown (Cayman Is)	30	27	25	15	11	14	13	14	10	23	20	22	224
23	Naples	2	4	4	16	23	29	29	34	28	30	19	6	224
24	Funchal	37	26	37	32	5	2	2	4	2	6	35	26	214
25	Rhodes			4	12	20	23	34	31	23	28	20	17	212
26	Aalesund			2	6	19	19	43	43	31	22	11	15	211
27	Stavanger	2	12	13	25	31	41	20	22	25	13	5		209
28	Key West	16	15	18	19	18	13	19	20	12	17	19	20	206
29	Philipsburg	26	18	34	13	9	8	10	8	8	12	21	29	196
30	Castries	29	21	24	16	6	8	8	10	8	10	25	28	193
31	Copenhagen				13	38	25	35	30	34	14		4	193
32	Split		2	2	13	30	29	18	26	24	28	13		185
33	Lisbon	14	6	5	23	31	13	6	15	12	28	17	13	183
34	Arrecife de Lanzarote	29	26	27	25	4	2	2	4	2	9	23	28	181
35	Bridgetown	23	16	23	13	5	9	6	9	7	12	19	36	178
36	Rostock				9	31	27	24	34	34	12		4	175
37	Tromso	2	12	17			12	23	31	25	17	24	12	175
38	Port Everglades	21	12	12	17	8	11	8	9	8	17	29	20	172
39	Dover		7	5	18	18	11	28	29	29	19	2		166
40	Santa Cruz de Tenerife	27	14	25	23	6			4	2	4	25	35	165
41	Cartagena (Colombia)	22	13	23	17	11	10	9	9	9	10	15	16	164
42	Oranjestad (Aruba)	8	9	10	11	14	10	12	15	11	21	20	19	160
43	Bari				13	23	23	15	31	27	25	2		159
44	Colon	14	18	22	10	13	11	8	11	11	12	14	12	156
45	Hamburg		7	20	28	18	13	12	7	11	14	7	13	150
46	Corfu				18	18	20	19	23	26	19	6		149
47	Las Palmas	27	16	24	16	4	2	2	2	2	9	19	26	149
48	San Juan	14	13	14	9	10	11	9	10	12	8	15	24	149
49	Willemstad	10	11	12	12	11	10	10	12	13	16	11	15	143
50	Kralendijk	9	12	8	13	13	11	12	12	12	18	12	10	142

#	Port	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	Split	3	6	9	16	46	43	44	50	66	50	3	7	343
2	Dubrovnik	2	6	9	20	34	45	41	45	53	47	3	7	312
3	Panama Canal	63	66	35	20	4	4	4	1	2	24	28	53	304
4	Piraeus	1	2	2	22	45	29	36	42	42	40	22	5	288
5	Juneau				7	39	40	57	51	34	5			233
6	Kiel			1	8	36	53	35	36	37	5			211
7	Tromso	17	13	20	10	10	19	18	12	10	20	15	10	174
8	Civitavecchia				10	35	20	15	26	19	23	6	2	156
9	Valletta		2		17	17	12	22	18	22	29	11	1	151
10	Klickitat			3	13	19	16	18	11	14	38	16		148
11	Augusta				8	24	27	20	10	16	24	11	5	145
12	Bergen	4	3	4	8	19	33	20	21	13	10	7	3	145
13	Kiel Canal			2	7	32	37	19	19	25	2	1		144
14	Nice			3	18	44	19	4	9	26	18	2		143
15	Gustavus				2	34	24	35	24	23				142
16	Campbell River				6	17	22	27	20	43	6			141
17	Malaga	1	4	7	24	24	9	7	9	12	20	20	3	140
18	Lisbon	3	1	4	31	26	12	4	4	17	22	14	1	139
19	Barcelona		1	2	14	28	16	14	12	19	22	10		138
20	Thira				5	22	17	20	27	22	17	5	2	137
21	Reykjavik			2		9	20	34	43	23	3	1		135
22	Rhodes			1	5	15	15	16	21	17	27	16	2	135
23	Philipsburg	18	19	32	11	2	2	2			2	15	28	131
24	Venice	5	8	1	5	9	15	16	15	22	13	8	11	128
25	San Juan	11	18	20	6			2			4	26	37	124
26	Singapore	16	13	15	12	7	4	1		4	9	19	23	123
27	Longyearbyen			3	6	11	15	34	27	16	8			120
28	Hamburg				3	26	17	7	20	28	10	6	2	119
29	Siracusa				6	17	18	15	6	17	27	11	1	118
30	Kobe	6	2	15	17	20	6	2	7	11	13	7	8	114
31	Monaco				5	20	21	11	25	15	14	3		114
32	Corinth Canal			1	17	8	13	11	18	20	15	9		112
33	Oban			2	10	20	19	13	24	11	13			112
34	Sitka				1	17	27	29	23	14	1			112
35	Aalesund	7	10	9	9	3	20	12	12	2	12	9	6	111
36	Copenhagen			4	1	14	16	20	34	15	7			111
37	Rovinj	5	10			9	17	16	7	19	6	8	12	109
38	St John's (Antigua)	10	16	22	8	1	2	2			4	12	30	107
39	Ketchikan				2	11	25	25	20	21	2			106
40	Gustavia	11	15	26	16							20	17	105
41	Lipari				5	24	21	9	10	17	19			105
42	Palma	2	2		11	17	14	17	7	6	24	5		105
43	Quebec					2	6	9	7	35	43	1		103
44	Gibraltar	3	5	8	11	14	7	10	9	11	18	6		102
45	Tallinn				1	7	22	30	27	12	3			102
46	Bridgetown	14	13	23	15	1		2				15	18	101
47	Genoa			3	4	32	15	8	9	15	11		4	101
48	Cadiz	1	1	2	11	8	9	9	10	18	19	10	2	100
49	Castries	16	17	17	8	2		8	2		2	10	18	100
50	Colon	22	24	10	11	3	4				6		20	100

Figure 5-8 Monthly degree of the top 50 ports with the highest degree

Seasonal changes in the degree distribution by ship size are shown in Figure 5-9. Unlike the previous figure, this figure is not limited to the top 50 ports with the highest order but covers all ports where calls were made each month by ship size. As a result, several hub ports with degrees over 70 for mega- and large-size ship networks have appeared. However, the timing of the appearance of the hub ports was exactly the opposite: the mega-size was from November to March, and the large-size was from April to September. In the mid-size and small-sized networks, hub ports with a degree of around 60 appeared, but ports with a degree of 80% or more had an order of 10 or less. Furthermore, for all sizes, the proportion of ports with a degree of 10 or less tended to decrease from June to August.

