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Cruise shipping network of ports in and around the emission control areas: a network structure perspective

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Abstract

Purpose – The rapid growth in cruise shipping coupled with increasing public awareness of climate change has led to increasing concerns about the impact cruise shipping poses on the environment, especially regarding air emissions. This study analyses the cruise shipping network of ports in and around the emission control areas (ECAs) to understand the structural properties of the network and ports.

Design/methodology/approach – A complex network approach was used to analyse the network data of 239 voyages serviced by 14 international cruise lines, visiting 127 ports across 44 countries in the Caribbean Sea.

Findings – It is found that the network has a small-world property with a short average path length and a high clustering coefficient. The regulations affect connections among ports, in which most ports in ECAs have lower connections than ports outside ECAs. A few ports in ECAs play important key roles, but many ports outside ECAs play a more important role in the network because the regulations are barriers for cruise ships entering the ports.

Originality/value – The findings of this study have drawn useful guidelines for cruise lines and port authorities to improve their operations. Constrictive recommendations are suggested to policymakers for designing reasonable regulations to attract more cruise shipping to travel in ECAs.

Keywords Emission control areas, Cruise shipping, ECA regulations, Complex network analysis, Port connectivity

Paper type Research paper

1. Introduction

Cruise shipping is a form of shipping service used primarily for pleasure and leisure purposes, where the voyage itself, the ship's amenities and stops along the way all form a part

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of passenger experiences. It is one of the fastest-growing sectors in the transport industry. In 2019, global cruise passengers increased by more than 29.7 million and were expected to reach 32 million in 2020 (CLIA, 2021). The annual growth rate of the global cruise passenger volume grows at 6.63% (Sun *et al.*, 2021). The average ocean-going cruise ship weighs 222,900 tonnes and can carry 5,400 passengers (Lau and Yip, 2020). Pollutants and waste from cruise ships include wastewater, solid waste and air emissions. On a one-week voyage, the cruise ship generates 210,000 gallons of sewage, 1 million gallons of sewage and eight tons of solid waste (Musilli, 2017). Each passenger generates an average of 30 litres of sewage, 120–300 litres of greywater and 3.5 kilograms of solid waste onboard a cruise ship in a day (Lau and Not, 2020). The rapid growth in cruise shipping coupled with increasing public awareness of climate change has led to increasing concerns about the negative impact cruise shipping poses on the environment, especially regarding air emissions (Tichavska *et al.*, 2019), which is most apparent from a visual perspective. The emissions from cruise ships are typically most evident when berthing, where large hotel loads combined with their proximity to port cities result in bad air quality for city residents. This adversely influences city residents' physical conditions, such as asthma, lung cancer and respiratory diseases.

The negative health impacts of the two main ship emission pollutants, nitrogen oxides and sulphur oxides (SOx), have been well established. This leads to the introduction of emission control areas (ECAs) to curb excessive emissions. According to the International Maritime Organisation (IMO), ECAs are maritime areas in which stricter environmental controls were established to minimise emissions from ships (IMO, 2016). These emission regulations of emissions and thus the need to change fuel type both stem from the growing concerns about air pollution and the environmental impacts of the shipping industry (Chen *et al.*, 2018). Annex VI contains provisions for two sets of emission and fuel quality requirements, a global requirement and the more stringent controls in ECAs. ECAs currently encompass the Baltic Sea, the North Sea and the English Channel, the North American area and the United States Caribbean coasts.

Studies on cruise shipping focus mainly on the global service supply chain (Soriani *et al.*, 2009; Véronneau *et al.*, 2015), itinerary design (Wang *et al.*, 2017a, b) and capacity deployment and itineraries (Rodrigue and Notteboom, 2013). Cruise ship emission has begun getting attention in estimating and analysing ship exhaust emissions (Dragović *et al.*, 2018; Maragkogianni and Papaefthimiou, 2015). In terms of maritime studies in ECAs, most works concentrate on speed optimisation of ships, sailing paths, ship routing and scheduling based on ECA regulations to minimise the total costs (Fagerholt *et al.*, 2015; Gu and Wallace, 2017; Chen *et al.*, 2018). Only Zhen *et al.* (2018) conducted rescheduling voyage plans by optimising speeds, sailing patterns and ports-of-call sequences to reduce fuel costs in ECAs. These studies did not consider network analysis and connectivity among ports in ECAs and non-ECAs, especially a cruise shipping network. Therefore, this study aims to analyse the cruise shipping network of ports in and around ECAs to reflect network structure, characteristics and connectivity using a complex network approach. The findings have drawn implications for the cruise sector, ports authorities, industrial practitioners and policymakers.

The rest of this paper is structured as follows. Section 2 provides a literature review, while Section 3 describes the analytical methods. Section 4 presents the findings and discussion, while Section 5 provides managerial implications. The conclusion and the implications for future research are represented in Section 6.

2. Literature review

The threshold for sulphur limits in fuels both globally and within ECAs has been gradually lowered. The introduction and subsequent enforcement of ECAs have remarkably successfully controlled marine pollution but have impacted the shipping industry as with any restrictive measure. In terms of operations, fuel costs are a major total cost factor (Zhen *et al.*, 2018). For example, the *Harmony of the Seas* by Royal Caribbean has two four-storey-high 16-cylinder engines, which at maximum power could burn through approximately 66,000 gallons a day. Cost wise, this would mean that about two to three dollars per gallon could cost upwards of 200,000 dollars per day in fuel costs alone (Cullinane and Bergqvist, 2014). This expense is further magnified as cruising in ECAs requires the use of low-sulphur fuel compared to relatively cheap bunker fuel (Cullinane and Bergqvist, 2014).

