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Empirical Analysis of the Cruise Shipping Network in Asia

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Abstract: The cruise shipping market has been growing dynamically in the past two decades. This study presented an empirical analysis of the Asian cruise shipping network (ACSN) in which the nodes are cruise ports and links are cruise routes connecting the ports, using complex network analysis. An analysis of 245 voyages operated by 16 cruise lines between 215 ports in 26 countries found that ports in the ACSN are connected by 704 links. The ACSN is a small-world network with a small average path length and a high clustering coefficient, and its degree distribution follows an exponential function. A small number of ports have high connectivity, and most ports have low connections. Most high-degree ports connect to low-degree ports. The important roles and properties of ports vary depending on centrality measures.

Keywords: network analysis; cruise shipping; port connectivity; network characteristics; topological property analysis; port property

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Citation: Kanrak, M.; Lau, Y.-y.; Zhou, J.; Ge, J.; Traiyarach, S. Empirical Analysis of the Cruise Shipping Network in Asia. *Sustainability* **2023**, *15*, 2010. https://doi.org/10.3390/su15032010

Academic Editor: Luca D'Acierno

Received: 14 December 2022
Revised: 12 January 2023
Accepted: 17 January 2023
Published: 20 January 2023

1. Introduction

The cruise industry started in the 1920s. The role of cruising has significantly shifted from a means of transportation to a holiday experience [1,2]. Since the 1960s, line voyages have been replaced by predetermined itineraries during different ports of call. Time at sea was to be engaged with a varied mixture of entertainment and gourmet dining, as well as port visitation, which allowed tourists shore excursions, visits, and trips. Cruise shipping has evolved from luxury to affordable comprehensive products that can be tailor-made to local preferences, with a low average price per day [3].

Scientific and technological advancements have induced tremendous improvements in cruise ships ranging from accommodation, catering facilities, design, and power supply in the past 30 years. In the meantime, modern cruise tourism encounters stiff competition from land-based holidays. Thus, classic cruise ships were transformed into modern ships between the 1980s and 1990s and into third-generation ships in the 2000s [4]. In the 2000s, Genesis and Freedom classes emerged as the largest and most expensive cruise vessels in the world. The construction cost was about $1.24 billion and had more than 5,400 passenger capacity [5].

In the past two decades, the cruise industry has been growing dynamically [6]. According to the Cruise Line International Association (CLIA), in 2019, the global total number of cruise passengers increased to more than 29 million. However, the number decreased significantly to 5.8 million as a result of the COVID-19 pandemic [7]. In 2021, the passenger volume in Asia was 626 thousand, which was 83.2% down compared to that in 2019 before the pandemic. However, this number shows a slight increase in 2020, when the passenger volume was only 497 thousand.

As several cruise markets in Asia, such as Hong Kong and Mainland China, have not fully restarted. The Asian cruise market is expected to recover in the following years. The average duration of cruising decreased from 4.2 days in 2019 to 3.1 days in 2021 [8], showing that short cruises are relatively popular in the cruise shipping recovery phase. Cruises of two to three nights accounted for 53% of all cruises during the pandemic era, while before the pandemic, the highest share of cruises was four-to-six-night cruises [9,10]. Cruise lines in Asia mainly catered to the premium and contemporary segments, with 19 cruise lines, while the rest of the segments covered 11 upscale cruise lines, five luxury cruise lines, and four expedition cruise lines in 2019 [10]. No expedition cruise lines or ships were witnessed in 2020 [9]. Compared to the North American cruise lines, which operate in more market segments, ample opportunities exist to further segment the Asian cruise market to attract corporate meetings, family markets, and weddings [11].

The outbreak of the COVID-19 pandemic has induced the cruise industry to seriously suffer from loss of customers and cancelled trips. However, the removal of travel restrictions and the increasing vaccination rate has encouraged tourists to travel again. Rebounded demand has generated a boost in bookings in 2022 and 2023. Uni world reveals that the number of cruise bookings increased by 425% from late 2021 and 2022. To rebuild cruise passengers' confidence and sustain cruise market development, cruise lines plan to design various itineraries to upgrade onboard experiences to attract potential passengers and maintain repeat passengers. To this end, world cruising, non-peak season destinations, shorter sailing, and cold-weather cruising are identified as cutting-edge and innovative services provided to the public in challenging times [12].

A complicated distribution of cruise lines that design various cruise voyages and a large number of cruise ports to serve many passengers who have different needs lead to the structure of a cruise shipping network showing some complex characteristics [4,13]. A complex network can be understood easily as it exhibits transport networks' characteristics, especially maritime networks [14]. The Asian cruise shipping network (ACSN) is also complex, consisting of many cruise ports (nodes) that are connected to other ports by cruise routes (edges or links).

Most studies on cruise shipping focused on tourism management. To a certain extent, maritime transport management is limited. Regarding regional studies, most studies considered the Caribbean and the North American markets, while the Asian cruise market is under-researched. Since 2000 various studies generally addressed cruising economics, activities, tourists' perceptions, regulations, cruise ship operational efficiency and organizational behaviour [5]. Studies on Asian cruise shipping have performance deficiency mostly concentrated on specific locations or itineraries [2,15–17]. Only a few studies analysed the cruise shipping network in Asia [4,18]. However, limited research analyses cruise shipping networks using complex network analysis. Thus, this study conducts an empirical analysis of the cruise shipping network in Asia in order to show the topological properties of the ACSN and ports based on 245 cruise voyages.

The remainder of the article is structured as follows. Section 2 presents the literature review on the cruise shipping market and network. Section 3 represents the research methodology for network analysis. In Section 4, the article provides empirical analysis results and discussion. The article ends with a conclusion and directions for future research.