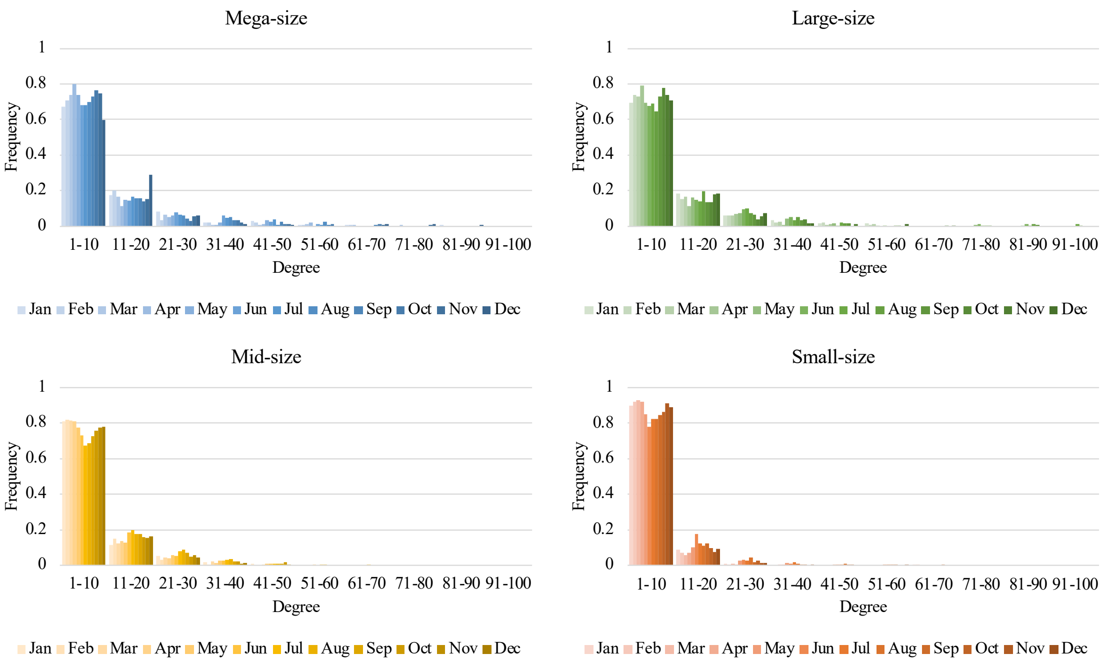

Figure 5-9 Degree distribution

Differences in the number of monthly degrees by ship size can be measured by a coefficient of variation. Figure 5-10 plots the coefficient of variation of the monthly degrees for the 50 ports with the largest annual degrees by ship size. Figure 5-8 shows the calculated coefficients of variation by ship size. As a result, the highest coefficient of variation was found in the small-size ship network, and conversely, the lowest in the mega-size ship network. In the mega-size ship network, Caribbean ports such as St John's (Antigua), Castries, and Bridgetown had high coefficients of variation. In addition, the coefficient of variation for Southampton in the UK was also high. The network of large-size ship networks had high coefficients of variation for the Caribbean ports of San Juan, Port Everglades, and Willemstad, as well as the Nordic ports of Zeebrugge and Copenhagen. The mid-size ship networks had high coefficients of variation, including the Atlantic ports of Funchal, Las Palmas, and Arrecife de Lanzarote, as well as Bergen in Northern Europe. Ports with high coefficients of variation in the network of small-size ships cover a wide area. Quebec in Canada had the highest coefficient of variation, followed by Panama Canal, Reykjavik and Lisbon in Europe, and St John's (Antigua) in the Caribbean.