ECA regulations also affect cruising speed and routing, in turn affecting itinerary design and port selection. Three alternatives are used in addressing the sulphur standards as regulated in ECAs (Fagerholt *et al.*, 2015). First, scrubber systems that remove sulphur from ship exhaust allow cruise ships to continue using bunker fuel or heavy fuel oil. Second is the use of liquefied natural gas (LNG) and onshore powering when berthed. Ports with LNG bunkering and capable of supplying power to ships become important drivers of port attractiveness to cruise lines. Equally important is the public perception of cruise lines as a clean and environmentally friendly alternative in the tourism sector. A port's status as a hub, where its attractiveness lies in its location and facilities, can be an essential factor in cruise lines adding or removing them from itineraries. Third, fuel switching allows ships to switch between burning heavy fuel oil outside ECAs and marine gas oil with low sulphur content inside ECAs (Gu and Wallace, 2017).

In July 2021, Venice banned cruise ships from entering its canals (Asero and Skonieczny, 2018). This is because the canals are listed as a UNESCO cultural heritage site and there are increasing concerns about the emissions that the ships bring to the city. Venice is the largest European cruise port, with 1.7 million passenger movements. With its landmark move to ban cruise ships, other ports might follow suit to promote an environmentally friendly image. Without countermeasures, the emissions of cruise ships would result in worsening air quality in ports due to the large hotelling loads even when berthed. Additionally, being green and sustainable has also been increasingly part of cruise and port authority agendas due to the cruise industry's heavy reliance on a positive public perception (Gonzalez-Aregall and Bergqvist, 2020).

From a tourist perspective, the inclusion of ports in ECAs could be an important decision-making factor if the cruise itineraries are being marketed as being more environmentally friendly. The Florida-Caribbean Cruise Association (FCCA) made several predictions for 2019 cruise travel, of which "Conscious Travel" is the most relevant to this study (FCCA, 2021). Travellers want to travel the world more consciously and are paying more attention to the environmental impacts of cruise shipping. This also extends to cruise lines implementing innovations that decrease the environmental footprint of cruise travel. Florida leads the US market share with 2.4 million passengers, with Miami being an important port for many cruises with Caribbean itineraries. In March 2010, the IMO designated the waters off North American coats as an area where stringent international emission standards exist, known as ECAs (EPA, 2010).

The ECAs extend 200 nautical miles away from the coast. As a result, ships travelling within these coasts are required to burn cleaner fuel or seek other alternatives such as scrubbers to clean exhaust fumes. These standards seek to lower emissions from ships and help safeguard port communities. Cruise lines can increase cruise fare, thus passing the increased fuel cost onto customers, minimise an itinerary's route inside ECAs or eliminate certain itineraries (CLIA, 2020). As many cruise ships sail in ECA bounds to offer views of the shoreline to cruisers, it might be a case where they are disproportionately affected compared to other forms of maritime traffic such as container ships. Following the 1% sulphur limit on fuels, Carnival Cruise Lines (CCL) announced an agreement with the United States of America (USA) and Canadian environmental agencies to invest US$180m in emission-reducing technologies on its ships to comply with ECA standards. CCL installed scrubbers and diesel particulate filters on ships to reduce SOx and particulate matter, which are pollutants damaging human health and contributing to smog. A similar deal between the US Environment Protection Agency and Royal Caribbean Cruises (RCC) was also agreed upon, which called for installing pollution controls instead of using low-sulphur fuels to meet the emission standards (EPA, 2010).

The Caribbean is the leading market for cruise ship fleet deployment, accounting for 34.4% of the global deployment capacity market share in 2018. The FCCA forecasted a 6.4% increase in passengers for 2019. In Caribbean and Latin American destinations, the cruise industry's economic impact cannot be discounted. Between 2015 and 2018, direct expenditures generated by cruise tourism increased by 6.3%. Ports welcomed 25.2 million onshore visits from passengers, with an average spend of US$2.56bn. A single transit cruise call with approximately 4,000 passengers and 1,640 crew members generates almost US$400,000 in spending alone. Additionally, cruise line expenditures generated US$534m, including port fees and taxes, repair and maintenance, payments to tour operators and payments to local businesses for supplies and services. This clears that the cruise industry's economic impact on the Caribbean and Latin America is significant and is projected to continue to grow.

3. Methodology

This study analyses the cruise shipping network covering ports in and around ECAs using a complex network approach. The approach is used to create the network studied based on nodes (cruise ports) connected by edges or links (cruise shipping routes) in direct ways. A complex network has been used to analyse maritime networks extensively, such as Ducruet and Zaidi (2012), Tsiotas *et al.* (2018), Kanrak and Nguyen (2022), Kanrak and Nguyen (2022) and Kanrak *et al.* (2022).

This study interprets network structure and properties and the roles of ports. The study gives prominent importance to network visualisation as a whole. The study is based on data from cruise itineraries offered by cruise lines. Network analysis is conducted at the network and port levels to reflect the connectivity between ports inside and outside ECAs in the Caribbean. At the network level, the structure and properties of the cruise shipping network in the Caribbean are analysed using network density, average path length, clustering coefficient, assortativity and rich-club coefficient. The roles and properties of ports are analysed using degree, betweenness and closeness centralities. The details of these measures are presented in Table 1.

