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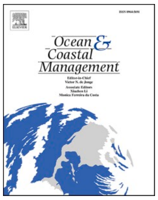

# Vulnerability analysis of cruise shipping in ASEAN countries facing COVID-19 pandemic

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ABSTRACT

The COVID-19 pandemic has significantly affected the cruise shipping industry, disrupting ports and shipping. However, current research predominantly focuses on the impact on individual ports or vessels, leaving a gap in understanding how these disruptions propagate across cruise shipping networks. To address this gap, a novel vulnerability assessment methodology that offers a comprehensive perspective on the broader impact of COVID-19 on cruise shipping networks is developed. It first uses a new weight social network analysis approach to quantify the vulnerability of each cruise port in a shipping network and then combines the curie port local pandemic risk to generate a new index to reveal the COVID-19 impact on the whole cruise shipping network systematically. The new methodology is applied to analyse the ASEAN cruise shipping network. This real-world COVID-19 pandemic case study yields valuable insights that bridge theoretical and practical domains. Integrating local port-level vulnerabilities with shipping network-level vulnerabilities creates a unique index. This index quantifies the individual and collective influence of COVID-19 risks at different cruise ports on the entire regional cruise shipping network. The results directly impact cruise lines seeking to enhance their operations' resilience in the face of COVID-19 challenges. The vulnerability index explains how risk exposure at various ports shapes the network's dynamics. This insight empowers cruise lines to optimise ship deployment schedules, lowering the network's overall COVID-19 pandemic risk. The research method and outcomes offer a pioneering perspective on the vulnerability of cruise shipping networks to COVID-19 disruptions, and other possible disruptions (e.g., climate change) in a broad sense. By elucidating interconnected vulnerabilities, cruise lines are equipped with actionable insights to navigate the complexities of global challenges.

## 1. Introduction

Cruise shipping has rapidly expanded worldwide, relevant to the increasing vessel supply and tourist demand in the last decade (Di Vaio et al., 2021; Liu et al., 2016). In 2019, the global cruise industry welcomed nearly 30 million passengers, creating jobs for 1.8 million people worldwide and contributing over $154 billion to the global economy. Compared with the data a decade ago, there is a 67% increase in passengers (CLIA, 2021). Indeed, the cruise shipping industry was expected to reach 32 million passengers in 2020 globally, compared with 30 million passengers in 2019 (Davies, 2019).

The tourism sector significantly contributes to the economy of ASEAN countries. The key ASEAN countries include ten different countries: Brunei, Cambodia, Indonesia, Lao, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam. ASEAN, consisting of many popular travel destinations, various top attractions (e.g., Sentosa Island, Dong Khoi Street, Phang Nga Bay), and a long coastline, are favourable to developing remarkable cruise tourism. As a result, more ports and sightseeing infrastructures are created, increasing the ship routes and benefiting local tourism industries regionally and globally (Gibson, 2018). Interestingly, tourists are increasingly exploring rich tourism resources, warm weather throughout the year, unique destinations, and distinctive oriental cultures they may find in ASEAN. In addition, the emergence of new destinations in ASEAN countries has created an opportunity to investigate new cruise itineraries. As a result, 39.58% of ASEAN cruise ports are top-scheduled port calls in the Asian

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regions (Lau and Yip, 2020). The list of top scheduled port calls in Appendix 1 is generated by all cruising ships scheduled to pass through ASEAN region, which shows the importance of cruising networks in ASEAN countries (CLIA, 2020). The area is predicted to receive 4.5 million passengers before 2035, ten times rise from 2016 (Gibson, 2018). In doing so, ASEAN countries actively participate in infrastructure investment projects in response to the possibility of cruise tourism growth.

The COVID-19 pandemic breaks the growth pattern of the cruise industry while bringing new research dimensions to risk and resilience studies in the field. Since the fourteen-day quarantine measure on Diamond Princess anchored at Yokohama Port made it out of schedule on 3rd February 2020, the outbreak of COVID-19 has generated a catastrophic economic impact on the cruise (Tzourouni, 2021). The forecasts have been negatively overtaken by the sudden and quick outbreak of the COVID-19 pandemic, following the social distancing measures, "lockdown" policy, and travel restrictions (Cruise Critic, 2020). In 2021, the cruises resumed operations around the world based on the policies and situations in different countries (Thakkar, 2021). The number of onboard tourists and experiences is significantly reduced due to Covid-19 preventive measures (Radic et al., 2021; Yuen et al., 2021). To rationalise the preventive measures and minimise their negative impact on the cruise economy, the issue of assessing the vulnerability of cruising shipping to COVID-19 risks becomes necessary and urgent to address. Given that the spread of the virus is a national issue, it is reasonable to assume that cruise ports would use national-level data to assess the risk of COVID-19 outbreaks and make decisions accordingly. Furthermore, many countries have implemented the same safety measures to reduce the risk of COVID-19 transmission across different transport sectors, including cruise terminals within the countries (Earley and Newman, 2021). For example, all ASEAN countries consistently include mandatory mask-wearing, temperature checks, and social distancing requirements on public transportation throughout the country (Harrington and Hadjiconstantinou, 2022).

The current literature reveals that COVID-19 risk studies in cruise ports are conducted at a local port level (Florentina and Gabriela, 2022; Knight et al., 2020), assuming that the vulnerability of a local port-level COVID vulnerability will exist independently and generate no effect on the other cruise ports in the same shipping network. However, given the high-level connections between the cruise ports in a region and the risk that can be cascaded from one port to another port in its downstream connections, it is vital to conduct a new vulnerability assessment from a global cruise shipping network perspective, taking into account the influence magnitude of one cruise port in the whole shipping network.