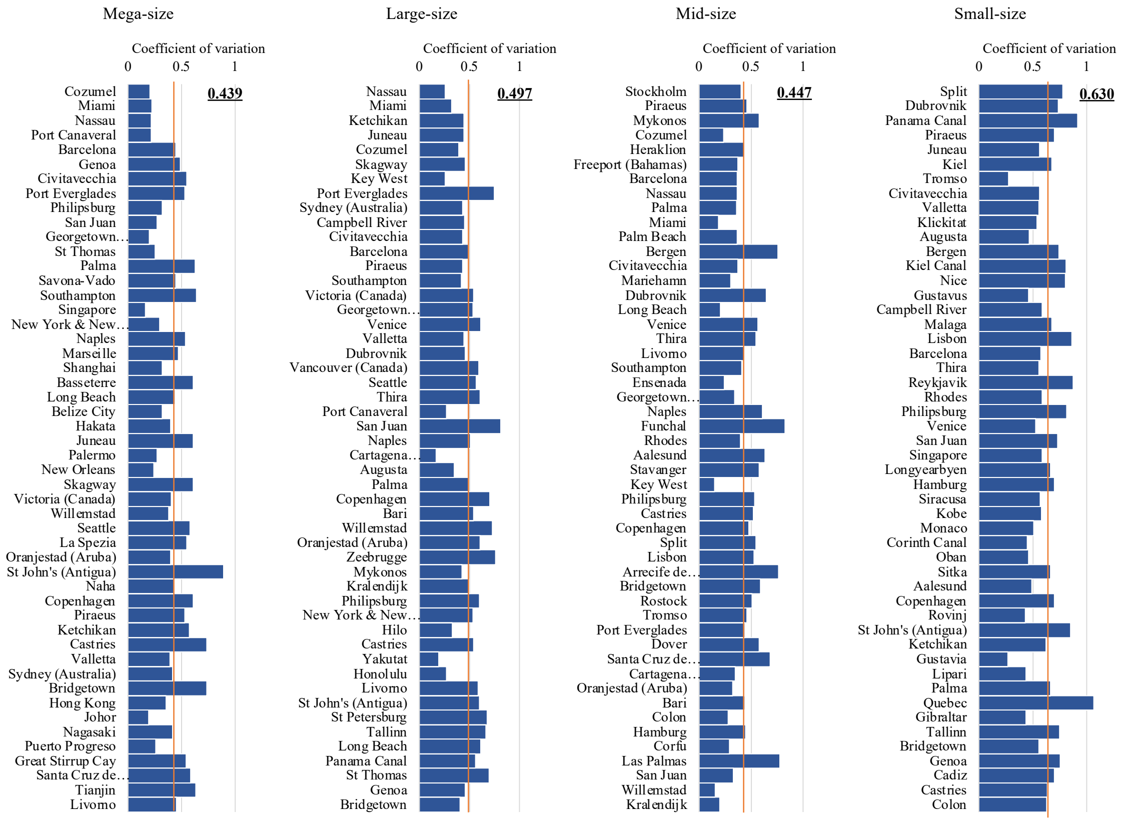

Figure 5-10 Coefficient of variation of monthly degrees for the top 50 ports

5.4.4. Seasonality of cruise ship movements

What size ship travels the furthest latitude distance throughout the year? The percentage of port calls by quarter was measured by latitude in Figure 5-11. This allows us to understand the spatial and temporal changes in the structure of the cruise network depending on the season. Note that in Figure 5-11, the north latitude is shown as a plus and the south latitude as a minus.

Mega-size ships called more frequently in the second and third quarters at higher northern latitudes, and more frequently in the first and fourth quarters as latitudes moved south. And below 30°N, the number of port calls in the first and fourth quarters exceeded the number of port calls in the second and third quarters. This trend, with 30 degrees north latitude as the boundary, was the same for large-, mid-, and small-size ships.

However, the main difference between the mega-size ships and other sizes was the percentage of the area near 80°N and near 60°S. Mega-size ships called near 80°N in the second quarter and third quarter and a half, and near 60°S only in the first quarter. Conversely, near 80°N, the large-size ships had a fourth-quarter call, while the mid and small-size ships also had a first and fourth-quarter call. Small-size ships, in particular, had a similar percentage of port calls throughout all quarters. Around 60°S, mega-size ships only had port calls in the first quarter, while large-size ships had port calls in the first and fourth quarters, and mid-size ships had port calls in the first, second, and fourth quarters as well. In addition, small-size ships had port calls throughout all quarters.

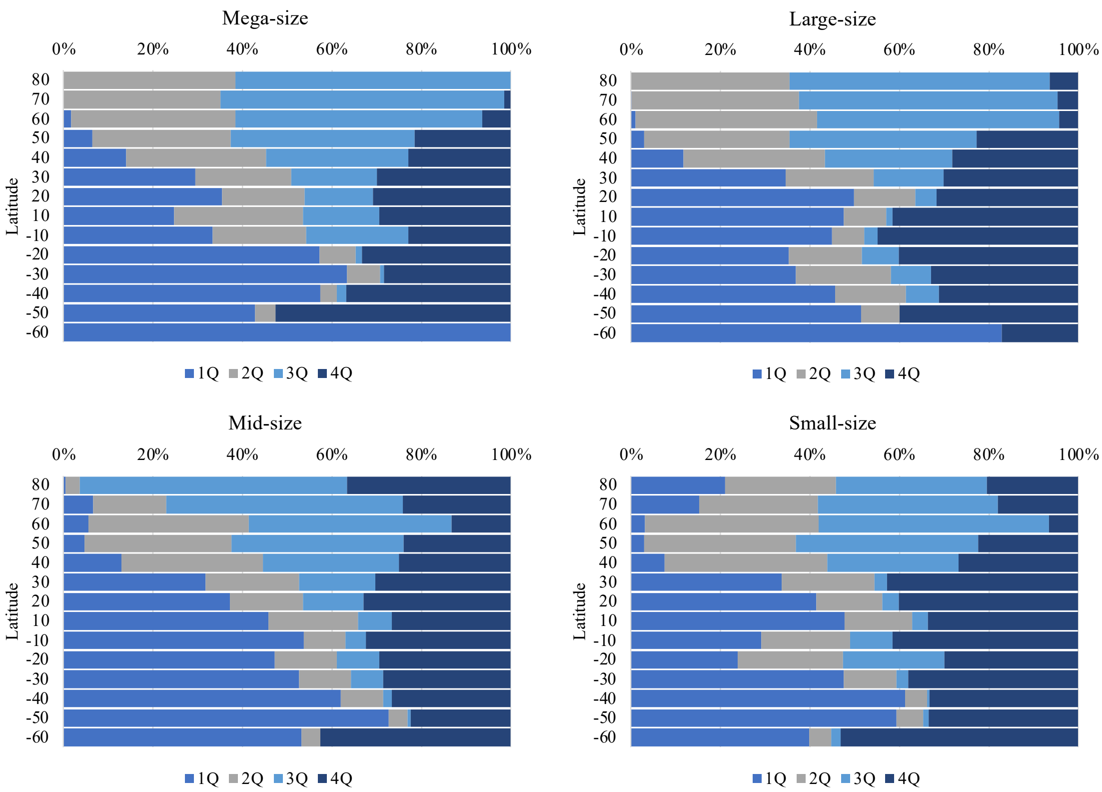

Figure 5-11 Percentage of port calls by season at each latitude

Figure 5-12 shows the distribution of travel latitude distances for each ship size throughout the year. Mega-size ships were highest at a latitude distance of 20, followed by around 50. 110 was also high. Large-size ships were highest around latitude distance

50, followed by those around 110. Mid-size ships were highest around latitude distances 10 to 20, followed by those around 130 and 70. Small-size ships were highest around latitude distance 10 and were otherwise flat. Characteristically, many of the small ships traveled long distances, as long as latitude distance 140.