At the network level, network density indicates network connectivity by determining the ratio of links to nodes. A network with high network density reflects its high connectivity level. This shows that the interconnectivity of links serves to reinforce and strengthen the connections between other ports. Average path length measures the mean shortest path between two nodes. A network with a high short average path length has the efficiency of information or mass transport between nodes. The clustering coefficient reflects the degree to which nodes tend to cluster together, indicating the level of cluster or group of a network. Therefore, it is the average clustering coefficient of all nodes. Assortativity indicates the preference of nodes to connect to others with the same properties. Assortativity usually examines the tendency of a high-degree node to be connected to other high-degree nodes. The rich-club coefficient measures the extent to which well-connected nodes also connect to each other. A network with a relatively high rich-club coefficient indicates *the rich-club effect* or *the rich-club phenomenon* and will have many connections between nodes of a high degree.

At the individual port level, degree centrality reflects the number of links that connect to a node. A port has a high degree of centrality if it is connected to many ports. Thus,

Measure		Description	Equation
Network level	Network density	Fraction of the number of links and the possible number of links	$\rho(G) = \frac{m(G)}{n(n-1)}$
	Average shortest path length	Proportion of the sum of the shortest connection steps between nodes i and j and the total number of possible links	$L = \frac{1}{n(n-1)} \sum_{i \neq j}^{n} d_{ij}$
	Clustering coefficient	Probability of a new pair of nodes to the third node	$C_i = \frac{2E_i}{k_i(k_i - 1)}$
	Assortativity	Proportion of nodes to connect to others with the same properties	$r = \frac{\sum_i e_{ii} - \sum_i a_i b_i}{1 - \sum_i a_i b_i}$
	Rich-club coefficient	Proportion 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	$\phi(k) = \frac{2E_{>k}}{n_{>k}(n_{>k} - 1)}$
Port level	Degree centrality	Sum of number of links that a node has	$C_D = \sum_{j=1}^{n} a_{ij}$
	Betweenness centrality	Ratio of the shortest paths passing through it and the number of the shortest paths	$C_B = \sum_{s \neq i \neq t} \frac{\sigma_{st}(i)}{\sigma_{st}}$
	Closeness centrality	Inverse of the average shortest paths from a node to all other nodes	$C_C(i) = \frac{n-1}{\sum_{j \neq i} d_{ij}}$

Note(s): The equations in Table 1 use the following notations.
$m(G)$ = the number of links, n = the number of nodes, d_{ij} = connection steps between nodes i and j, E_i = the number of links between the neighbour of node i, k_i = the number of links of node i, a_i and b_i = ratio of each type of a link attached to nodes of type i, e = matrix's elements, e_{ij} = fraction of links connection nodes of type i to the nodes of j, $\|x\|$ = sum of all elements of the matrix x, $E >_k$ = the number of links between nodes and degree greater than or equal to k, $n >_k$ = the number of nodes with a degree greater than or equal to k, a_{ij} = constant is one if a link connects nodes i and j; zero if otherwise, $\sigma_{st}(i)$ = the number of the shortest paths passing through node i and σ_{st} = the number of the shortest paths
Source(s): Table courtesy of Scott (1988) and Albert and Barabási (2002)

Table 1.
Network and port statistical measures

a high-degree node is an important node playing as a hub controlling network connectivity. Betweenness centrality presents the degree to which two nodes stand between each other. Closeness centrality measures the average shortest path from one node to all others, reflecting the ability of a node that is able the spread information and transport very effectively through a network. A node with high closeness centrality has the shortest distance to other nodes.

In this study, network density is used to analyse network connectivity and the potential connections among ports. The average path length was used to analyse the efficiency of network connectivity. The clustering coefficient is used to analyse the level of intra-connection among ports, explaining the level of meeting cruise connections among a port's neighbours. Assortativity is used to analyse the tendency of ports with a similar degree to connect to each other. The rich-club coefficient is used to examine *the rich-club phenomenon* that exists in the network studied. Degree centrality is used to identify a hub port with high connectivity. Betweenness centrality is used to identify an intermediary port with high accessibility. Closeness centrality is used to identify a port with high reachability, reflecting its ability to reach all other ports.

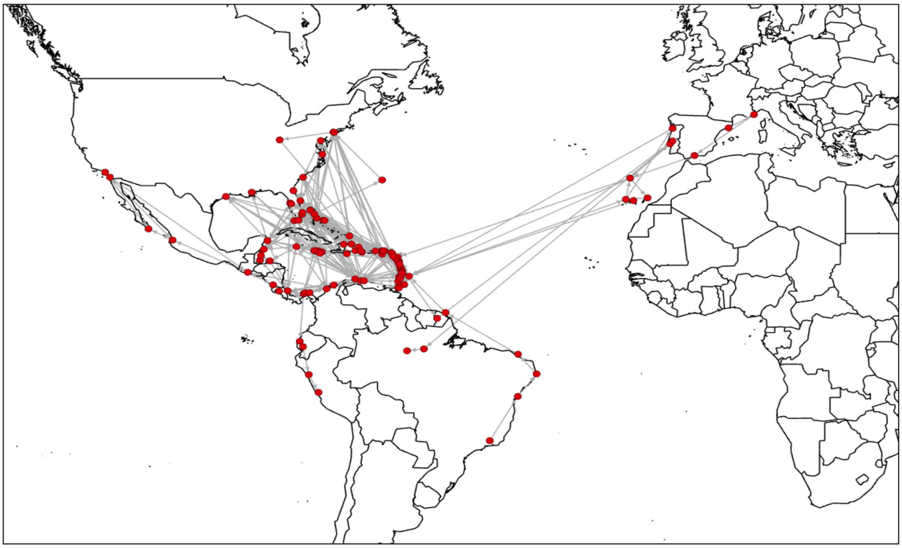
This study utilises secondary data collected from the Australian cruise agent website (www.ecruising.travel/). The data cover 127 ports in 44 countries, mainly in the Caribbean, with 239 cruise voyages operated by 14 international cruise lines. Note that different states in the USA are considered separate countries. This study considers different voyages with durations of 1–15 nights in the peak season, visiting the Caribbean from November 2022 to April 2023. This is because short itineraries are very famous for passengers cruising during this season, and cruise lines often design their itineraries to serve the increased need in cruise demand. Cruise lines also need to take into account emission control regulations due to the enforcement of ECAs. These may affect network and port connectivity. The analysis was conducted using the R statistical software.