Centrality assessment is a powerful tool for vulnerability assessment in networks (Mishra et al., 2012), including shipping networks. It allows for the identification of nodes that are important to the network in multiple ways, which can help to prioritise these nodes for vulnerability assessment and mitigation efforts (Liu et al., 2018c; Wan et al., 2021). For the first time, this paper integrates local port-level vulnerability indicators and shipping network-level vulnerability analysis for a cruise shipping system. To analyse the sensitivity of a cruise port to the entire network within the ASEAN countries, the concept of network resilience is introduced in order to keep a good harmony with the relevant literature. Network resilience measures the ability of a network to maintain its functionality and connectivity despite disruptions (Wang et al., 2023b), such as the COVID-19 pandemic.

In the context of the cruise industry in ASEAN countries, a cruise port's resilience to the entire network would depend on several factors, including its centrality within the network, the availability of alternative routes and ports in case of disruptions, and the capacity and preparedness of the port to handle health and safety measures related to the pandemic (Beh and Lin, 2022). The COVID-19 pandemic has demonstrated that the impact on the cruise industry goes beyond local ports and can have cascading effects throughout the network, highlighting the need to assess the vulnerability and resilience of the entire network (Lau et al., 2022b). The application of centrality theory can be a valuable tool in modelling the shipping network's resilience and identifying vulnerable cruise ports. The findings can inform policy and decision-making to reduce the risk of disruptions and ensure the continued functioning and connectivity of the network.

This paper aims to develop a new vulnerability assessment method to enable better visualisation and understanding of the overall impact of COVID-19 on cruise shipping from a network perspective. The method has revealed two novelties in shipping network analyses, including 1) constructing a weighted shipping network with local vulnerability input and 2) developing a global cruise shipping network vulnerability analysis framework. Its main contributions include its pioneering attempt to combine a port-local COVID-19 vulnerability indicator with a cruising network-level vulnerability by a weighted cruise shipping network configuration. It can aid in shifting shipping vulnerability studies from the current foci on either a global network-level cruising network vulnerability or a local port-level safety towards an advanced hybrid solution in which network-level external and port-level internal vulnerabilities are presented and integrated with weight assignments.

To achieve this aim, this paper is organised as follows. In Section 2, this paper thoroughly reviews the literature on COVID-19 impacts and Social Network Analysis (SNA) on cruising. Then, in Section 3, the methodology of the new vulnerability analysis is developed by combining local port-level vulnerability indicators and network-level vulnerability assessment. Then, the vulnerability assessment of an ASEAN cruising network, which presents one of the fastest-growing global cruising markets, is undertaken as a real case to demonstrate the feasibility of the new method in Section 4. Afterwards, the result of the assessment is then presented in Section 5. Finally, the essential findings and their implications are summarised in the conclusion in Section 6 and Section 7.

## 2. Literature review

In this section, the review is split into two parts. The first part presents the relationship between COVID-19 impacts and the cruising industry, while the second section presents the latest development in network analysis and vulnerability analysis on shipping networks. They give the state of the art of COVID-19 studies in the cruise shipping industry and the vulnerability assessment of shipping networks, respectively.

### 2.1. *COVID-19 and cruising*

Tourists are not only victims of pandemics but also carriers driving the spread of the virus. Therefore, isolation and social distancing are crucial for minimizing a COVID-19 pandemic (Ege et al., 2021). Cruise ships are operated as "isolated communities" with unique features and confined settings. As a result, these ships have an ideal environment for spreading the virus. As such, Moriarty et al. (2020) described that "cruise ships are often settings for outbreaks of infectious diseases because of their closed environment, contact between travellers from many countries, and crew transfers between ships". Therefore, the cruise industry suffers from COVID-19 much heavier than the cargo shipping industry (Dahl, 2020). The world-leading cruise lines (e.g. Celestyal Cruises, Crystal Cruises, Cunard Line, Fred. Olsen, Hebridean Island Cruises, Victory Cruises, Viking, and Windstar) have cancelled their 2020 seasons because of the COVID-19 pandemic (Saunders, 2020). After implementing robust social distancing policies and large-scale vaccination programs, some countries, including the United States (US) (Hines, 2021) and the United Kingdom (UK) (Payne, 2021), start to resume cruise sailings in the 2021 summer.

Even cruise travel is gradually recovering. The tourists who have been seriously curtailed cannot receive their rights as before (Baum and Hai, 2020). Quarantine, vaccination, and rapid antigen testing are essential and have become standard measures for boarding. Batista et al.

(2020) indicated that most tourists and crew are vaccinated. The quarantine perhaps slows the disease spread. Also, vaccine passports are still under discussion. There may be limited capacities for venues and restaurants on the ships for entertainment, which also limits the cruising experiences during the journey. In addition, it is relatively tricky for cruise lines to postpone cruise operations or revise cruise itinerary planning because they must take 2–3 years before an actual journey (Ito et al., 2020). On the demand side, travellers were hostile toward taking a cruise in the future, and most said they would not travel until there was a vaccine (Holland et al., 2021). Some tourists were economically impacted during the pandemic, and the budgets for luxurious travel declined (Pan et al., 2021). Therefore, the recovery rate of cruising trips is generally slow, and different regions show significant rate variation.