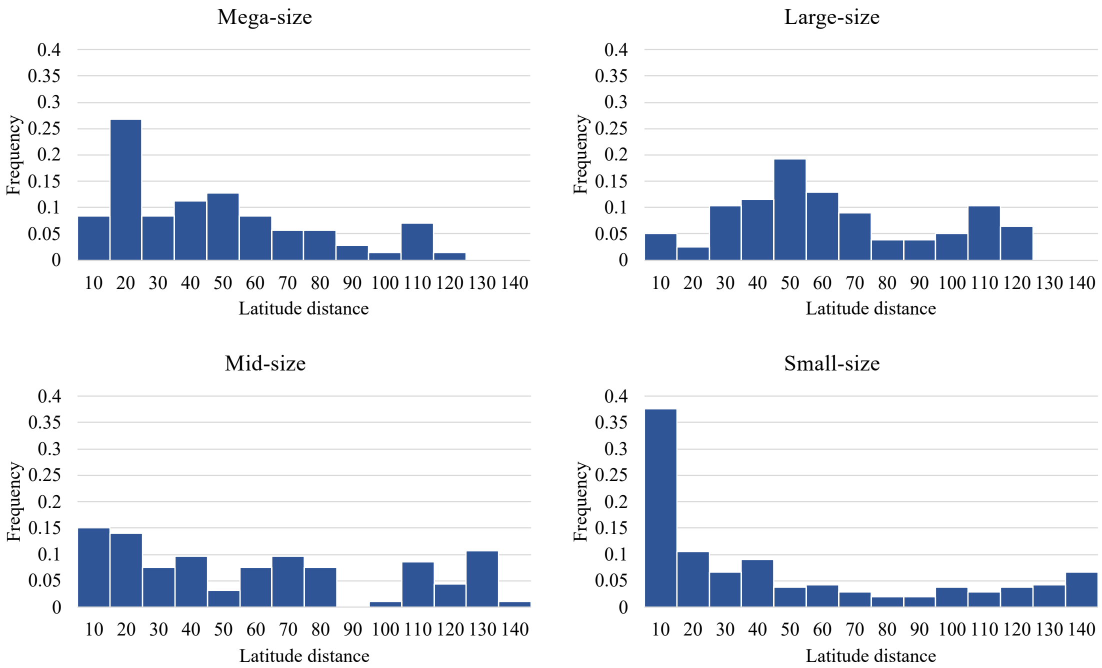

Figure 5-12 Latitude distance distribution

Figure 5-13 is a box plot showing the maximum, mean, median, 50% distribution of data (75% distribution, 25% distribution), and minimum values of latitude distance for each ship size. Maximum values were higher for small- and mid-size, but 75% distribution was higher for mid-size ships. Averages were higher for large- and mid-size ships, while mega- and small-size ships were equally low. Medians were also high for large- and mid-size ships, followed by mega-size ships, and lowest for small-size ships. 25% to 75% distributions showed that large-size ships were widely distributed, followed by small-size ships.

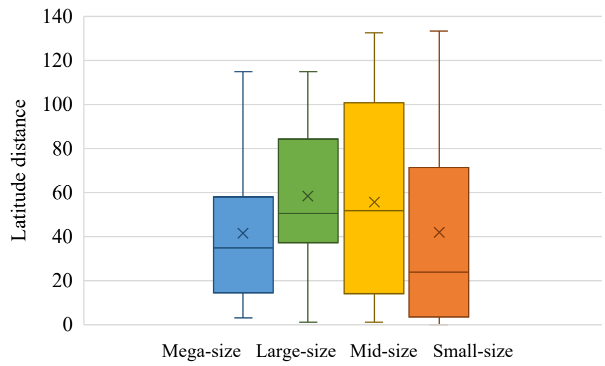

Figure 5-13 Box plot of latitude distance by ship size

5.5. Discussion

The purpose of this chapter is to understand how seasonality changes the spatial and temporal structure of the cruise network. The results of the chapter are summarized in five categories and described below.

First, the smaller the ship size, the higher the number of nodes and edges, and also the highest at the positioning (moving the deployment area) timings of April-May and September-October. This is because smaller ships have more port options due to fewer constraints on port facilities and passenger operations. Conversely, average degree, average clustering coefficient, density, and degree centralization had higher values for larger ships. This is indicative of the tendency for larger ships to have more limited ports of call and a higher degree of hub ports. Interestingly, while the average degree and average clustering coefficient and density for mega- and large-size ships were high from May to September, degree centralization for the same period was high for large-size ships, while that for mega-size ships remained low. This is due to deployment to Alaska; May through September is the best season for deployment to Alaska, with both mega- and large-size ships moving. However, some mega-size ships have a low degree centralization due to their inability to pass through the Panama Canal because of their excessive ship size (TIME, 2018). As a result, unlike large-size ships, mega-size ships cannot become hubs in Alaska's major ports. In addition, for many indicators, the timing of the figure changes from April to May and from September to October. This may be due to port selection behavior known as "positioning", where cruise ships move from one deployment area to another.

Second, hub ports did not appear only in the Caribbean or Mediterranean but varied geographically depending on the season and the size of the cruise ship. Mega-size ships had hub ports in the Caribbean, and South America (Brazil) in winter and the Mediterranean, Alaska, and Northeast Asia in summer, while large-size ships had hub ports in the Caribbean and Australia in winter and in Alaska, Northern Europe, and the Mediterranean in summer. Mid-size ships had hub ports in and around the Caribbean Sea, Canary Islands, and Scandinavia in winter and various locations in Northern Europe, the Mediterranean, Adriatic sea, Aegean seas, and Alaska in summer, while small-size ships had hub ports in the Panama Canal, South America (Argentina), and Scandinavia in winter, and to the Adriatic and Aegean Seas, Alaska, Northern Europe, Svalbard, and Arctic Canada in summer. As Rodrigue and Notteboom (2012) pointed out, the Caribbean was dominantly serviced during the winter while the Mediterranean experiences a summer peak season. This assertion was true only in the case of mega-size ships.