4. Results and discussion

4.1 Network topological properties

Figure 1 illustrates the graph of the cruise shipping network in the Caribbean, built based on voyages designed by cruise lines, comprising home ports, ports of call and cruise routes (links) connecting ports during voyages. The network has 127 ports connected by 596 links, of which 41 ports are in ECAs across 16 countries. Caribbean ports connect to ports in the same and other regions because cruise lines design itineraries specifically to bring passengers to visit the Caribbean Sea during the peak season. Caribbean cruise ports (destinations) are characterised by nice weather and attractive coastal areas providing various manmade and natural attractions (Sun *et al.*, 2021). The network comprises subnetworks with ports connected mainly to ports in the same areas. The graph also presents that cruise shipping traffic is very crowded, reflecting that ports in the same region tend to connect to each other rather than ports in other regions. However, some ports in other regions are still connected to the Caribbean ports because cruise lines want to bring people from other regions to experience Caribbean cruising.

The network density is 0.0373, which is relatively low, reflecting that the network has a low connectivity level. That is, cruise shipping covers only 4% of possible links between ports, reflecting that cruise lines efficiently design itineraries by serving a large network with a small number of links. This is also because they have to design voyages in line with ECA regulations in the Caribbean. Thus, they try to optimise benefits by designing itineraries that



Source(s): Figure by authors

Figure 1. Graph of the cruise shipping network of ports in and around ECA areas in the Caribbean, with 127 ports and 596 links

cover the most cruise ports in this area using the smallest number of links. A low network density also reflects that ports in the network do not have a tight relationship.

The top three ports chosen as the departure ports of voyages were Miami, Fort Lauderdale and Bridgetown. Forty-eight voyages depart from Miami, 43 voyages from Fort Lauderdale, 21 voyages from Bridgetown and the rest from other home ports. These three ports are popular because they are the top 10 busiest ports globally with large passenger numbers (Avoid-Crowds, 2020). This signifies that they are popular for cruising, although some ports are in ECAs, especially Miami and Fort Lauderdale. This also indicates that some passengers do not consider ECA regulations when choosing cruising. They primarily focus on cruise packages and destinations.

The most popular voyage departing from Miami is Miami→ Puerto Plata→ San Juan→ Gustavia→ Roseau→ St. John's→ St. Maarten→ Miami (Figure 2a). It is a round trip with a total sailing distance of 2,715 nautical miles (nm). Miami and San Juan are in ECAs. For this itinerary, the cruise ship sails 320 nm within ECAs (green). The most popular voyage departing from Fort Lauderdale is a round trip: Fort Lauderdale→ Princess Cays→ San Juan→ Tortola→ Point-A-Pitre→ Martinique→ St. Maarten→ Fort Lauderdale (Figure 2b). The voyage has a sailing distance of 2,878 nm, and 298 nm in the ECAs is included. The most popular voyage departing from Bridgetown is a round trip: Bridgetown→ Scarborough→ Port of Spain→ St.George'S→ Kingstown→ Roseau→ Castries→ Bridgetown (Figure 2c), with a sailing distance of 842 nm. It does not pass ports in ECAs. Most voyages depart from Bridgetown and visit ports outside ECAs because cruise lines probably do not want to bear the costs of entering ECAs. The average cruise price per day of the voyages departing from this port is lower than those departing from Miami and Fort Lauderdale. Therefore, it might not be profitable for cruise lines to design voyages departing from Bridgetown to visit ports in ECAs.

The network has an average path length of 3.799, which is relatively low, indicating that each port has about four connection steps on average to link to another port in the network. This reflects the high efficiency of mass cruising on the network with a short number of connection steps to another port. This also reflects that the network is efficient and easy to navigate. It is convenient for a cruise ship to sail from one port to another port since most ports are close to each other as a ship takes the shortest distance to reach ports. In addition, the network has hubs facilitating short connections among ports. That is, the neighbours of a port are likely to be neighbours of each other, and most ports can be reached from every other port by a small number of links (connection steps).

The network has a high average clustering coefficient of 0.321, indicating that it has a high intra-connectivity among ports. This also reflects the high tendency of meeting neighbours of a port as neighbours themselves (Carlini *et al.*, 2021). That is, there are many among a port's neighbours. In addition, ports mostly rely on the hubs connected to others.

Compared with a random network with the same number of ports and links, a random network has an average path length of 3.226 and a clustering coefficient of 0.080. The network

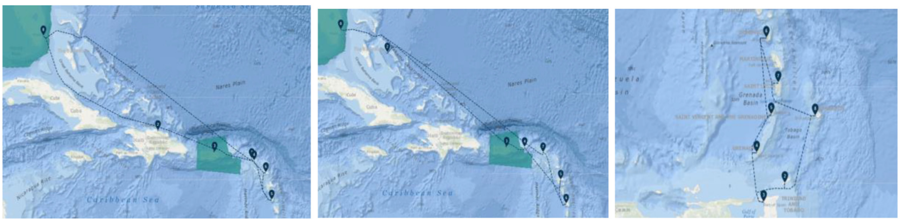


Figure 2.
Three most popular voyages departing from the three most popular departure ports passing through ECAs (in green)

Source(s): Figure by authors

studied has a short average path length similar to a random network, but the clustering coefficient is larger than that of the random one. Therefore, the network is a small-world network, reflecting that the neighbours of a port are likely to be neighbours of each other. Due to this, most neighbouring ports can be reached from every other port by a small number of links (Downey, 2018). A small-world network also indicates that although the network is large-scale, the shortest path length between any two ports is small. That is, ports are closely connected, and cruise shipping efficiency is high (Zhang and Zeng, 2019).