2. Literature Review

2.1. Cruise Market in Asia

Cruise shipping in Asia has been popular for the past decade. There are several representative countries in the Asian cruise market, such as Mainland China, Singapore, Japan and India. As a result of the COVID-19 pandemic, the Chinese cruise market has not resumed yet. Cruise lines service only some domestic itineraries, such as from Haikou to Xisha and from Xiamen to Zhoushan. Chinese cruise passengers only contribute a 1% share of all Asian cruise passengers in 2021, whereas this number was 51.4% before the pandemic [8]. The resumption of domestic itineraries indicates that China has started to ease its restriction policy on cruise businesses. The current 'Zero-COVID' policy is the main restriction to cruise development in China. Even after cruise businesses return to a full resumption in China, the Chinese cruise market still needs to handle some long-term issues, such as the imbalance of inbound and outbound cruise tourism [15]. China is the dominant source market in Asia before the pandemic [19], but it has largely failed to attract an equal number of international passengers who do not consider it a popular cruise destination. In the future, China needs to provide attractive onshore activities, fly-cruise packages, and more policy and administrative support for customs clearance so that China can become both a top cruise-passenger source market and a popular cruise destination in Asia. In addition, because cruise tourism has not yet been widely accepted by Chinese people, more efforts are expected in marketing and advertising to expand the customer base and attract more cruise passengers in China [16].

Singapore is the top source market in 2021, contributing 57.6% of cruise passengers in Asia [8], compared to its passenger share of 8.7% in 2019. Singapore's passenger volume even increases a bit from 324 thousand in 2019 to 360 thousand in 2021. According to the International Trade Administration [20], cruise capacity in Singapore is projected to more than double in the next five years, and the cruise market volume is expected to grow at an annual growth rate of 13.86%. In addition, Singapore is investing USD 380 million in modernizing its state-of-the-art cruise centre and has set up its own budget to promote cruise businesses [20]. With Singapore's prime location amidst major international shipping routes and excellent land, air and sea connectivity to destinations in Southeast Asia, Singapore is an emerging cruise market. Despite these advantages, Singapore failed to provide attractive onshore recreational activities, which require further advancement [5].

The Japanese cruise market saw a year-on-year gain from 2016 to 2019 growing 12.66% annually [9]. Japan is the top cruise destination in Asia before the pandemic, mainly due to a large number of Chinese passengers choosing itineraries from China to Japan. However, Japan ranked fifth and sixth in 2019 and 2021 among all Asian markets [8,21], showing that there is potential to increase Japanese participation in cruise activities. The average age of Japanese passengers was 57 in 2019 and 43 in 2021, which is much higher than the average age in Asia with 46.2 in 2019 and 35.4 in 2021 [8,21]. One major problem of the Japanese cruise market lies in the relatively outdated cruise port infrastructure [5]. In addition, Japanese cruise ships mainly serve passengers who want to travel in a Japanese cultural environment, making the market a specialised and niche market [22]. Considering these, future strategies may provide traditional culture-related services to attract more retirees to cruising, such as hot springs and local food, to increase the retirees' cruising intentions, and provide shorter itineraries to meet the needs of those with time constraints, such as office workers [17].

The Indian cruise market has also witnessed a surge in the past few years before the pandemic with an annual growth rate of 28.3%, increasing from 148 thousand in 2016 to 313 thousand in 2019 [21]. It ranked second as a top source market in Asia in 2021 [8]. With the long and beautiful coastlines and scenic destinations, as well as the rapidly growing middle class, cruise tourism in India has great potential. The main factors that restricted the development of the Indian cruise market are the strict regulations and the lack of specific cruise ports. However, in recent years, there have been a few changes to this. The government eased the regulations on immigration rules for cruise passengers (e.g., e-visa) [23]. In addition, India issued its national cruise tourism development plan [16] and is developing infrastructure for handling cruise ships at its major ports (Mumbai, Mormugao, Cochin, New Mangalore, Chennai), which provided government support for the cruise business development. There also have been several itineraries from India to Southeast Asia and domestic itineraries in the river Ganges. Despite these positives, the development of the cruise business in India should pay special attention to its socio-ecological impacts. Cruise port cities are suffering from air pollution, noise pollution and waste from cruise ships [16,24]. As India has as many as 3,300 villages populated by around 4 million fish workers who are dependent on oceans [25], ports and coastal tourism have been experiencing strong resistance from local communities. The market should handle its impact on the local ecosystems, environment and communities well for future development.

2.2. Studies on Asian Cruise Shipping

Many works studied cruise shipping in Asia. Singh [11] is among the first authors who systematically studied the Asian cruise market. He believed that cruising in Asia was expected to grow rapidly due to the attraction of Asian cruise products, the increase in cruise passengers, the entry of new cruise operators and the expansion of port infrastructure. Several market strategies were proposed, including creating new cruise products to attract first-time passengers, repeat passengers and family market, innovative product differentiation strategies to target corporate meetings and specialized cruise products to target niche markets such as weddings. Kwag and Lee [26] reviewed the development, trends and business environment of the global and Asian cruise markets. They forecasted the future growth of the Asian cruise market with the implementation of strategic plans and marketing strategies. Sun et al. [16] investigated the development of the cruise industry in Mainland China in terms of the characteristics of Chinese passengers, the berthing capacity of each port and the government policy related to cruise businesses. They found several challenges in the Chinese cruise market, including the inadequate port infrastructure in China, the comparatively small consumer base, the immature distribution system and the lack of a national cruise tourism development plan.

Wang et al. [27] identified the factors that affect cruise port selection using the fuzzy-AHP method. They found that the top priorities are tourism attractions and the connectivity and agility of a port, which are important for ports of call in the future to attract cruise ships in Asia. Chen [28] explored how Taiwan can promote its cruise businesses using the fuzzy Delphi and fuzzy IPA methods. The analysis results showed that Taiwan should develop more onshore activities, increase investment in port infrastructures, and cooperate with other countries.