Table 5-2 Deployment areas in summer and winter by ship size

Ship size	Winter	Summer
Mega-	Caribbean, South America (Brazil)	Mediterranean, Alaska, Northeast Asia
Large-	Caribbean, Australia	Alaska, Northern Europe, Mediterranean
Mid-	Caribbean, Canary Islands, Scandinavia	Northern Europe, Mediterranean, Adriatic sea, Aegean seas, Alaska
Small-	Panama Canal, South America (Argentina), Scandinavia	Adriatic sea, Aegean seas, Alaska, Northern Europe, Svarbard, Arctic Canada

Third, the monthly changes in the number of degrees at hub ports in the small-size ship network varied most significantly with the seasons. It was lower for mega-size ships, followed by mid- and large-size ships, which did not fluctuate as much as small-size ships. The reason for the large fluctuations in the degree of ports for small-size ships from season to season stems from their deployment patterns, in which they move from one popular port to another seasonally, depending on the climate, rather than calling mainly at major ports, as mega- and large-size ships do. Interestingly, small-size ships had higher Panama Canal degrees from December to February. This indicates that small-size ships were crossing between the Atlantic and Pacific Oceans during this period. In other words, small-size ships changed their deployment areas significantly depending on the season, resulting in a higher degree of variability in the degree of each port.

Fourth, there were no mega-size ships deployed around the Arctic region (above 80°N) or around the Antarctic region (above 60°S), with the boundary around 30°N reflecting differences in deployment due to seasonality. Using this as a boundary, the larger ships, such as mega-size ships, had more distinct seasonal deployment latitudes, deploying above 30°N during the second and third quarters and shifting to below 30°N (south) in the fourth and first quarters. Conversely, the smaller ships showed more consistent deployment throughout the year in all latitudes. Smaller ships, in particular, were deployed in the fourth to first quarter, the winter period when the 80°N area is out of season. Similarly, they were also deployed in the second to third quarters, the summer months when the 60°S area was out of season. This means that warmth is not necessarily the only factor in port selection behavior for cruise lines.

Finally, in terms of latitudinal distance, mega-size ships did not move much throughout the year, but neither did small-size ships. Bagis and Dooms (2014) pointed out, that the itineraries of larger vessels (mass cruise tourism) tend to be more stable than that for smaller vessels. In terms of ship movement (latitudinal distance) by ship size, mega-size ships tended to be more stable (less mobile) throughout the year than other ship sizes. They were correct in their assertion that mega-size ships were stable, but not necessarily that small-size ships were not stable (moving). The distribution of the latitudinal travel distances of the small-size ships shows that most of the small-size ships did not move throughout the year, but some of them did move extremely long distances (Figure 5-12). This situation can be seen in the degree centrality map in Figure 5-7. Some small-size ships gathered in Alaska and North Europe in the summer, in South America and Australia in the winter, and in the Panama Canal in the middle of the season. Conversely, some small-size ships continued to be deployed to areas such as Scandinavia and Scandinavia throughout the year. This means that ships classified under the same small-size ship type also have separate characteristics.

Our findings allow for a deeper analysis to clarify changes in the spatial and temporal changes in the structure of the cruise network due to seasonality, taking into account the following data limitations. First, AIS data show the movement of cruise ships but do not distinguish between arrival/departure ports and ports of call. Therefore, this chapter could not analyze the data on an itinerary basis. Second, AIS data do not provide the number of cruise passengers per route. Ideally, if not only the movement of cruise ships but also the movement of cruise passengers could be depicted in a network diagram, the process of change in the relationship between supply and demand due to seasonality could be analyzed.

5.6. Chapter conclusion

The results of this chapter revealed that seasonality played an important role in the cruise industry. In particular, seasonality influences the spatial and temporal changes in the structure of the cruise network, resulting in different geographic relationships of hub ports and changes in cruise networks depending on cruise ship size. The findings of this chapter are used to contribute through proposals to countries and cruise ports.

The positioning and repositioning of cruise ships by seasonality resulted in different combinations of deployment areas and hub ports depending on the ship size. Changes in cruise ship distribution areas due to seasonality could lead to problems for port operations, such as fluctuations in employment opportunities during off-peak periods. Therefore, countries and ports should promote cooperation with the countries and ports of the positioning partner based on the information on the combination of deployment areas and hub ports that differ depending on the ship size as a result of this research. At that time, the center of the world cruise market has been the Caribbean and the Mediterranean, but it is necessary to consider that the cruise market will expand to South America, Asia, Africa, etc. in the future.

In this chapter, mega-size ships were characterized by their positioning area being limited to the Caribbean and Mediterranean Seas, their latitude distances being short, and their immobility. However, this fact is problematic due to physical restrictions, such as restrictions on the size of the port where mega ships can call and restrictions on the size of the Panama Canal. According to Cruise Industry News (2022), 23 new mega-size ships, 6 MSC Cruises, 5 Royal Caribbean Cruises, 3 Princess Cruises, 2 Carnival corporation, 2 Carnival China, 2 TUI Cruises, 1 Costa Cruises, 1 AIDA Cruises, and 1 Dream Cruises, will be deployed in the market over the seven years from 2021 to 2027. Given the plans for many of these new mega-size ships to be deployed shortly, governments and ports will need to develop ports and expand canals on a scale that can accommodate mega-size ships.

There are three challenges for future studies. First, the small-size ships, which had been bifurcated into those that move and those that do not, could be sorted by category (luxury type or expedition type), ice class level, etc., and then analyzed for seasonality, which would allow for more realistic analysis. Second, since the movement of mega-size ships may be gradually becoming more widespread due to the construction of port facilities and the expansion of canals, the impact of port development on seasonality will be analyzed in the future. Third, the impact of global warming and seasonality on cruise operations will be analyzed. This is because global warming is expected to allow cruise ships to operate in the Arctic Ocean during the summer months and, conversely, to avoid cruise ship operations in areas of extreme heat.

6. CONCLUSIONS

6.1. Summary

The purpose of the dissertation is to understand the spatial and temporal changes in the structure of the cruise network. By taking the trajectory of all cruise ships navigating in a given area as a network, and by getting a bird's eye view, and understanding the growth areas and timing where cruise lines are deploying ships and developing routes, it may be possible to avoid a situation where cruise ships do not arrive after a port has been built. To this end, this paper proposes the following four sub-objectives, the results of which are as follows:

- Sub-objective 1 (SO_1): To clarify the spatial and temporal changes in the cruise network structure between normal and contingency situations. Case study of the March 2017 THAAD event that halted routes between China and South Korea.

- Sub-objective 2 (SO_2): To observe changes in the connections between cruise ports during the early stages of the COVID-19 outbreak, such as port closures. The relationship between the cruise industry and the COVID-19 outbreak was analyzed.