The assortativity coefficient of the network is 0.085. This reflects that only 8.5% of high-degree ports connect to each other, but most high-degree ports connect to low-degree ports. This implies that cruise lines design voyages consisting of ports in the same areas without considering the degree of ports. However, cruise lines consider ECA regulations for designing voyages, leading to ports in ECAs having small connections. For example, ports inside ECAs tend to connect to each other. Likewise, ports outside ECAs most likely connect to each other, leading to ports with a high degree tending to connect to low-degree ports. This helps cruise lines organise their services. For example, ports outside ECAs are on the same voyage with a longer duration than a voyage with ports inside ECAs. The positive assortativity coefficient implies the network's tendency to have central ports with high interconnection (Mai *et al.*, 2017). This is corroborated by the rich-club coefficient. The network has a rich-club coefficient of 0.063, reflecting the level of well-connected ports that are connected to each other. Thus, the positive assortativity and rich-club coefficient confirm that the network exhibits *a rich-club phenomenon*, leading the network to have many connections between ports with high degrees.

4.2 Port properties

Cruise ports in the Caribbean have different roles defined by different measures of centrality. Ports with a larger degree of centrality are more important. A high-degree port is better serviceable for cruise shipping. Table 2 shows that Miami ranks first with 42°, followed by St.

Rank	Port	All degree	Port	In-degree	Port	Out-degree
1	Miami	42	St. John's	23	Miami	23
2	St. John's	39	Oranjestad	22	Fort Lauderdale	19
3	Fort Lauderdale	37	San Juan	20	Bridgetown, Basseterre	18
4	Bridgetown, San Juan	36	Miami	19	Nassau	17
5	Basseterre	34	Fort Lauderdale, Bridgetown	18	St. Thomas, San Juan, St. John's	16
6	Oranjestad	32	Basseterre	16	St. Maarten, Gustavia	15
7	Nassau	30	Port Canaveral, Nassau, Castries	13	George Town, Castries	14
8	St. Thomas	28	George Town, Grand Turk, St. Thomas, St. George's, Gustavia	12	Port Canaveral, Willemstad, Martinique, St. George's	12
9	Castries, Gustavia	27	Cozumel, Puerto Plata, St. Maarten	11	Grand Turk, Tortola, Kralendijk	11
10	George Town, St. Maarten	26	Half Moon Cay, Tortola, Martinique, Cartagena	10	Oranjestad, Key West, Cartagena	10

Source(s): Table by authors

Table 2. Top ports with the highest degree centrality values

John's, Fort Lauderdale, Bridgetown, San Juan, Basseterre, Oranjestad, Nassau, St. Thomas, Castries, Gustavia, George Town and St. Maarten. Namely, they have more cruise shipping relationships with other ports and are hubs of cruise shipping in the network. Among these, Miami, Fort Lauderdale, San Juan, Oranjestad, St. Thomas and St. Maarten are the ports with core locations in ECAs. Thus, they can be preliminarily thought to have a relatively strong demand for cruise shipping. They also have a wide scope of cruise shipping trade inside and outside ECAs.

St. John's, Oranjestad and Miami are the top three ports with high in-degree centrality values, indicating that they are directly connected to many incoming ports. Thus, they are incoming hubs of the network, which import cruise shipping from other ports to them. Miami, Fort Lauderdale, Bridgetown and Basseterre have the largest outdegree centrality values. That is, they directly connect to outgoing ports. This indicates that they are outgoing hubs that export cruise shipping to other ports with a high connectivity level.

The degree distribution of all ports describes how links are distributed across ports of the network. In Figure 3, the degree distribution of the network follows an exponential function ($y = 1.1792e^{-0.102}x$ and $R^2 = 0.9768$), reflecting that most ports have low connectivity, while only a small number of ports are highly connected. Fifteen percent of ports have more than 20° and above. Eighty-five percent of ports have degrees less than 20. Among these, 5.51% have 16–20°, 10.24% have 11–15° and 17.32% have 6–10°. Ports with 1–5° accounted for the largest proportion, totalling 51.97%.

In terms of betweenness centrality, Bridgetown has the highest betweenness centrality, followed by Fort Lauderdale, St. John's, Cartagena, Gustavia, Oranjestad, Willemstad, Miami, San Juan and Castries. Thus, they are defined as intermediate and transition ports with the highest accessibility for cruise shipping routes. There are 21 peripheral ports with a betweenness centrality of zero. This is because these ports do not have the shortest path between them and another port. Ports with betweenness centrality values from 1 to 500 account for 60.63%, whilst 12.60% have a betweenness centrality of 501–1000. Only 4.72% have a betweenness centrality of 1001–1500, and 2.36% have a betweenness centrality of 1501–2000. Ports with a betweenness centrality of more than 2000 account for a small proportion of 3.15% for over 2000. This betweenness distribution indicates that the network does not have a strong hub-and-spoke structure.