Tao and Kim [29] investigated cruise passengers' experience and satisfaction in terms of online cruiser reviews in the Asian cruise market by text mining and semantic network. They found that half of the passengers were dissatisfied with cruising in Asia and they paid attention to cruise products, facilities and amenities, port cities and onshore attributes. Especially onshore attributes deserve future research attention. Kawasaki and Lau [17] studied the preferences of potential Japanese passengers and discussed ways to attract more passengers in Japan. They provided several suggestions to increase cruising intentions, including shortening itineraries, lowering the prices and providing local culture-related services. Jiao et al. [30] examined the historical cruise ship accident data in Asian regions and found that human error is the main cause of cruise ship accidents. They suggested that Asian countries should improve cruise ship safety management through sufficient training, increasing safety awareness and implementing safety plans.

Sun et al. [15] developed a CRUISE framework and discussed the location characteristics of Hong Kong and Shanghai cruise terminals. Based on this framework, they identified the insufficiency of cruise business development in terms of connectivity, regional competitiveness, utilization of ports, infrastructure, security, and environmental management. Lau and Yip [5] used the CRUISE PORT framework to examine four representative cruise markets in Asia, South Korea, Japan, Vietnam and Singapore. They compared and studied the current situation from ten aspects, including the number of cruise ports established as home ports, ocean conditions, recreational activities and the amount of cruise traffic, and provided suggestions for further development of these markets. Lau et al. [31] used the CRUISE PORT framework to study the Asian cruise market in the post-COVID-19 Era. They argued that future cruise travel should be innovative and safe, and proposed several strategies by cruise lines, cruise port operators and port city governments, such as providing itineraries covered by islands with low infection risk and providing medical services for the pandemic.

Jeon et al. [4] used social network analysis (SNA) to study the characteristics of cruise hub ports in the Asian cruise market. They found several ports that can be regarded as hub ports, including Singapore, Shanghai, Hong Kong, Penang, Phuket and Port Klang. Kanrak and Nguyen [13] applied SNA to analyse the structure, characteristics and connectivity of the cruise shipping network in the Asian and Australasian regions. The results revealed that Singapore, Shanghai, Hong Kong, Benoa, Ho Chi Minh and Kobe play a central role in the network of this region.

2.3. Studies on Cruise Shipping Networks

A maritime transport network can be described by tracking the activity of ships since they navigate between ports. The network explains the location and quantity of nodes (ports) that form the network and their edges or links (shipping routes) because of ship activities [32]. An investigation of network connectivity addresses associations amid nodes in a network that are connected by links between them. Cruise shipping network analysis explains the network of cruise ports (nodes) that are connected by cruise links (cruise routes). Different methods have been adopted to exhibit network connectivity, such as centrality measures, clustering coefficient, network density and average path length [33]. Kanrak and Nguyen [13,33,34] used assortativity, cluster structure, and connectivity of the cruise shipping network in the Asian-Australasian region. Kanrak et al. [35] further analysed the change in the cruise shipping network by comparing the networks before and after the pandemic. Ito et al. [32] investigated the structural changes in the cruise shipping network via ship size in Northeast Asia adopting network science approaches along with AIS data. Rodriguez et al. [36] adopted 2018 itineraries covering 902 ports to understand structural changes in Northern Europe and the Caribbean cruise networks. Jeon et al. [4] investigated the centrality of cruise ports in the Asian cruise shipping market. Tsiotas et al. [37] examined the spatial networks of two cruise companies operating in the Mediterranean. Gou and Wang [38] analysed the hierarchical structure and spatial differentiation characteristics and summarized the general spatial laws of the cruise shipping network in the Caribbean.

Cruise port accessibility is associated with the potential or chance for passengers to reach other ports via the network's links. This is completely suitable as an explanation of nodal accessibility that indicates the attractiveness of every specific node in a network considering the costs to access those nodes and the aggregation of other nodes via the network [39]. As such, a port has the greatest possible accessibility for cruise shipping implying the hub port in the network [33]. The cruise ship size can potentially be a limiting factor in accessing the port, and thus, the cruise traffic is concentrated on the specific market along with the network [40]. In response, determining the ship size to be anchored is the starting point of cruise port development [32]. This is crucial in placing ports in a strategic position of home ports in the region and sustaining the competitive position of cruise destinations [37,41].

Interestingly, the instability of cruise shipping because of climatic effects interferes with itineraries and cruise tourism [5]. The extreme effect of tropical cyclones on the cruise shipping network structures, notably in the Indian and Pacific Oceans, has induced East Asian ports to be the most seriously influenced port clusters via tropical cyclones. Thus, Chen et al. [42] and Chen et al. [43] used the AIS data to calculate the cruise ships' emissions in the Arctic cruise shipping network by using a robust pollution emission model. Browse et al. [44] combined Arctic shipping emissions inventories from 2004 with both a chemical transport model and a worldwide aerosol microphysics model to compute the possibility of forthcoming shipping activities in the Arctic to high-latitude black carbon deposition in 2050. These studies concentrated mainly on a particular area and were inclined toward robust optimization and modelling behaviour operation issues.

3. Research Method and Data

This study is an empirical analysis of the ACSN using complex network analysis. The approach is used to build a network consisting of nodes (vertices) as cruise ports that are connected by edges (links) as cruise shipping routes. Links are connected between ports in direct ways. This approach has been applied by many scholars to analyse many transport networks, such as Isaksen [45], Wang et al. [46], Soh et al. [47], Dai et al. [48], Bombelli et al. [49] and Hussain and Fusté-Forné [50]. Complex network analysis has also been used to analyse maritime transport networks, such as Hu and Zhu [51], Tsiotas and Polyzos [52], Ducruet [53], Tsiotas et al. [37], Kanrak and Nguyen [13], Ducruet et al. [54], Kanrak et al. [35], Kanrak and Nguyen [33] and Gou and Wang [38]. In this study, analysis is conducted both at the network and port levels.

3.1. Network Level

At the network level, the topological properties of the ACSN are analysed using network density, average path length, the clustering coefficient and the rich-club coefficient.