In the current literature, there are no lacking studies on the impact of COVID-19 on cruising shipping, mainly from tourism, transportation, and sustainability perspectives. However, transportation-related studies are limited and largely based on qualitative review without implementing statistical analyses, and suggestions have been given to the industry (DA SILVA, 2021a; Holland et al., 2021). More specifically, many studies within this context have been conducted to understand the impact of the pandemic during and after its occurrence. Florentina and Gabriela (2022) examine the paths of recovery and resilience for the whole cruising industry by reviewing the industry's response to unprecedented events. Sharma et al. (2021) provide a resilience-based framework by including sustainable tourism and climate action as new crucial developments by literature review. Knight et al. (2020) generate a vulnerability assessment of the tourism and hospitality sectors in the epicentre of Wuhan and Hubei Province, China, by phone interview and questionnaire. Lee et al. (2022) use online questionnaires to investigate the critical influence of social support on the spread of COVID-19. It is evident that cruising vulnerability assessments at a local scale are successfully examined using qualitative methods. It reveals two research challenges to address: 1) quantitative analysis of cruising vulnerability when facing COVID-19 and 2) the impact analysis of COVID-19 on cruising networks from both local and global perspectives. For the former studies, if the resilience assessment cannot be assessed quantitatively, the developed management system does not motivate industrial professionals for its implementation, possibly because their effects are not visible in a state-of-the-art risk assessment (Yang et al., 2014). For the latter, if the global network-level vulnerability cannot be effectively incorporated into the overall vulnerability analysis, COVID-19 risk-cascaded effects will be overlooked in the modelling, leading to error-prone results.

There may be subsequent pandemic waves in the forthcoming years, and COVID-19 impacts on cities are different. Furthermore, international cruises involve many travellers and stakeholders from different countries (Shrestha et al., 2020). Therefore, it is necessary to respond to inconsistent control measures among other countries and companies (Zhang et al., 2022). Also, the onboard and local experiences are required to be sociable and enjoyable, which must come with social dynamics (Papathanassis, 2012). Given such challenges, cancellation and adjustment of calls could happen (Pallis and Papachristou, 2021). Thus, it is exceptionally critical to enhance the resilience of cruise shipping networks (Zhang et al., 2022) and provide a more resilient framework for maintaining ship operations (Barnes and Oloruntoba, 2005). The significance of this study is further evident when the additional multiple unfolded challenges threatening the development of the cruising industry are taken into account, including the pandemic (Li et al., 2022), climate change (Di Vaio et al., 2021, 2022), connectivity (Lau and Yip, 2020), and other safety issues (Liu et al., 2016). Considering this concern, it is necessary to holistically analyse and integrate cruise port connectivity and the local-level port COVID-19 vulnerability for a comprehensive cruise vulnerability assessment.

### 2.2. Network robustness and vulnerability

This review section focuses on the methods applied to assess network robustness and vulnerability, with a specific emphasis on cruise shipping networks. In the intricate realm of cruise shipping, various pivotal elements converge to shape a complex network. "Mother cruise ports" act as central hubs, facilitating connections with a unique passenger group known as "flyers," which seamlessly merge cruise and air travel. These interactions, such as Singapore and Ho Chi Minh City, substantially impact the network's passenger flow and overall structure (Ito et al., 2022). Complementing this, "calling ports" serve as stopover destinations for cruise ships, collectively moulding the intricate patterns of the cruise shipping network, such as Nha Trang and Sihanoukville (Lau et al., 2022b). The network's dynamism is underscored by the juxtaposition of regular ports, integral to standard itineraries, and irregular ports, which introduce variability into cruise routes. Crucially, the classification of cruise ship service types, termed "products," plays a pivotal role (Lau et al., 2020). Aligned with varying experiences like cultural exploration, nature-based or adventure tourism, these service types intricately dictate the quantity and geographical distribution of calling ports, thus further influencing the network's configuration and connectivity (Lau et al., 2023; Wang et al., 2023a).Therefore, network robustness and vulnerability assessments are common for cruising networks, and they involve six approaches, each offering unique insights:

Random Failure and Targeted Attack Models assess the impact of node or link failures on network connectivity, considering both random failures and deliberate, targeted attacks. Notable applications include evaluating vulnerabilities in air transportation and maritime supply chains, as demonstrated in works by Zanin et al. (2018) and Liu et al. (2018a).

Percolation Theory, a theoretical framework, examines network breakdown points as failures propagate through the system. It finds applications in diverse fields, ranging from studying urban rail transit networks to analyzing food webs. Bai et al. (2023) and Kolzsch and Blasius (2011) have contributed to understanding network resilience using percolation theory.

Cascading Failure Models simulate how failures spread through networks, emphasizing the potential for small failures to trigger extensive cascades. Researchers have employed this approach to assess vulnerabilities in maritime transportation networks exposed to natural disasters and air transportation networks susceptible to targeted attacks, as illustrated by Xu et al. (2022) and Wen et al. (2022).

Graph Theory Metrics provide valuable insights into network robustness, including the size of the most significant connected component, average path length, clustering coefficient, and degree distribution. These metrics have found utility in studying vulnerabilities in various networks, including air transportation and railways, as indicated in studies by Wong et al. (2020) and Xu et al. (2022).

Network Flow Models focus on capacity and resource allocation efficiency in network vulnerability assessment. This approach has practical applications, such as optimising container flow distribution in port networks and planning the safe transport of hazardous materials in complex transportation networks. Researchers like Christiansen et al. (2020) and Wu et al. (2019a) have contributed to this area.

Game-theoretic models employ game theory to evaluate network vulnerabilities by considering the strategies of both attackers and defenders. It offers insights into defence strategies for critical infrastructure networks like power grids and informs decisions on optimal security investments in networks such as container shipping. Recent studies by Do et al. (2023) and Sahin et al. (2021) have applied game-theoretic approaches to enhance network security.

While these approaches offer valuable insights, graph theory metrics are particularly well-suited for assessing cruise shipping network vulnerability. Graph theory metrics possess several advantages, including their versatility in various network types, insights into a network structure, and potential for combining with other methods (Liu et al., 2018c; Barthélemy, 2011).