- Sub-objective 3 (SO_3): To identify changes in the spatial and temporal changes in the structure of the cruise network by ship size. The case study is the Northeast Asian cruise market 2014-2019, which has experienced rapid growth in recent years.

- Sub-objective 4 (SO_4): To understand how seasonality changes the spatial and temporal structure in the cruise network by ship size around the world. The case study is the global cruise network in 2019.

Regarding sub-objective 1 (SO_1), that cruise network structure differs between normal and contingency conditions, which can be elucidated by tracking cruise ship movements using AIS data, the following was found.

    - Immediately after the THAAD event, to keep the sailing days, that is, to adhere to the schedule strictly, the number of ports of call was reduced to a single port, which is a marquee port, and the number of port calls was reduced and the ship continued to operate.

- Then, while gradually testing discovery ports, itinerary patterns were increased, and after one and a half years, the next best itinerary was created.
- Due to the THAAD event, the centers of the cruise market in Northeast Asia shifted from Shanghai port in eastern China to Shekou and Xiamen ports in southern China, Keelung port in Taiwan, and Tokyo/Yokohama ports in Japan.

Regarding sub-objective 2 (SO_2), the spatial and temporal structure in the cruise network changes due to port closures in the early stages of the COVID-19 outbreak, which revealed a relationship between the cruise industry and the COVID-19 outbreak, the following was found.

- The number of cruise ship operations in Asia had declined since the end of January 2020, while those in Western countries had not changed.
- Consequently, it was found that COVID-19 infection rates in countries that have ports of arrival and departure are higher than in countries with only ports of call. To add, COVID-19 infection rates in countries that continued to accept cruise ships until March were higher than those in countries that did not.
- The second analysis focused on the characteristics of cruise ships infected with COVID-19. As a result, the cruise ships infected with COVID-19 were large. Also, most cruise ships were sailing from the same home port to the same port of call in a week.

Regarding sub-objective 3 (SO_3), that the spatial and temporal structure in the cruise network changes by the size of the ship, which can be revealed by tracking cruise ship movements using AIS data, the following was found.

- The number of nodes and edges in the mega- and small-sizes was growing faster than those in the other sizes in Northeast Asia. The small-size had the highest number of nodes and edges, and new ports and routes were opened.
- The growth pattern of the small-size differed from that of the other sizes. The small size grew uniquely, with low network density and an average clustering coefficient.
- Hub ports differed depending on the size of the ship. In 2019, the mega-size hub was Shanghai; the large-size ones were Busan and Yokohama; the mid-

size ones were Busan and Keelung, and the small-size ones were Hiroshima and Kobe. The mega- and small- size hubs remain unchanged, while the large- and mid-size hubs were gradually replaced.

- Shanghai was a mega-size hub port. It was also, until 2017, a hub port for large- and mid-size ports. However, after 2018, Shanghai was no longer a hub port. At the time, many of the major cruise lines were the first to deploy their new mega-size ships to Shanghai. This resulted in the existing large- and mid-size ships in Shanghai being displaced by the new mega-size ships.
- Modularity increased for all sizes, which indicates that the community structure has become clearer over time. Moreover, the small-ship network had more communities and different boundaries than the other sizes. Many communities of the small-ship were located in Japan, and the boundaries between the communities differed from other ship sizes.

Regarding sub-objective 4 (SO_4), the difference in the spatial and temporal structural changes in the cruise network depending on the season by cruise lines can be clarified by tracking cruise ships that change according to the four seasons, the following was found.

- The smaller the ship size, the higher the number of nodes and edges, and also the highest at the positioning (moving the deployment area) timings of April-May and September-October.
- Hub ports did not appear only in the Caribbean or Mediterranean but varied geographically depending on the season and the size of the cruise ship.
- The monthly changes in the number of degrees at hub ports in the small-size ship network varied most significantly with the seasons. It was lower for mega-size ships, followed by mid- and large-size ships, which did not fluctuate as much as small-size ships.
- There were no mega-size ships deployed around the Arctic region (above 80°N) or around the Antarctic region (above 60°S), with the boundary around 30°N reflecting differences in deployment due to seasonality.
- In terms of latitudinal distance, mega-size ships did not move much throughout the year, but neither did small-size ships. Mega-size ships tended to be more stable (less mobile) throughout the year than other ship sizes. The distribution of the latitudinal travel distances of the small-size ships shows that most of the small-size ships did not move throughout the year, but some of

them did move extremely long distances.

6.2. Limitations and future works

This study has several limitations. Although AIS data provides information on cruise ship movements, it is not possible to distinguish between arrival and departure ports and ports of call, and thus itinerary analysis could not be performed in this study. Since AIS data does not provide information on the number of cruise passengers per route (edge), landing demand was estimated from the capacity of the ship.

There are five future works. As follows.

1. Cruise network prediction modeling by elucidating 'Supply-Driven Mechanisms'
   The results of the spatial and temporal structural changes in the cruise network in this study can be used to clarify the mechanism of supply-driven unique to the cruise industry, such as how cruise demand develops after port development. This will allow us to understand how the entire network grows through the development of ports (addition of nodes) and the opening of shipping routes (addition of edges), which may be used to build a model to predict the growth of the cruise network.

2. Impact of route disruptions, etc. using causal inference techniques
   Using the findings of this study on spatial and temporal structural changes in the cruise network under contingency conditions, such as route disruptions due to THAAD events and port closures due to the spread of COVID-19 infection, the impact can be measured using causal inference and other methods. This may enable specific studies of coordination among ports, such as preparing alternative ports in advance.

3. Port infrastructure development of cruise ship movement data by size
   To the network data on ship movements by size based on the AIS data constructed in this study, we added information on the specifications of each port, such as berth length, water depths, and passenger terminals, as well as information on the functions of each port, such as whether the port is used as a home port, arrival and departure port, or port of call by each cruise line. By building a new network data, it may be possible to develop efficient port development strategies, such as specifications of port infrastructure required for different sizes of cruise ships, and

gradual development of facilities to accommodate small-, large-, and mega-size ships.