3.1.1. Network Density

Network density reflects network connectivity. It measures the fraction of the number of links and the possible number of links between nodes in the network, written as

$$\rho(G) = \frac{m(G)}{n(n-1)} \tag{1}$$

where m is the total number of links that the network has, and n is the total number of nodes in the network. Network density is equal to one, indicating that the network is a complete network as all nodes connect to each other. Network density is less than one, indicating that the network is sparse as all nodes cannot connect to each other. In this study, network density is used to analyse the connectivity of the network and potential connection among cruise ports.

3.1.2. Average Path Length

Average path length (geodesic) is the average number of links along the shortest path for all possible pairs of nodes in the network [55], defined as

$$L = \frac{1}{\frac{1}{2}n(n-1)} \sum_{i>j} d_{ij} \tag{2}$$

where d_{ij} is the number of links for the shortest path between nodes i and j. The diameter of the network is the maximum value of all d_{ij}. The average path length is the mean length of the path between cruise ports, reflecting a minimum number of connection steps between two ports. The average path length is used to analyse network connectivity efficiency. A low average path length indicates that the network has a high connectivity efficiency, while a high average path length refers to a low efficiency of network connectivity.

3.1.3. Clustering Coefficient

The clustering coefficient (transitivity) of a node is the number of triangles shaped by the node, calculated by the fraction of the links between nodes within its neighbourhood and the maximum possible links between them.

$$C_i = \frac{E_i}{k_i(k_i-1)/2} \tag{3}$$

Thus, the clustering coefficient of the network is the average clustering coefficient of all nodes in the network.

$$\langle C \rangle = \frac{1}{n} \sum_{v_i \in V} C_1 \tag{4}$$

In the context of a cruise shipping network, the clustering coefficient is used to analyse the local connectivity around a cruise port as it indicates the intensity of triangles around a port. A high clustering coefficient indicates that a port has more connections within its neighbours. This means that the port is more likely to reach another port within short transfers or connection steps [56]. The average clustering coefficient is used to analyse intra-connectivity among ports in the same clusters in the ACSN.

3.1.4. Rich-Club Coefficient

The rich-club coefficient measures well-connected nodes that connect to each other. It is defined as the fraction of the number of links among nodes of a degree greater than or equal to k to the total possible number of links if nodes are fully connected.

$$\phi(k) = \frac{2E_{>k}}{n_{>k}(n_{>k}-1)} \tag{5}$$

where $E_{>k}$ is the number of links between nodes and the degree greater than or equal to k. $n_{>k}$ is the number of nodes with a degree greater than or equal to k. The network with a high rich-club coefficient indicates the rich-club effect or the rich-club phenomenon, reflecting that there are many connections between high-degree nodes. The rich-club coefficient is used to analyse the rich-club phenomenon of the network, reflecting a connection between nodes of a high degree.

3.2. Port Level

At the port level, centrality measures are used to identify the important key ports and their roles, including degree, betweenness and closeness centralities

3.2.1. Degree Centrality

Degree centrality is the most intuitive topological measure of centrality, reflecting the connectivity of a node in the network. The degree of centrality of node i is the sum of the number of links that connect to it.

$$C_D(i) = \sum_{j=1}^{n} a_{ij} \tag{6}$$

where a_{ij} = 1 if nodes i and j are connected by a link, and a_{ij} = 0 otherwise. A node with large degrees indicates its high connectivity. Thus, it is defined as an important and popular node in the network. In a directed network, in-degree is the number of links that connect to a node, while out-degree is the number of links that a node connects to others.

3.2.2. Betweenness Centrality

Betweenness centrality measures the extent to which a node lies between the other two nodes in the network. The betweenness centrality of node i is defined as the proportion of all possible shortest paths passing through it to all shortest paths.

$$C_B(i) = \sum_{s \neq i \neq t} \frac{\sigma_{st}(i)}{\sigma_{st}} \tag{7}$$

where $\sigma_{st}(i)$ is the number of shortest paths passing through node i, and σ_{st} is all shortest paths between nodes s and t. Betweenness centrality reflects the transitivity or intermediary role of a node.

3.2.3. Closeness Centrality

Closeness centrality measures how a node is close to all other nodes along the shortest paths, reflecting the reachability and accessibility of a node. The closeness centrality of a node is the inverse of the average shortest distance (connections) from it to all others in the network. A node with a large closeness value is more convenient to connect to other nodes [46].

$$C_C(i) = \frac{n-1}{\sum_{j \neq i} d_{ij}} \tag{8}$$

In this study, degree centrality is used to analyse the connectivity of ports in the ACSN. A port with a high degree is defined as important and popular for cruise shipping in this region. It also has high connectivity in the network. Betweenness centrality is used to analyse accessibility to reflect the transitivity of a port. A port with a high betweenness value plays as a transitivity port in the network. A port with a high degree and betweenness values is also defined as a hub of the network. Closeness centrality is used to analyse the reachability of a port to reflect its convenience to reach all other ports.

3.3. Data

The data of this study were obtained from an Australian cruise agent website (https://www.ecruising.travel/ accessed on 1 December 2022), which provides cruise packages serviced in 2022 operated by 16 cruise lines using 37 cruise ships. The data includes 245 voyages covering 215 cruise ports in 26 countries in Asia. The ports are distributed in different countries, which are listed in Table 1. Note that the data is based on the original plans of cruise lines, any cancellations and schedule changes in the future are not considered and updated.

Table 1. Number of cruise ports in Asian counties.