### 2.3. Social network analysis for cruising networks

SNA is a valuable tool for studying cruise shipping networks with graph theory metrics (Wasserman and Faust, 1994). It provides a visual representation of the network's complexity, aiding in understanding its structure and dynamics (Liu et al., 2018b). SNA also helps identify central players and quantitatively assesses network properties, such as vulnerability and robustness (Poo and Yang, 2022). Additionally, it enables researchers to understand information flow and make predictive analyses, making it essential for risk assessment and planning in the cruise shipping industry. Therefore, SNA in constructing networks and assessing the centrality of ports is widespread among scholars from different disciplines. They have provided various assessments to evaluate scales and purposes, including shipping network vulnerability and resilience.

By implying SNA approaches in cruise shipping, Jeon et al. (2016) investigate the cruise network in Asian regions. Tsiotas et al. (2018) examine the two spatial networks constructed by cruising groups performing in the Mediterranean by employing complex SNA. Apart from network analysis, descriptive statistics of ports and hinterlands were also presented in the paper. Jeon et al. (2019) then further propose the hub and authority centrality (HAC) metric based on dual-directional centrality values for the Asian cruising market. In 2021, Kanrak and Nguyen (2022) analyse the Asia-Pacific cruising networks' structure, characteristics, and connectivity. In the same year, Rodriguez et al. (2021) assess the cruise shipping network by SNA, and the ports were further considered the most important concerning HAC by degrees. Although SNA and HAC on cruise shipping networks can generate a successful unweighted SNA with an independent study on hubs by HAC, the analysis and results are based mainly on the port of call and overlook the link's capacity for weighted SNA (Liu et al., 2018a, 2018b). The weighted SNA can present the significance of different links and simulate a network that can better reflect reality. The strength of links can be described by physical distances and/or operation costs involved in various transport networks (Ahnert et al., 2007).

Based on the tourism nature of cruising, the cruising schedule is designed based on product categories, locations of tourist resources and customers (Sun et al., 2021). Therefore, the weights of cruising networks can be more diverse than the other shipping networks (Rosa-Jiménez et al., 2018). If there is no weighted assignment, the result can be very arguable to have any real representation and generate meaningful implications. By understanding the development of weighted SNA for cruise shipping, it is possible to observe the critical changes in weighted links and nodes for better scheduling and routing management during and after the impact of COVID-19.

### 2.4. Research contributions

Previous relevant studies in the literature (Poo and Yang, 2022, WU et al., 2019a) reveal that multiple-centrality assessment can generate a more comprehensive evaluation of the importance of nodes in a network compared to individual centrality measures. The Borda count method (Liu et al., 2018c) can help identify essential nodes for different reasons and gain a more nuanced understanding of the network by assigning points to each node based on their ranking in each measure. This approach can be beneficial when analysing complex networks with many nodes and different types of interactions. Such benefits are witnessed and appreciated by a few illustrative studies that used a combination of degree, closeness, and betweenness centrality to assess the vulnerability of transportation networks using the Borda count method. ZHANG et al. (2022) used these three measures in combination with other criteria to evaluate the vulnerability of maritime transportation networks. Chen et al. (2019) used degree, closeness, and betweenness centrality to assess the vulnerability of liner shipping networks under different attack scenarios. Finally, Wu et al. (2017) used these three measures and other criteria to assess the vulnerability of airline networks. Therefore, when degree centrality, closeness centrality, and betweenness centrality are jointly used to assess the robustness and vulnerability of a network, the Borda Count approach can provide an overall ranking of the nodes in the network with an equal weight among the three centralities.

In the analysis of the state-of-the-art studies on shipping network vulnerability, a significant research gap becomes evident. Most current research has primarily concentrated on assessing global network-level vulnerability by examining the dependencies among nodes and links, overlooking the integration of local-level port vulnerability into global assessments. This gap in two-dimensional vulnerability studies can result in error-prone safety decisions and hinder the rational development of strategies for enhancing shipping network resilience. For instance, during local-level port risk analyses, ports with low local port-level risks but high global network-level vulnerability (or vice versa) are frequently overlooked in global risk management efforts.

To address this gap and foster more rational risk-based decision-making, this paper pioneers a novel approach that combines local and global vulnerabilities to create a unified index. This index offers a more comprehensive perspective on the vulnerability of shipping network nodes from a methodological standpoint. The main contribution of this research lies in bridging the gap between local and global vulnerability assessments, providing a more holistic view of network vulnerability. This approach empowers decision-makers to make informed choices in managing risks within the global cruise shipping network.

Moreover, while non-weighted Social Network Analysis (SNA) has effectively highlighted the significance and robustness of ports within the shipping network context, it falls short of addressing the localized vulnerability of individual ports when confronted with various risks. This limitation becomes particularly critical when assessing substantial global issues rather than random or cascading failures. To address this, our paper introduces a weighted SNA approach guided by link capacities, acknowledging the geographical disparities in cruising networks' demands and supplies. This innovative approach utilises a link's cumulative annual shipping capacity to construct the weighted SNA, providing a more accurate reflection of the annual passengers travelling through the link. This original methodology captures the repercussions of external factors on distinct ports and the overarching global cruise shipping network, enhancing the accuracy of vulnerability assessments and risk management strategies.

In light of these considerations, a hybrid approach that combines SNA with the Borda count method is introduced initially. This approach capitalises on the strengths of both methodologies, leveraging SNA to comprehend the network's intrinsic vulnerabilities and dynamics while incorporating the Borda count method to systematically aggregate preferences and evaluate the impacts of external factors, such as COVID-19-related capacity reductions, on the network structure. This combined approach provides a comprehensive framework to analyse and mitigate vulnerabilities in cruising networks under complex global challenges.

In the upcoming section, the analysis delves into the influence of the COVID-19 pandemic, which has reduced cruise ship capacity. Given the varied COVID-19 circumstances and regulations across different countries, the magnitude of these capacity reductions also varies, potentially altering the network's structure due to the pandemic's influence.