Figure 4 presents the spatial heterogeneity for the degree and betweenness centralities of cruise ports. Ports with high-degree centrality values are in the USA, Antigua, Barbados, St. Barthelemy, St Kitts & Nevis, Aruba and the Bahamas (Figure 4a). That is, these countries are important and popular for cruise shipping, although they have some ports in ECAs. Ports

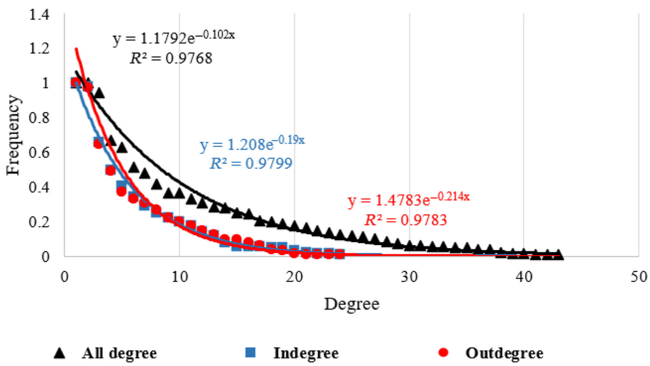


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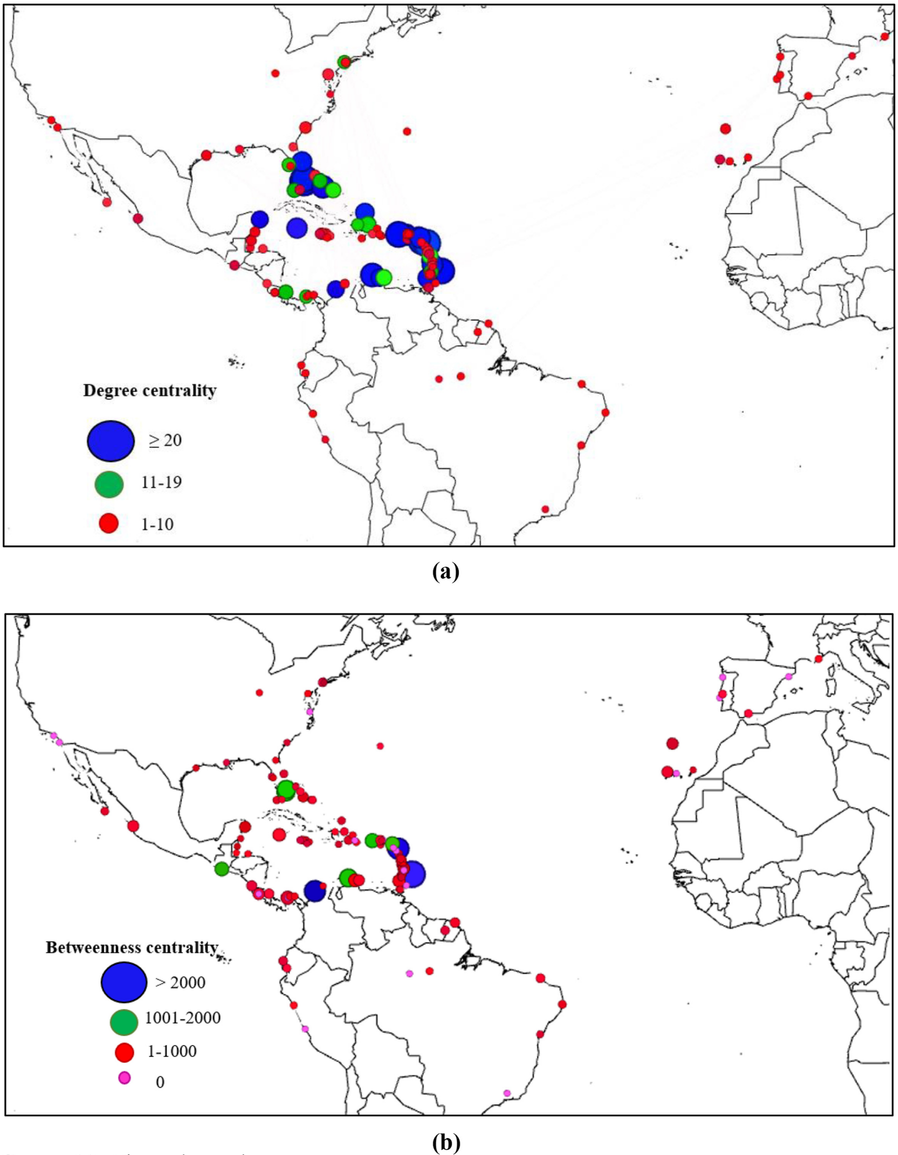
Figure 3.
Degree distribution of ports in the network



Source(s): Figure by authors

Figure 4. Spatial heterogeneity for the centralities of ports

with high-betweenness centrality values are in Barbados, the USA, Antigua, Colombia, St. Barthelemy, Aruba and Curacao (Figure 4b). This reflects that these countries are high accessibility with the shortest path to connect to another county. Overall, the USA, Antigua, St. Barthelemy and Aruba have high degree and betweenness centralities. Thus, they have high connections and the shortest path to connect to others. They also are hubs of cruise shipping in the Caribbean.

Regarding closeness centrality, all ports have a similar closeness centrality that is close to zero. That is, it is difficult for all ports to connect to each other because they are located in different locations. Some cruise lines also do not want their ships to visit ports in ECAs. Thus, all ports cannot connect to each other. However, Rio De Janeiro has the highest closeness centrality, followed by Salvador De Bahia, St. George's, Recife, Castries, Gustavia, Fort Lauderdale, Fortaleza, Basseterre, Ile Royale, Miami, Bridgetown and Point-A-Pitre. This reflects that they have high reachability to others. Overall, 63.78% of ports have closeness centrality values of 0.00050–0.00059, while 7.87% have a closeness centrality lower than 0.00040. Ports with a closeness centrality of 0.00040–0.00049 account for 3.15%. Only 25% have a high closeness centrality of at least 0.00060.