Country	Number of Ports	Country	Number of Ports
Australia	36	Papua New Guinea	8
Bahrain	1	Philippines	8
Brunei	1	Qatar	1
Sihanoukville	1	Russia	2
China	9	Singapore	1
India	7	Solomon Islands	2
Indonesia	37	South Korea	3
Japan	49	Sri Lanka	4
Malaysia	7	Taiwan	4
Maldives	1	Thailand	5
Myanmar	1	Timor-Leste	2
New Zealand	8	United Arab Emirates	5
Oman	3	Vietnam	9

4. Empirical Analysis Results

4.1. Network Topological Properties

Figure 1 presents the graph of the Asian cruise shipping network (ACSN) with 215 cruise ports connected by 704 cruise routes (links). The network that appears consists of many clusters that are connected. This reflects that cruise ships can call at more than one port in the same country. Some ports are connected to ports in other regions. This is because cruise lines want to offer attractive and long-distance itineraries by including Asia and other regions. This also leads cruise lines to increase the prices of cruise packages. The ACSN has a reciprocity of 0.534, indicating 53.40% (375 links) of the total number of links that the network has connected between ports in both directions. The rest of the links connect between ports in only one direction. Note that reciprocity describes the likelihood of ports in the ACSN being mutually linked.

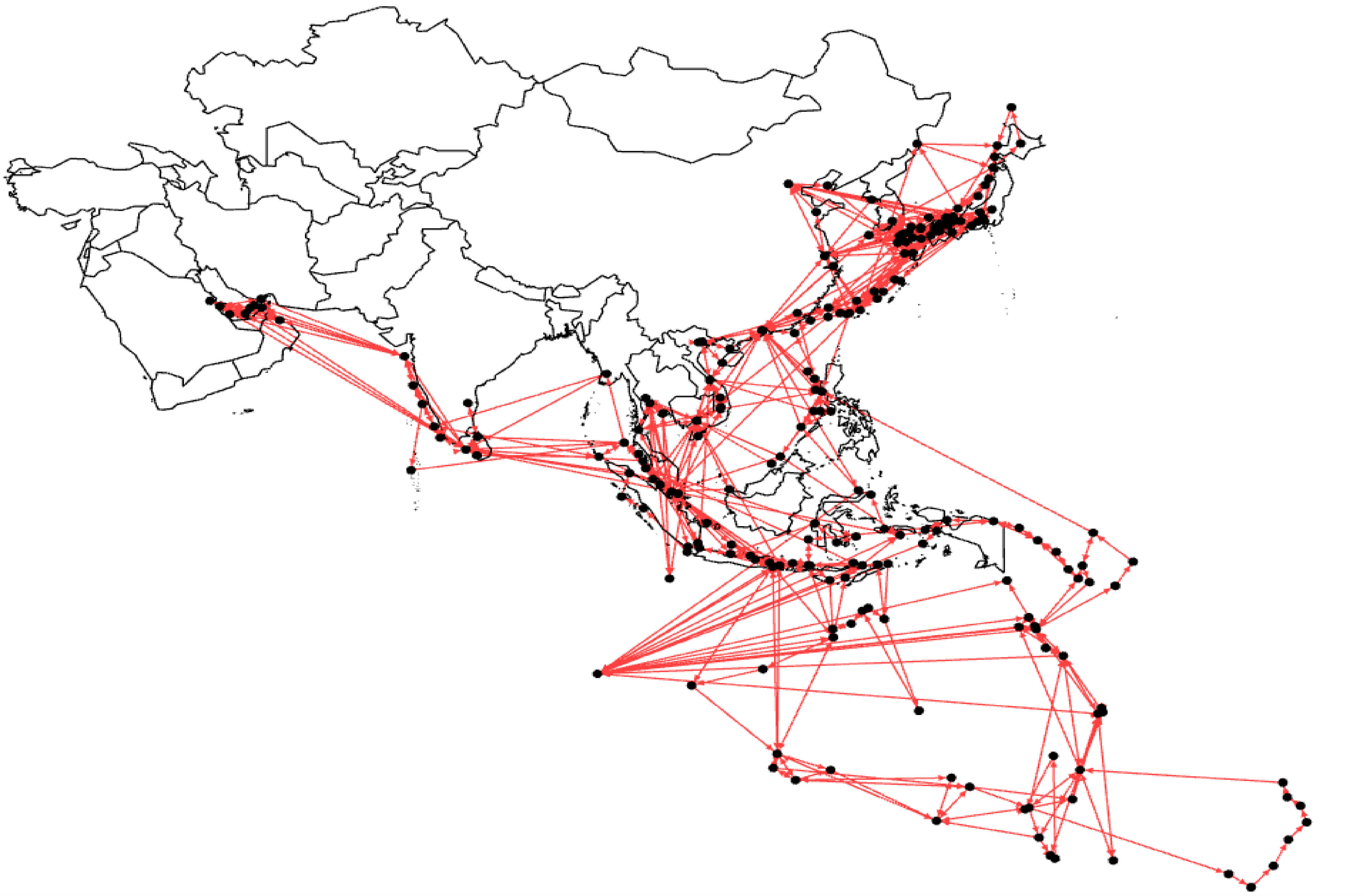

Figure 1. Graph of the Asian cruise shipping network with 215 ports and 704 links.

The ACSN has a network density of 0.015, indicating that only 1.5% of possible number links connect ports in the network. Thus, the ACSN is a sparse network as all its ports cannot connect to each other. Note that all ports can connect to each other when the network density is one. However, all ports are connected to the network (no isolated ports). This is because cruise lines provide across-country and across-region services [13].

The ACSN has a small average path length of 5.87, which is the average number of connection steps between two ports in the network. This means that cruise passengers that cruise in Asia need to visit no more than five ports of call to arrive to their last destination in each itinerary. Compared to the network size (N = 215), the average path length is relatively small [51]. This implies that the network has efficient connectivity. The network has a diameter of 42, indicating the maximum number of connection steps between two ports.

The overall clustering coefficient of the ACSN is about 0.257, which is relatively high, indicating that ports are well connected to others in the same clusters. In other words, it has a high intra-connection among ports. This might be because cruise lines offer direct cruising services to ports that are relatively close or have already existing cruising routes to maximize profit and reduce cruising costs [57]. This leads to hup ports connecting to many ports that are directly connected [51]. A high average clustering coefficient also indicates that some closely interconnected ports with high degrees connect to ports with larger degrees among themselves. That is, high-degree ports have a high tendency to form interconnected clusters or groups with high-cruise traffic links. This shows that the network exhibits the rich-club phenomenon, as detailed in the next section. A high clustering coefficient also reflects that it is easy to form regional agglomeration in the spatial distribution for cruise shipping [57].