4. Competitive relationships among cruise lines considering differences in services and clientele

By adding information on cruise lines' service level (service category) and clientele (wealthy class, nationality of passengers, etc.) to the network data on ship movements by size based on AIS data constructed in this study, new network data can be constructed, which will allow us to analyze the competitive relationships among cruise lines and to better understand the strategies and principles of port selection by cruise lines.

5. Impact of global warming on cruise industry seasonality

In this study, spatial and temporal cruise network structural changes due to seasonality were analyzed using AIS data from 2019. In the future, ship movement data of all cruise ships operating worldwide will be traced back to the past to capture changes in the cruise network structure over a long period. Then, by comparing this data with indicators (temperature and other data) that show the effects of global warming, etc., which have been changing over a long period, it may be possible to analyze the effects of global warming, etc., on the actual conditions of movement and migration of cruise ships at latitudes (north and south).

APPENDICES

Appendix 1 List of cruise areas and countries

Cruise area	Country
North America	Canada, Costa Rica (West coast), El Salvador, Guatemala (West coast), Mexico (West coast), Nicaragua, Panama (West coast), St Pierre and Miquelon, US (Northeast coast, West coast)
Caribbean Sea	Antigua, Aruba, Bahamas, Barbados, Belize, Cayman Islands, Colombia, Costa Rica (East coast), Cuba, Dominica, Dominican Republic, French Guiana, Grenada, Guadeloupe, Guatemala (East coast), Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico (East coast), Montserrat, Netherlands Antilles, Panama (East coast), Puerto Rico, St Kitts & Nevis, St Lucia, St Vincent, Suriname, Trinidad & Tobago, Turks & Caicos Islands, US (Southeast coast), Venezuela, Virgin Islands
South America	Argentina, Brazil, Chile (West coast), Ecuador, Falkland Islands, Peru, South Georgia, Uruguay
Pacific Ocean	Chile (Around Easter islands), US (Around Hawaii islands)
Oceania	American Samoa, Australia, Christmas Island, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Micronesia, New Caledonia, New Zealand, Norfolk Island, Northern Mariana Islands, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Vanuatu
Asia	Brunei, Cambodia, China, Indonesia, Japan, Myanmar, Philippines, Russia, Singapore, South Korea, Taiwan, Thailand, Timor, Vietnam
Middle East, South Asia	Bahrain, Egypt, India, Iran, Israel, Jordan, Kuwait, Maldives, Oman, Pakistan, Qatar, Saudi Arabia, Sri Lanka, United Arab Emirates, Yemen
Mediterranean Sea	Albania, Algeria, Bulgaria, Croatia, Cyprus, Egypt, France (South coast), Gibraltar, Greece, Israel, Italy (South coast), Lebanon, Libya, Malta, Monaco, Montenegro, Romania, Russia (West coast), Slovenia, Spain (South coast), Syria, Tunisia, Turkey, Ukraine
Northern Europe	Belgium, Channel Islands, Denmark, Estonia, Faroe Islands, Finland, France (North coast), Germany, Greenland, Guernsey, Iceland, Ireland, Isle of Man, Jersey, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Russia (North coast, East coast), Spain, Sweden, UK
Africa	Angola, Benin, Cameroon, Canary Islands, Cape Verde Islands, Comoros, Congo (Republic), Cote d'Ivoire, Djibouti, Eritrea, Gabon, Gambia, Ghana, Guinea, Kenya, Liberia, Madagascar, Madeira, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Nigeria, Reunion, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Tanzania, Togo, Western Sahara

Source: Author

Appendix 2 Top 30 countries with ports of arrival and departure among cruise products sold in early April

Rank	Countries with arrival and departure ports	Number of products	Cumulative Percentage
1	United States	7930	42.9%
2	Italy	2834	58.2%
3	Spain	1054	63.9%
4	Canada	715	67.7%
5	France	693	71.5%
6	Australia	467	74.0%
7	Greece	392	76.1%
8	United Kingdom	386	78.2%
9	Ecuador	369	80.2%
10	Denmark	283	81.7%
11	Germany	280	83.3%
12	Japan	272	84.7%
13	Puerto Rico	266	86.2%
14	Netherlands	253	87.5%
15	United Arab Emirates	247	88.9%
16	Singapore	171	89.8%
17	Brazil	167	90.7%
18	Argentina	140	91.4%
19	Barbados	120	92.1%
20	China	120	92.7%
21	Turkey	109	93.3%
22	Sweden	104	93.9%
23	South Africa	100	94.4%
24	Hong Kong	93	94.9%
25	Martinique	89	95.4%
26	New Zealand	78	95.8%
27	Portugal	63	96.2%
28	Norway	54	96.5%
29	Qatar	44	96.7%
30	Monaco	41	96.9%
Others		567	100.0%
Total		18,501	–

Source: Authors based on the Expedia, 2020 cruise product search site.

Appendix 3 Cruise ships affected in the US by COVID-19

Ship name	Voyage start date	Voyage end date
Carnival Imagination	5-Mar	8-Mar
Carnival Valor	29-Feb	5-Mar
Carnival Valor	5-Mar	9-Mar
Carnival Valor	9-Mar	14-Mar
Carnival Vista	15-Feb	22-Feb
Carnival Vista	29-Feb	7-Mar
Celebrity Infinity	5-Mar	9-Mar
Celebrity Eclipse[a]	2-Mar	30-Mar
Celebrity Reflection	13-Mar	17-Mar
Celebrity Summit	29-Feb	7-Mar
Crown Princess	6-Mar	16-Mar
Disney Wonder	28-Feb	2-Mar
Disney Wonder[a]	6-Mar	20-Mar
Grand Princess	11-Feb	21-Feb
Grand Princess[a]	21-Feb	7-Mar
MSC Meraviglia	1-Mar	8-Mar
Norwegian Bliss[a]	1-Mar	8-Mar
Norwegian Bliss	8-Mar	15-Mar
Norwegian Breakaway	29-Feb	7-Mar
Norwegian Breakaway[a]	7-Mar	14-Mar
Norwegian Pride of America[a]	29-Feb	7-Mar
Oceania Riviera[a]	26-Feb	11-Mar
RCCL Explorer of the Seas	8-Mar	15-Mar
RCCL Liberty of the Seas[a]	15-Mar	29-Mar
RCCL Majesty of the Seas[a]	29-Feb	7-Mar
RCCL Oasis of the Seas[a]	8-Mar	15-Mar
RCCL Symphony of the Seas[a]	7-Mar	14-Mar

Source: Centers for Disease Control and Prevention.
[a] CDC was notified of COVID-19-positive travelers who had symptoms while on board these ships.