4.3 Breakdown the topological structure of each cruise line network

Fourteen cruise lines provide services for 1–15 nights in the Caribbean. Most voyages depart and end at ports outside ECAs. Few cruise lines service voyages departing and ending at ports inside ECAs. Among these, 63.60% of voyages depart from four ports. Namely, 43 voyages depart from Fort Lauderdale, 21 from Bridgetown, 20 from Port Canaveral and 20 from Tampa. The rest depart from the 20 other ports.

In Table 3, the RCC has the biggest network with the largest number of ports and links. This implies that RCC focuses on the Caribbean Cruise market rather than other markets as the RCC is the biggest cruise company in this region and has been providing cruise services in this area for a long time. Therefore, the RCC is more familiar with regulations in the Caribbean, allowing the cruise line more ease in operating services.

Cruise line	Ports	Links	Network density	Average path length	Clustering coefficient	Assortativity	Hub	Intermediary	High reachability
CCL	33	93	0.09	3.6	0.26	0.16	Nassau	Miami	Miami
CEC	27	76	0.108	2.957*	0.282	−0.011	Fort Lauderdale	Fort Lauderdale	Fort Lauderdale
CRC	27	33	0.047	5.199	0.05	−0.239	Miami	Miami	Gustavia
CUL	6	6	0.2*	3	0	–	–	–	–
HAL	20	28	0.074	4.047	0.061	−0.01	Fort Lauderdale, Half Moon Cay	Half Moon Ca	Fort Lauderdale
Norwegian Cruise Line (NCL)	41	117	0.07	3.96	0.27	0.04	Puerto Plata	Cartagena	Great Stirrup Cay
Oceania Cruises	30	68	0.078	3.528	0.289	0.15	Bridgetown	Bridgetown	St. George's
Ponant	29	48	0.059	5.156	0.311	0.322	Les Saintes	Les Saintes	Les Saintes
PRC	28	42	0.056	7.747	0.236	0.518*	Fort Lauderdale	Martinique	Martinique
RSSC	18	35	0.114	3.899	0.379*	0.306	Roseau	Roseau	Roseau
RCC	45*	143*	0.07	3.42	0.28	0.18	Cococay	Bridgetown	Labadee
SCL	29	63	0.08	3.37	0.25	−0.27	Carambola Beach	Carambola Beach	Carambola Beach
Silversea Cruises	34	67	0.06	4.237	0.284	0.106	Gustavia, St. John's	Bridgetown	Rio De Janeiro
Viking Cruises	21	24	0.057	3.771	0.162	0.408	Castries, St. John's, Roseau	Roseau	Roseau

Note(s): * refers to an efficient value
Source(s): Table by authors

Table 3.
Structural properties of each cruise line service network

Cunard Line has the highest network density since it has the smallest number of ports and links. Therefore, all ports have a high potential to connect to each other, leading to the network having a high efficiency as its ports can connect easily to each other with a low shortest path, as confirmed by its lowest average path length. Regent Seven Seas Cruises (RSSC) has the largest clustering coefficient, indicating the neighbour of a port have high connections to each other. This reflects a high intra-connecting among ports. Ports in this network also rely on hubs to connect to other ports.

Nine cruise lines have positive assortative coefficients, reflecting that high-degree ports in their networks connect to each other, thus showing a rich-club phenomenon. Princess Cruises (PRC) has the highest assortativity coefficient of 0.518, followed by Viking Cruises, Ponant and RSSC. The highest assortativity of PRC indicates that high-degree ports connect to other high-degree ports. Celebrity Cruises, Crystal Cruises, Holland America Line and Seabourn Cruise Line have negative assortativity coefficients, reflecting that high-degree ports connect low-degree ports. The CUL's network does not show the assortativity coefficient since its ports have the same degree.

To sum up, RCC has the biggest share of the network in the Caribbean by benefiting from being a pioneer for cruising in this area. Therefore, RCC is familiar with the cruising policies and ECA regulations of the Caribbean. Some cruise lines with large networks have no important ports in ECAs. Some small networks have important ports in ECAs because their voyages depart from ports in other areas. Three ports in ECAs play important roles in some networks, such as Miami, Fort Lauderdale and Martinique. In contrast, some ports outside ECAs play key roles in some networks. That is, some ports play key roles in the network of a cruise line but do not play essential roles in the overall cruise network. Most ports are outside ECAs. Different centrality measures suggest different roles that ports can play in their networks. These require different conditions and strategies to promote themselves. Other ECA ports also can promote themselves to have more links. However, this would be difficult because they are subject to ECA regulations that are barriers for cruise ships to visit.

5. Implications

Cruise lines operating inside ECAs entail a heavier financial burden in terms of wastewater management, emissions and energy. Also, fuel costs are the key factor influencing total operational costs, as well as a bunker fuel is much cheaper than low-sulphur fuel. Thus, it will significantly increase total operational costs. ECA regulations determine routing and speed decisions, which are key fuel cost determinants (Zhen *et al.*, 2018). This leads to unwillingness in operating their services inside ECAs as it lowers operating margins and higher unit costs. In the competitive global business environment, it can be challenging for cruise lines to keep pace with new environmental regulations whilst maintaining profitability. Governments and IMO should provide technical support and a financial incentive in supporting the transition of cruise lines to greener shipping with the latest abatement technologies. Using LNG can be promoted to minimise greenhouse gas emissions and comply with strict ECA regulations. However, LNG is not yet ready for cruise ship propulsion. The rationale behind this is due to safety concerns regarding the storage of LNG onboard as well as the logistical challenges of LNG supply. Most cruise ports lack LNG facilities, and existing cruise ships have to be retrofitted to store LNG safely. Ports need to provide LNG facilities, which can be part of a government initiative to promote more sustainable tourism and smart cities.