## 3. Methodology

It is necessary to choose the corresponding centralities for the network vulnerability analysis and issue their meanings. Degree centrality measures the number of direct connections a node has and can be used to identify port importance for maintaining communication and tourism within the network. A node with a high degree may not necessarily be the most critical node in terms of controlling the flow of information or resources in the network if it does not have connections to other key ports. Closeness centrality measures the degree to which a port node is close to all other nodes in the network and can be used to identify essential ports for maintaining network efficiency. Closeness centrality assumes that all nodes are equally important, which is not the case in a network where some port nodes are more influential or powerful than others. However, closeness centrality cannot by itself capture the importance of nodes not directly connected to the rest of the network. Finally, betweenness centrality measures the degree to which a node lies on the shortest paths between other nodes in the network and can be used to identify critical ports for maintaining network functionality. Betweenness centrality fails to capture the importance of nodes with longer paths than other nodes, as it only considers the shortest paths. Hence, it cannot capture the importance of nodes in the multiple paths that are not necessarily the shortest.

While eigenvector centrality is also a valuable measure of node importance, it measures the transitive influence of nodes within a network. It is less relevant for analysing cruise shipping networks (Kanrak and Nguyen, 2022). Compared to container networks, transhipment is very rare in cruising tourism (Sun et al., 2019), so eigenvector centrality is applicable in this paper. On the other hand, hub and authority centralities are primarily concerned with identifying the most influential nodes in a network. In contrast, degree centrality, closeness centrality, and betweenness centrality are used in tradition to capture different aspects of node importance such as popularity, accessibility, and brokerage roles (Oldham et al., 2019). It means that the three used centrality indices can address the influential power of ports (as the hub and authority centralities) and the other required features for the vulnerability analysis of the cruise networks. Overall, combining centralities by the Borda Count can effectively accommodate the weaknesses of individual degree centrality, closeness centrality, and betweenness to present an effective solution to assessing the vulnerability of cruise shipping networks.

Therefore, a new methodology of incorporating the impacts of local port-level risk into the link weights of a cruise shipping network is presented in Section 3.1, and the associated preliminaries are discussed to emphasise its rationale and applicability in Section 3.2.

### *3.1. Formulations*

The research flowchart is shown in Fig. 1. The whole analysis can be divided into four steps: structuring an ASEAN cruise shipping network, modelling the ASEAN cruise shipping network, vulnerability assessment with COVID-19 impact, and vulnerability assessment without COVID-19 impact.

The formulation for weighted SNA, known as the network-level vulnerability assessment, is presented first to understand the vulnerability assessment mechanism. Based on the graph theory, a network is built by ports (also called vertices or points) and links (also called edges or lines) (Biggs, 1993). The structure of a network with $N$ ports can be presented by a $N \times N$ binary matrix ($W$):.

$$W = \begin{bmatrix} w_{11} & \cdots & w_{1N} \\ \vdots & \ddots & \vdots \\ w_{N1} & \cdots & w_{NN} \end{bmatrix} \tag{1}$$

The unnormalised weight $w_{ij}$ is 0, assuming that there is no connection between ports $i$ and $j$. In the case of undirected networks with no loops, the adjacency matrix is symmetric ($w_{ij} = w_{ji} \geq 0$), and all elements of the main diagonal, from $i$ to $i$, equal 0 ($w_{ii} = 0$).

Three different centralities, closeness centrality, degree centrality, and between centrality, are all appropriate to measure the centrality, known as the importance of a port in the system (Wang and Cullinane, 2016, WU et al., 2019a). Degree centrality is the first invented and calculated by the number of links connecting to a port, as shown in Equation (2) and Equation (3). In-degree ($D(in)$) is the number of connections that point inward at a vertex, and out-degree ($D(out)$) is the number of connections that originate at a vertex and point outward to other vertices. The lesser the degree value of a port, the less it is connected to or from other cruise ports, and vice versa.