Figure 2 shows the clustering coefficient of all ports in the ACSN. The clustering coefficients whose values are 1 account for 11.63% of total ports. This indicates that these ports are connected to adjacent ports. The clustering coefficients whose values are zero account for 32.56% of ports, reflecting that these ports are in the star structure of the network, which is the only path between adjacent ports [57]. The rest (55.81%) have clustering coefficients between 0.01 and 0.99.

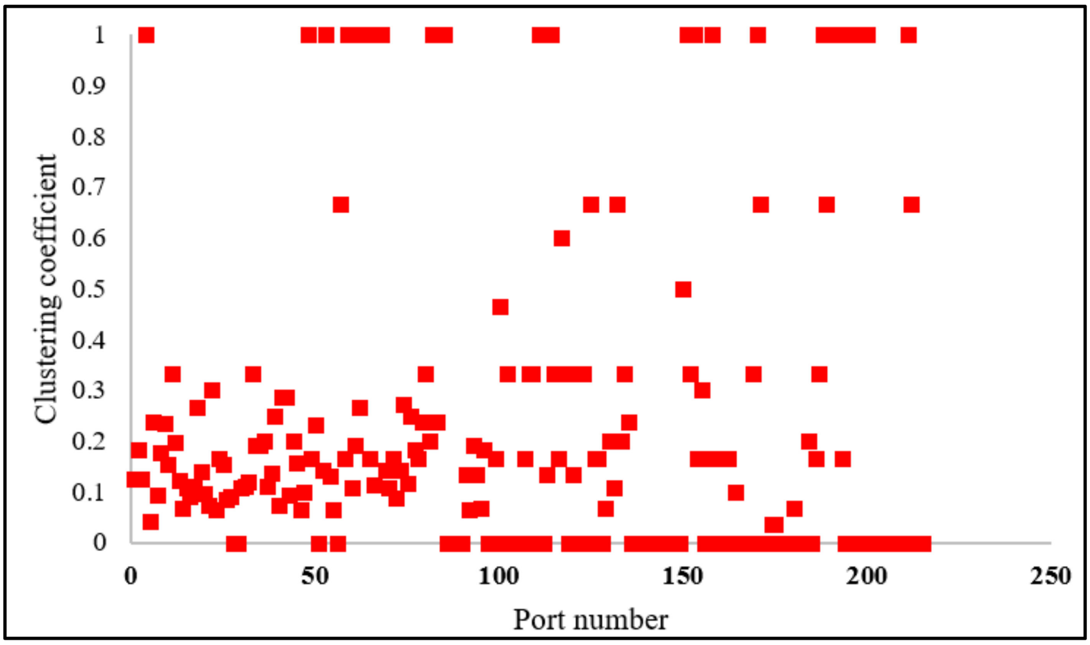

Figure 2. Clustering coefficients of cruise ports.

The ACSN has a rich-club coefficient of 0.0224, which is relatively low, indicating that only 2.24% of well-connected ports connect to each other. This means that well-connected ports are less connected to each other, but they tend to connect to not well-connected ports. In other words, ports with a high degree connect to other ports with low degrees rather than connecting to high-degree ports. This is maybe because the ACSN has a small number of ports with large degrees, but most ports have low degrees. In addition, high-degree ports also are in different countries, for example, Singapore, Yokohama (Japan), Hong Kong and Shanghai (China). Thus, it is difficult for high-degree ports to connect to each other, as most cruise lines design their voyages consisting of ports mostly in the same countries [33]. Thus, the network exhibits a small rich-club phenomenon.

4.2. Ports Properties

The average degree of ACSN is 6.55, signifying that each port in the network can be connected to at least six ports. Table 2 shows the top ten cruise ports in ACSN with the largest degree centrality values. Singapore is the most connected port with the largest number of links,42, followed by Yokohama (28), Hong Kong (28), Shanghai (26), Kagoshima (26), Osaka (24), Ho Chi Minh City (24), Hiroshima (23), Darwin (22), Benoa (20), Busan (19), Keelung (19), Cairns (18), Nagasaki (18), Kochi (18) and Komodo Island (17). These ports also have the highest in- and out-degree centrality values. This indicates that it is the most important and busy port in this region.

Table 2. Top ten ports with the largest values of centrality measures.

Rank	Port	Degree	Port	Betweenness	Port	Closeness
1	Singapore	42	Singapore	19,309.45	Darwin	0.000612
2	Yokohama, Hong Kong	28	Kochi	15,593.04	Kochi	0.000594
3	Shanghai, Kagoshima	26	Komodo Island	10,094.42	Kota Kinabalu	0.000587
4	Osaka, Ho Chi Minh City	24	Ho Chi Minh City	8593.52	Singapore	0.000581
5	Hiroshima	23	Darwin	8460.35	Miyakojima	0.000577
6	Darwin	22	Surabaya	8185.37	Kagoshima	0.000570
7	Benoa	20	Broome	8103.66	Banda Neira	0.000563
8	Busan, Keelung	19	Manila	6293.66	Cooktown	0.000562
9	Cairns, Nagasaki, Kochi	18	Hong Kong	5967.35	Benoa	0.000560
10	Komodo Island	17	Miyakojima	5429.10	Con Dao Islands	0.000558

Figure 3 presents the degree distributions of cruise ports with the same in-degree, out-degree and all degree. The degree distribution of the ACSN shows the exponential function ($y = 1.0993e^{-0.147x}$, $R^2 = 0.9788$) rather than the binomial or Poisson distribution. In-degree and out-degree distributions of the network also exhibit exponential distribution, $y = 0.9962e^{-0.289x}$ and $R^2 = 0.9760$ for in-degree distribution, and $y = 1.3621e^{-0.292x}$, $R^2 = 0.9759$ for out-degree distribution. These characteristics are also found in many real-world networks [58]. This reflects that the network has most ports with low connectivity, while a small number of ports have high connections. That is the ACSN is a small-world network. The degree distribution also shows that 60% of total ports have degree centrality values of 1-5 degrees, while 19.54% have values of 6-10 degrees. Only 20.46% of ports have degree centrality values larger than 5 degrees, in which 10.23% of ports have degree centrality values between 11 and 15 degrees, 6.04% have values of 16-20 degrees, and 4.19% have degree centrality values of more than 20 degrees.