Appendix 4 Cruise operators by ship size

Mega ship operators	**Midsize ship operators**	**Small ship operators**
Costa Crociere SpA	Aida Cruises	Azamara Club Cruises
Dream Cruises Management Ltd	Astro Ocean Cruise	Hapag-Lloyd Kreuzfahrten GmbH
MSC Crociere SpA	Costa Crociere SpA	Japan Cruise Line Inc
NCL Bahamas Ltd	Cruise & Maritime Voyages Ltd	Mitsui Passenger
Princess Cruise Lines Ltd	Crystal Cruises LLC	Noble Caledonia Ltd
Royal Caribbean Cruises Ltd	Diamond Cruise	Oceania Cruises Inc
	Dream Cruises Management Ltd	P&O Cruises
	Fred Olsen Cruise Lines Ltd	Phoenix Reisen GmbH
	Holland America Line NV	Plantours & Partner GmbH
Large ship operators	Maritime Holdings Group Inc	PONANT
Celebrity Cruises Inc	MSC Crociere SpA	Princess Cruise Lines Ltd
Costa Crociere SpA	Nina Services Corp	Regent Seven Seas Cruises Inc
Cunard Line Ltd	NYK Cruises Co Ltd	ROW Management Ltd
Holland America Line NV	Oceania Cruises Inc	Seabourn Cruise Line Ltd
NCL Bahamas Ltd	P&O Cruises	SeaDream Yacht Club Management
P&O Cruises	Phoenix Reisen GmbH	Semester at Sea
Princess Cruise Lines Ltd	Royal Caribbean Cruises Ltd	Sete Yacht Management SA
Star Cruises	SkySea Cruises	Silversea Cruises Ltd
	Star Cruises	Voyages of Discovery Ltd
	Viking Ocean Cruises Ltd	Windstar Cruises LLC
	Yantai Bohai Ferry Int'l Ship	

Source: Author

Appendix 5 Implications and interpretation of results of network indicators from the cruise industry perspective

Indicators	Meaning of indicators	Network characteristics	Understanding cruise lines' port selection behavior	Implications for ports
Number of nodes	Number of ports where cruise ships have called	The higher the number of nodes, the more developed and diversified the network of ports of call.	A higher number of nodes indicates characteristics that promote the development of new ports.	Determination of the need for new port development, etc.
Number of edges	Number of cruise ship routes navigated between ports	The higher the number of edges, the more developed (multidirectional) the route is in the network.	A high edge number indicates characteristics that promote the creation of a new route.	Determination of proposals for new routes connecting to new ports, etc.
Average degree	Number of shipping routes per port (number of directions)	The higher the average degree, the more routes are served per port and the denser the network. (Multidirectional shipping routes)	A high average degree indicates the characteristic of developing routes to various directions with the base port as the axis.	Decisions on proposals for new routes connecting to new ports, etc.
Density	The ratio of the actual number of shipping routes to the number of possible connections between ports	The higher the density, the higher the percentage of development of shipping routes is in the network. If the development of shipping routes is more advanced than the development of ports, density will be higher. (Progress in the development of new shipping routes by shipping lines)	If the density is high, new ports may not be developed and itineraries (combinations of ports of call) may become rutted.	Determination of the need for new port development, etc., and proposals for new shipping routes connecting to new ports, etc.
Average clustering coefficient	The ratio of ports that have shipping routes to and from one port to another.	The higher the average cluster coefficient, the more triangular the network (i.e., a product consisting of an arrival and departure port and two ports of call), or a network with many routes that are not connected but are triangulated.	Characteristics of (changes in) shipping routes in a given network, such as whether a shipper's itinerary is open or closed, longer or shorter in days, etc.	Determination of the need for new port development, etc., and proposals for new shipping routes connecting to new ports, etc.
Diameter	The longest path on the network	It does not consider connections on direct itineraries; the longer the	Characteristics of (changes in) shipping routes in a given	Determination of the need for new port development, etc.,

	between one port and another	diameter, the longer the connection (path) between ports on the longest route, and the sparser the network.	network, such as whether a shipper's itinerary is open or closed, longer or shorter in days, etc.	and proposals for new shipping routes connecting to new ports, etc.
Average shortest path length	The shortest path on the network between one port and another	Not considering connections on direct itineraries, the longer the average shortest path length, the longer the connections (paths) between ports on the closest route, and the sparser the network.	Characteristics of (changes in) shipping routes in a given network, such as whether a shipper's itinerary is open or closed, longer or shorter in days, etc.	Determination of the need for new port development, etc., and proposals for new shipping routes connecting to new ports, etc.
Degree centralization	The ratio of degrees biased toward the port with the highest degree	The higher the degree centralization, the more heterogeneous the network, with the degree biased toward the port with the highest degree (hub port).	The network as a whole can understand strategies such as whether or not a group of carriers participating in a given network is converting to a hub.	It will serve as a basis for strategic considerations, such as one port aiming to become a hub port, another aiming to connect to various ports as a spoke, etc.
Degree centrality	Number of shipping routes connecting to the port	Ports with a higher degree centrality have more shipping connections with neighboring ports. The port is a hub port with multimodal shipping routes.	It shows which ports the shipping lines operate out of. The cruise line’s strategy is revealed, such as whether or not they are promoting hubs in certain ports.	It will serve as a basis for strategic considerations, such as one port aiming to become a hub port, another aiming to connect to various ports as a spoke, etc.
Modularity	Quality of community (inter-port connections) division	The higher the modularity, the higher the quality of the network in terms of the division (boundaries) of communities (groups of ports) that are connected among ports.	From the perspective of which ports and which ports belong to the same community, the characteristics of the port selection behavior of shipping companies are understood.	Ports belonging to the same community can work together to attract other ports.

Source: Author

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