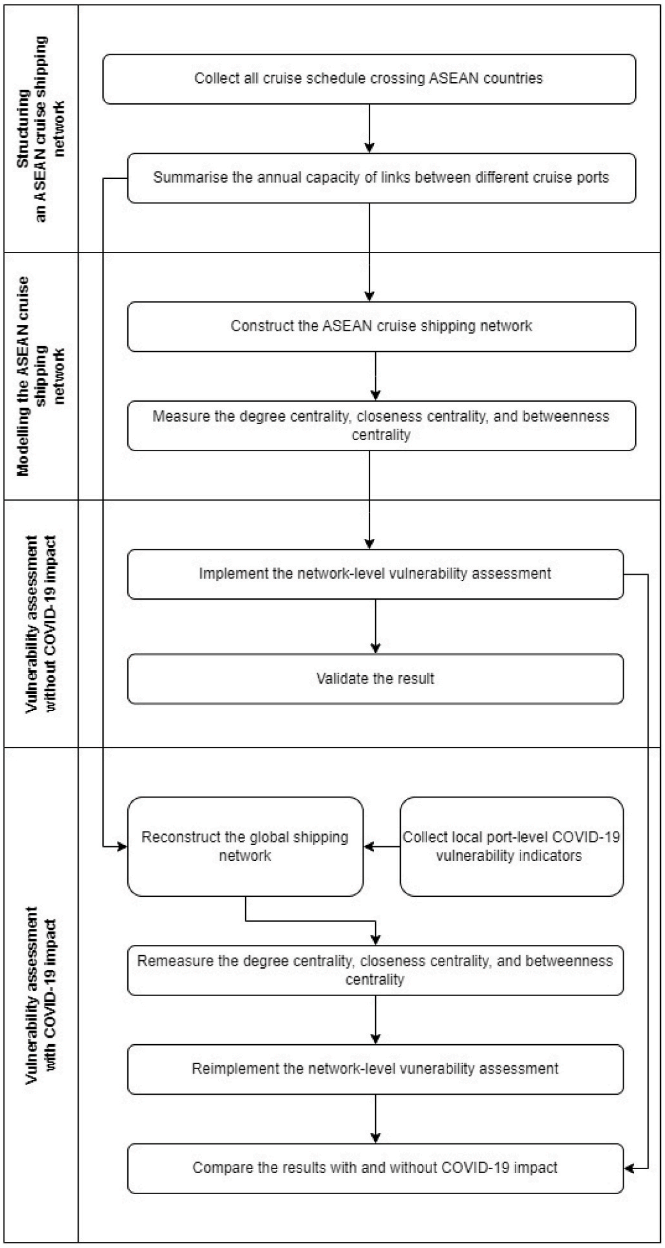

**Fig. 1.** The research flowchart.

$$D(in)_i = \sum_{h}^{N} w_{hi} \tag{2}$$

$$D(out)_i = \sum_{j}^{N} w_{ij} \tag{3}$$

$N$ represents the total ports within an investigated network, $w_{hi}$ represents the weighted link from $h$ to $i$, and $w_{ij}$ represents the weighted link from $i$ and $j$. In-closeness ($C(in)$) and out-closeness ($C(out)$) of a port are computed by Equation (4) and Equation (5) by dividing the number of the port in the network except for $i$ ($N-1$) by the length of the shortest path length between $i$ and other ports in the network.

$$C(in)_i = \frac{N-1}{D(in)_i} = \frac{N-1}{\sum_h^N w_{hi}} \tag{4}$$

$$C(out)_i = \frac{N-1}{D(out)_i} = \frac{N-1}{\sum_j^N w_{ij}} \tag{5}$$

Betweenness centrality (B) considers a port amid other port pairs illustrated in the diagram, showing the role of the port in the network. Since intermediate points control the linkage between these ports, the higher the betweenness ports, the more influential ports are. It can be defined by adopting Equation (6) where $s, t$ represents a port pair, $w(s, t|i)$ is the number of times that $s$ and $t$ cross the port $i$ with the shortest interval and $w(s, t)$ is the total number of shortest paths between $s$ and $t$.

$$B_i = \sum_{\substack{s,t \in N \\ s,t \neq i}} \frac{w(s, t|i)}{w(s, t)} \tag{6}$$

To measure the investigated cruise ports' full effect and vulnerability within a cruise shipping network, this study combines all three centrality measures by employing a Borda Count approach (Emerson, 2013; Liu et al., 2018c). The Borda Count method can accumulate different centrality properties into one rank while embedding easiness and visibility into the calculation process. The higher values calculated by Equations (2)–(6), the higher ranks of cruise ports are obtained. $R_{D(in)}$, $R_{D(out)}, R_{C(in)}, R_{C(out)}, R_B$ refer to the ranking position of all the cruise ports in the ASEAN countries by Equations (2)–(6), where the ranks for $D(in)$, $D(out), C(in), C(out), B$ can be obtained independently. The count score $(S_{D(in)}(i), S_{D(out)}(i), S_{C(in)}(i), S_{C(out)}(i), S_B(i))$ is provided by the ranking order of every centrality for the $i$th investigated cruise ports in the ASEAN countries, as shown in Equations (6)–(10).

$$S_{D(in)}(i) = N - R_{D(in)}(i) + 1 \tag{7}$$

$$S_{D(out)}(i) = N - R_{D(out)}(i) + 1 \tag{8}$$

$$S_{C(in)}(i) = N - R_{C(in)}(i) + 1 \tag{9}$$

$$S_{C(out)}(i) = N - R_{C(out)}(i) + 1 \tag{10}$$

$$S_B(i) = N - R_B(i) + 1 \tag{11}$$

The ranks of degree and closeness centrality measures involve two directions together. For ensuring a fair contribution by degree, closeness, and betweenness centrality, a one-third count score of each centrality type is used for the final result, according to Wu et al. (2019a), as shown in Equation (12).

$$S_O(i) = \frac{S_D(i) + S_C(i) + S_B(i)}{3} \tag{12}$$

Accordingly, $S_{D(in)}(i), S_{D(out)}(i), S_{C(in)}(i) and S_{C(out)}(i)$ indicate one-sixth to the final score independently, as they are bilateral pairs. Then, $S_B(i)$ indicates one-third of the result as it is not bilateral. The related fair contributions of bi-directional degree centrality and closeness centrality are shown in Equation (13) and Equation (14):

$$S_D(i) = \frac{S_{D(in)}(i) + S_{D(out)}(i)}{2} \tag{13}$$

$$S_C(i) = \frac{S_{C(in)}(i) + S_{C(out)}(i)}{2} \tag{14}$$

The local port-level impact ($LI$) of the new link weight $w'_{ij}$ is calculated in Equation (15) and Equation (16) to overview the COVID-19 impact by multiplying $w_{hi}$ and $w_{ij}$ with COVID-19 Performance Index CPI) (Leng and Lemahieu, 2021) as LI of a cruise calling port state to reflect the impact of COVID-19 on the reduced ship capacity, respectively.

$$w'_{hi} = w_{hi} \times LI/100 \tag{15}$$

$$w'_{ij} = w_{ij} \times LI/100 \tag{16a}$$

By implying the new weights $w'_{hi}$ and $w'_{ij}$ for building a new SNA, Equations (1)–(14) can be repeatedly used to integrate port-level vulnerability into network-level vulnerability assessment for each investigated cruise port. Therefore, the assessments with and without local vulnerability indicated can be compared. To demonstrate the methodology, a vulnerability analysis based on an ASEAN cruising network is constructed in Section 4.