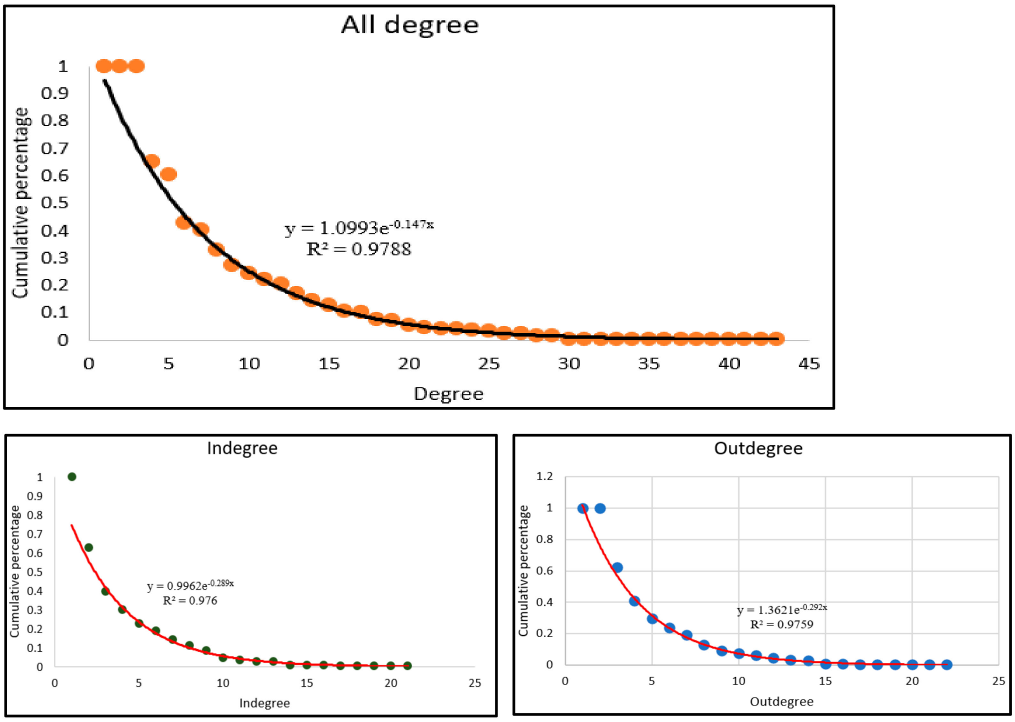

Figure 3. Degree distributions of ports in the network.

Figure 4 illustrates the in-degree and out-degree correlation of ports in the network. The ACSN has a positive correlation, indicating that the out-degree increases when in-degree increases. This reflects a strong in-out degree correlation [51]. The value of an out-degree is approximately linearly related to the value of an in-degree.

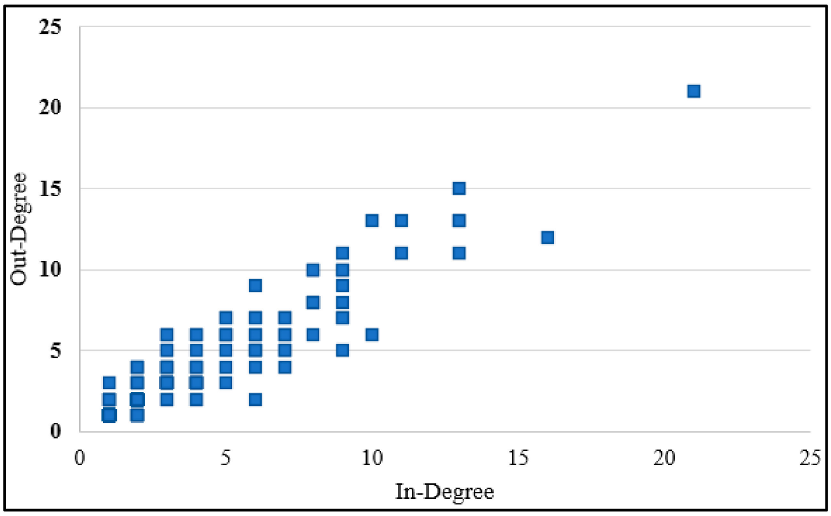

Figure 4. Positive correlation between in-degree and out-degree.

Betweenness centrality shows the direct accessibility of ports in the ACSN. The average betweenness centrality of ports in the network is 14,120.08. The top ten ports with the largest betweenness centrality values are Singapore, Kochi, Komodo Island, Ho Chi Minh City, Darwin, Surabaya, Broome, Manila, Hong Kong and Miyakojima, with betweenness centralities of 19,309.45, 15,593.04, 10,094.42, 8593.52, 8460.35, 8185.38, 8103.66, 6293.66, 5967.35 and 5429.10, respectively (Table 2). Thus, they are intermediary ports that tranship sea passengers between pairs of other ports that are not directly connected. The majority of ports (79.53%) have betweenness centrality values of less than 2000. Among these, 30 ports have the betweenness centrality of zero, which is at the periphery layer. Thus, they are periphery ports of the ACSN. A total of 7% of ports have betweenness centrality values between 2000 and 3000, while 5.12% have betweenness values from 3001–4000. Only 1.34% of ports have betweenness values between 4000 and 5000, and 6.05% have betweenness values larger than 5000. Singapore, Ho Chi Minh City, Darwin, Hong Kong, Kochi and Komodo Island have large values of degree and betweenness centralities. Thus, they are hubs for cruise shipping in the ACSN.