Cruise itinerary design is determined by dynamic market situations and conditions such as seasonal demand, tourist satisfaction, a balance between onshore and onboard time, must-see destinations and trip duration. Operational factors must be considered, such as nautical accessibility, the berthing capacity of ports and intermodal transport, which require the synchronisation between ports of calls and air transfers in longer itineraries spanning different countries (Rodrigue and Notteboom, 2013). These affect the network structure. Cruise passengers are the leading stakeholders of cruise tourism. Thus, cruise lines should design itineraries and products based on passengers' behavioural intentions and preferences. Port authorities should collaborate with destination authorities to provide unique experiences inside ECAs to attract cruise ships to call at ports. This leads to ports inside ECAs having a tighter relationship.

The COVID-19 pandemic has put passengers on high alert, whereby they more than ever are concerned about wellness tourism. Responsible cruise tourism mainly focuses on minimising negative social, environmental and economic impacts. ECA regulations align very closely with this increasing trend of responsible cruise tourism. Most tourists and cruise lines still overlook the notion of responsible cruise tourism. Thus, the promotion and enlargement of the cruise market in ECAs should be conducted thoroughly and critically. Cruise lines that comply with the regulations incur additional operational and administrative costs, which in turn cause an increase in the prices of cruise packages to offset the additional cost. Travellers being price sensitive might otherwise choose different cruise packages. Port authorities in ECAs may provide lower passenger fees and dockage tariffs.

Ports with low connectivity outside ECAs should promote themselves as home ports by increasing connections to other ports outside ECAs. This may benefit cruise lines to minimise costs relevant to entering ECA areas. Port authorities should promote their ports by providing promotions to attract cruise ships to visit them, thus reducing port fees, renovating facilities, extending berthing duration or organising attractive coastal or island cruise tourism activities. Only a small number of cruise lines design their itineraries visiting ports in ECAs because they do not want to bear the costs of entering the areas. Policymakers should consider redesigning regulations to attract more ships to visit these areas. Some regulations may need to be more flexible. These make the network more efficient, and ports have more connections. Some port authorities still get involved in the port liberalisation process (Lau and Yip, 2020). Port authorities keep giving short periods of contractual agreements and concessions. To this end, there will be a smaller investment size in the cruise industry. In other words, it will demotivate institutional investors to make large investments in cruise ports. The development of green cruise ports will become an obstacle in ECAs.

An analysis of the cruise shipping network in ECAs generates a new idea of evolution and exhibits a new spatial organisation pattern, which addresses the cooperation and specialisation of each connected cruise port. It is required to coordinate their related interests to intensify their coherent connectivity and collaboration. The network comprises regions and countries with various interests, encountering complicated governance matters and regional cooperation. The network is scattered with different functions of the primary hub and secondary hub ports. It also maintains spatial contact, giving equal development chances to individual centres. Authorities and governments can use these to generate the co-competition to strengthen the close coordination and minimise operational costs (Wang *et al.*, 2018). Adjacent port generation can enhance the port system in the forthcoming years. This will foster coordination between ECA and non-ECA ports, facilitate regional integration and maximise resource allocation (Wang *et al.*, 2022).

6. Conclusion

This study analysed the cruise shipping network of 127 cruise ports and 596 cruise links inside and outside ECAs. It was found that the network is sparse because ports have a relatively low network density. The network is a small-world network with a short average path length and a high clustering coefficient. Ports with high degrees connect to other high-degree ports, reflecting the rich-club phenomenon. Ports outside ECAs play more important roles than ports in ECAs. Miami, Fort Lauderdale and St. Johns are hubs with many connections. The intermediary ports are Bridgetown, Fort Lauderdale and St. John's, while Rio De Janeiro, Salvador De Bahia and St. Georges are ports with high reachability. The RCC provides the biggest service network with the largest number of ports and links since the cruise line benefits from being a pioneer for cruising in the Caribbean. However, most of its voyages consist of ports outside ECAs. Smaller cruise lines provide their services in ECAs.

The findings are useful for the relevant sectors. Cruise lines can improve their networks and redesign them with higher efficiency. Port authorities and policymakers, especially in ECAs, may promote their destinations to have more connections by reducing the barriers preventing cruise ships from entering. Unique value in terms of historical scenery inside ECAs to attract more travellers should also be considered.

Although this study analyses the network of ports inside and outside ECAs, there are still some limitations. First, the study is focused only on the Caribbean region. To generalise, future research may consider other regions like Asia, China coast, North America, the Arctic and other non-Atlantic rims recognised as remarkable ECAs. Second, the study uses a complex network approach to examine the cruise shipping network only from the network perspective. Future research may adopt the automatic identification systems (AIS) data with the bottom-up pollution emission models to comprehensively analyse cruise activities and examine the environmental impacts of cruise shipping. Future research may explore the behaviour and distribution of cruise ships and determine the effects of ship emissions. The use of AIS data may generate detailed emission estimations with valuable insights into the distribution of cruise ports in ECAs and non-ECAs. This may foster policymakers to design and implement regulations to motivate more cruise lines to provide cruise services in ECAs. Third, this study analyses a binary network, which does not consider the weights of links. Future research may analyse the weight of links in the network to reveal more insights into cruise operations and service networks. Fourth, the study analyses ports both in and out of ECAs. Future research may analyse only the network of ports inside the ECAs to reflect the network connectivity and relationships among ports that may be affected by ECA regulations.

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