### 3.2. Preliminaries

There are several preliminaries for implementing the new methodology. First, CPI (Leng and Lemahieu, 2021), a value between 0 and 100 provided by Lowy Institute, includes confirmed cases, confirmed deaths, per million confirmed cases, per million confirmed deaths, tests per thousand, and confirmed cases in the proportion of tests. CPI is sufficient to represent LI of ports as many cruise companies have only used the national COVID-19 policies to adjust their company level policy and to implement reduced capacity measures to promote social distancing and prevent the spread of COVID-19 during lockdowns, and the corresponding CPIs of different ASEAN countries are stated in Table 8 (Dammak et al., 2023). These measures typically involve reducing the number of passengers onboard and implementing other safety protocols such as mandatory masks, enhanced cleaning procedures, and pre-boarding health screenings depending on the levels of COVID-19 severity in the country (Radic et al., 2021; Yuen et al., 2021). For example, cruise port calls were suspended in Singapore from March 2020 until November 2020 due to the COVID-19 pandemic. However, since then, cruise port calls have resumed in a limited capacity, with strict health and safety protocols in place (Lau et al., 2022a). In Thailand, cruise port calls were suspended from March 2020 until October 2020 due to the COVID-19 pandemic. Since then, cruise port calls in Thailand have also resumed in a limited capacity, with strict health and safety protocols in place (Beh and Lin, 2022). These are well reflected by the national CPI values in different timeframes. Furthermore, the strategy for maximizing the profit for regular cruise lines is using revenue management and introducing the cruise fare reduction due to the expectation of having more expenditures on board by selling services and products at an extra price (da Silva, 2021b). This guarantees that the cruise ship capacity can be used to calculate the link weights with regular operation, while the CPI-adjusted capacity can be used to model the link weights during the pandemic. Therefore, CPI is implicated in Equations (14) and (15) to observe the capacity reduction by COVID-19 of different ports by accommodating two factors.

Second, LI of different ports in the same country is treated equally concerning the port state's CPI value. Given that the cruise port's COVID-19 risk level is mainly in line with the national COVID-19 risk levels and measures, which is further proven by the leading cruise lines operating in the region, admitting that they adjusted their COVID-19 policies by strictly referring to the port states' COVID-19 policies which are in line with the national CPI given the way it is calculated.

Third, in order to conduct the comparative analysis to find the effect of the outbreak of COVID-19, the model needs to be used twice for assessing the cruise networks in ASEAN countries by using the itinerary data from 1st September 2021 to 31st August 2022 (COVID-19 period) and from 1st April 2023 to 31st March 2024 (Normal period), respectively. In addition, the data was collected on 17th June 2021 and 28th March 2023, respectively, as mentioned in Section 4.1 (CRUISETIMETABLES, 2021, 2023).

## 4. Vulnerability analysis for ASEAN cruising network

The methodology introduced in Section 3 is applied to an ASEAN cruising network for demonstration in the coming subsections. This section is divided into four subsections based on the methodology: structuring an ASEAN cruise shipping network, modelling the ASEAN cruise shipping network, vulnerability assessment with COVID-19 impact, and vulnerability assessment without COVID-19 impact.

### *4.1. Structuring an ASEAN cruising network*

For implementing centrality assessment, raw data is collected in the first step. Hence, comprehensive cruising schedules are needed for the cruise shipping network, and CruiseTimetable (https://www.cruisetimetables.com/) is chosen to manage all cruising routes across the ASEAN region (CRUISETIMETABLES, 2021). Cruise routes are firstly collected by reviewing the port schedules of all ASEAN ports for the COVID-19 period (i.e. 1st September 2021 to 31st August 2022) by aggregating data from each vessel's itineraries for a year. As a result, 43 cruise ships from 24 cruise lines were obtained for the COVID-19 period, as shown in Table 1. 201 cruise itineraries across 243 ports are recorded for constructing the comprehensive cruise shipping network. In addition to the timeframe during COVID-19, there is another timeframe we need to consider. A dataset of ports with a start date from the normal period (i.e. 1st April 2023 to 31st March 2024) is also obtained as the cruising industry is reliving by releasing all safety measures and resuming most itineraries (Li et al., 2023). The two annual timeframes are chosen and one is up to 2024 because such selection can ensure a sufficient time frame for comparative analysis or accounting for potential recovery from the COVID-19 outbreak. As a result, 46 cruise ships from 27 cruise lines were obtained for the normal period, as shown in Table 1. The average cruise ship capacity during COVID-19 and normal periods is 1583.26 and 1576.91 passengers, respectively. It is shown that cruise lines use smaller ships to scatter the risk after the COVID-19 outbreak.

Then, data aggregation was carried out using Microsoft Excel and a macro app. The first step involved copying and pasting all corresponding itineraries into an Excel spreadsheet. Then, Macro, a function that can run a set of actions repeatedly, was used to extract and record the schedules and port calls for each itinerary. Cruise ship networks are typically bi-directional, meaning that the relationships between ports are asymmetrical and may have different meanings depending on the direction of travel (Jeon et al., 2019; Ito et al., 2022). Therefore, this network has bi-directional properties.

This process allowed for the efficient and effective analysis of a large volume of data related to cruise ship itineraries and port calls. Then, the annual capacity of each link between the pairs of investigated cruise ports is computed by the summary of all the ship capacities between a port pair annually, which are used for weighting the links.

Among the total 243 cruise ports, 81 ports (listed in Annex 2) are from the ASEAN countries, while the other 162 non-ASEAN ports (listed in Annex 3) connect with the 81 ASEAN ports through the 201 itineraries. For non-ASEAN countries, departure ports are selected for building the network because many cruise ships go around the world along the same itinerary. Still, the paper's objective is to assess the ASEAN network globally. Therefore, outside the ASEAN region, 162 crucial departure ports are chosen to be placed in the network to sketch the global cruising network to support the AESAN model establishment.