In terms of closeness centrality, ports with a high value of closeness centrality tend to have a small sum of connection steps to others and are more independent, as well as the highest reachability to other ports in ACSN. All ports are of low closeness centrality values, reflecting ports in the ACSN as a whole possessing low communication efficiency. To be specific, the relative value of closeness centrality of all ports is lower than 0.000, which indicates that cruise shipping between all pairs of ports cannot be achieved directly but needs to depend on one other intermediary port [14]. However, Darwin is the port with the largest closeness centrality (0.000612), followed by Kochi (0.000594), Kota Kinabalu (0.000587), Singapore (0.000581), Miyakojima (0.000577), Kagoshima (0.000570), Banda Neira (0.000563), Cooktown (0.000562), Benoa (0.000560) and Con Dao Islands (0.000558), as shown in Table 2. This indicates that they have the highest reachability to other ports. A total of 13.49% of the total ports have closeness centrality values lower than 0.00030, while 27.44% have closeness centrality values between 0.00030 and 0.00039. Ports with closeness centrality values between 0.00040 and 0.00049 account for 42.33%, which is the largest share. Ports with closeness centrality values of 0.00050 and higher account for 10.74%.

In conclusion, the ACSN has the characteristics of a small-world network with a small average path length, a high average clustering coefficient, and a degree distribution following an exponential function [57]. Singapore, Kochi Komodo Island and Darwin are the most important ports in the network as they have a high value of all centrality measures. The analysis results of centrality measures also reflect that the cruise shipping network does not have anomalous centrality like the airline network because it has a much smaller multicommodity structure than the airline network. This also may be because cruise transport has fewer geographical and political constraints than airline transport, leading cruise ships can travel a longer distance and visit many ports in one itinerary than aeroplanes [51].

5. Conclusions

This study conducted an empirical analysis of the Asian cruise shipping network (ACSN) of 215 cruise ports connected by 704 cruise routes in Asia using complex network analysis. Analysis results show that the ACSN is a sparse network with a relatively low density. It is a small-world network with a low average shortest path length, a large average clustering coefficient and degree distribution following an exponential function. There is a small number of ports that have high connectivity, and most ports have low connections. The ACSN also has a small rich-club coefficient, indicating high-degree mostly connect to low-degree ports.

A small number of ports play key roles in the network. Singapore, Yokohama, Hong Kong, Shanghai, Kagoshima, Osaka, Ho Chi Minh City, Hiroshima, Darwin, Benoa, Busan, Keelung, Cairns, Nagasaki, Kochi and Komodo Island are the most important and popular ports as they have high connectivity with the large values of degree centrality. Ports with high values of betweenness centrality are Singapore, Kochi, Komodo Island, Ho Chi Minh City, Darwin, Surabaya, Broome, Manila, Hong Kong and Miyakojima. Thus, they have high accessibility to others in the network. In addition, Singapore, Ho Chi Minh City, Darwin, Hong Kong, Kochi and Komodo Island are hubs for cruise shipping in the ACSN as these ports have a high degree and betweenness centralities. Darwin, Kochi, Kota Kinabalu, Singapore, Miyakojima, Kagoshima, Banda Neira, Cooktown, Benoa and Con Dao Islands with the highest closeness centrality have more reachability to other ports.

The above findings have drawn useful implications for the cruise sector to improve its operation and service network. The ACSN can become a tighter network with a larger network density by increasing the number of links. This can be achieved by cruise lines designing new cruise routes that have not existed in the network, for instance, Shanghai-Laem Chabang, Abu Dhabi-Hong Kong, Ha Long Bay- Banda Neira, etc. This leads to ports having a larger number of links. However, cruise lines have to consider potential passengers if they want to cruise for a long-distance itinerary without visiting the ports of call. The intra-connectivity among ports or an average clustering coefficient can be improved by encouraging ports in the same areas (clusters) to have more connections to each other rather than ports outside the clusters. This can be achieved by cruise lines designing voyages consisting of ports in the same clusters. This may also benefit cruise lines by reducing cruising costs and maximizing profit. Authorities can promote small-degree ports, such as Aburatsu, Belawan, Haiphong, Port Arthur, Hundred Islands etc., as hubs of the network by increasing cruise routes to connect to others or providing attractive promotions to attract more cruise ships and passengers. Cruise lines may design new itineraries consisting of hubs of the ACSN as they are ports with a large number of attractions and are in the big cities. This helps cruise lines increase the number of bookings and sales. Cruise lines can use 30 periphery ports with a betweenness centrality of zero as a guideline for promoting the ports to be a sustainable cruise network associated with a strategy and spatial characteristic for cruise port network integration. Cruise lines can improve the efficiency of cruise shipping by designing voyages consisting of ports with high reachability. This helps cruise ships reach all ports within a short distance. This also offers the maximum cruise shipping opportunities (i.e., cruise capacity.)

This study is subject to some limitations. First, this study conducted an analysis only based on voyage data to present the cruise shipping network but did not consider cruise lines' opinions to share how they design their voyages that might influence the network structure. This should be considered in future research. Second, this study did not take into account ports' properties that might affect the cruise network's formation, such as locations, attractions and infrastructure. Future research should connect network analysis by considering the attribute of ports and relevant factors. Third, the study analysed only a binary network. Weighted network analysis for cruise shipping should be conducted in future work. Future work may also analyse two cruise shipping networks in different regions and compare them.

Author Contributions: Conceptualization, M.K. and S.T.; methodology, M.K. and J.G.; software, M.K.; formal analysis, M.K. and S.T.; data curation, M.K. and S.T.; writing—original draft preparation, M.K., J.Z. and Y.-y.L.; writing—review and editing, M.K., Y.-y.L., J.Z., J.G. and S.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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