### *4.2. Modelling of the global cruise shipping network for ASEAN countries*

As mentioned above, the annual capacity between each pair of cruise ports is calculated by accumulating all cruising capacity going across the link annually for COVID-19 and normal periods, respectively. Based on the capacity data, UCINET 6 was chosen to model the ASEAN cruise shipping network with SNA techniques, as shown in Fig. 2. This is due to the fact that UCINET 6 has been used to visualise an extensive shipping

**Table 1**
Cruising ships across ASEAN countries.

| Company | Cruise Ship | Capacity | Availability during the COVID Period | Availability during the Normal Period |
|---|---|---|---|---|
| AIDA | AIDAcara | 1186 | v | |
| AIDA | AIDAbella | 2500 | v | v |
| Ambassador | Ambience | 1400 | | v |
| Azamara | Azamara Journey | 690 | v | v |
| Azamara | Azamara Onward | 670 | | v |
| Azamara | Azamara Quest | 690 | | v |
| Carnival | Carnival Luminosa | 2826 | | v |
| Celebrity | Celebrity Edge | 2908 | | v |
| Celebrity | Celebrity Millennium | 2218 | | v |
| Celebrity | Celebrity Solstice | 2850 | v | |
| Costa | Costa Deliziosa | 2826 | v | v |
| Crystal | Crystal Serenity | 980 | v | |
| Crystal | Crystal Symphony | 922 | v | |
| Cunard | Queen Elizabeth | 2092 | v | v |
| Cunard | Queen Mary 2 | 2620 | v | v |
| Cunard | Queen Victoria | 2014 | v | v |
| Fred Olsen | Borealis | 1360 | v | v |
| HAL | ms Europa | 408 | v | v |
| HAL | ms Noordam | 1972 | v | |
| HAL | ms Volendam | 1432 | | v |
| HAL | ms Westerdam | 1964 | v | v |
| HAL | ms Zaandam | 1432 | v | |
| HAL | ms Zuiderdam | 1964 | | v |
| Marella | Marella Discovery 2 | 1832 | v | v |
| MSC | MSC Magnifica | 2518 | | v |
| MSC | MSC Poesia | 2550 | v | |
| NCL | Norwegian Jewel | 2736 | | v |
| NCL | Norwegian Spirit | 2018 | v | |
| NCL | Norwegian Sun | 2400 | v | |
| Oceania | Insignia | 684 | v | v |
| Oceania | Nautica | 684 | v | v |
| Oceania | Regatta | 684 | v | |
| Oceania | Riviera | 1250 | | v |
| P & O | Arcadia | 2534 | | v |
| P & O | Aurora | 1874 | v | |
| P & O Australia | Pacific Adventure | 2636 | | v |
| P & O Australia | Pacific Explorer | 1998 | v | |
| Phoenix Reisen | Amadea | 624 | | v |
| Phoenix Reisen | Amera | 1200 | v | |
| Phoenix Reisen | Artania | 1188 | v | |
| Princess | Coral Princess | 2000 | | v |
| Princess | Diamond Princess | 2670 | | v |
| Princess | Island Princess | 2200 | v | v |

(*continued on next page*)

**Table 1** (*continued*)

| Company | Cruise Ship | Capacity | Availability during the COVID Period | Availability during the Normal Period |
|---|---|---|---|---|
| Princess | Royal Princess | 3600 | v | |
| RSSC | Seven Seas Explorer | 738 | v | v |
| RSSC | Seven Seas Mariner | 700 | v | |
| RSSC | Seven Seas Navigator | 490 | | v |
| Royal Caribbean | Serenade Of The Seas | 2476 | v | |
| Royal Caribbean | Voyager Of The Seas | 3840 | v | |
| Royal Caribbean | Spectrum Of The Seas | 5622 | v | v |
| Seabourn | Seabourn Encore | 600 | v | v |
| Seabourn | Seabourn Odyssey | 458 | | v |
| Seabourn | Seabourn Ovation | 600 | v | |
| Seabourn | Seabourn Sojourn | 458 | v | v |
| Silversea | Silver Moon | 596 | v | v |
| Silversea | Silver Muse | 596 | v | v |
| Silversea | Silver Shadow | 382 | v | v |
| Silversea | Silver Whisper | 382 | | v |
| Star Clippers | Star Clipper | 166 | v | |
| TUI | Mein Schiff 5 | 2534 | v | v |
| Viking | Viking Mars | 930 | | v |
| Viking | Viking Neptune | 930 | | v |
| Viking | Viking Orion | 930 | v | v |
| Viking | Viking Sky | 930 | | v |
| Viking | Viking Star | 930 | v | |
| Virgin Voyages | Resilient Lady | 2700 | | v |
| Windstar | Star Breeze | 312 | | v |
| Windstar | Wind Spirit | 148 | v | |

network in the literature. Further, it presents a better-visualised structure that contains the most prominent cruise ports in the network, compared to the figures generated by the Python package, NetworkX, after comprehensive experiments (Poo and Yang, 2022). It measures the degree centrality, closeness centrality and betweenness centrality as described in Equations (1)–(5), which are checked manually afterwards (Apostolato, 2013).

### 4.3. *Vulnerability assessment without COVID-19 impact*

For representing the impacts of COVID-19 on the cruising network of ASEAN countries, two assessments, without and with a local port-level COVID-19 vulnerability indicator (i.e. CPI in this study), are implemented for comparing the centrality changes of different ports. It aids in illustrating the value and significance of new SNA analysis in shipping networks in general and ASEAN cruising networks in specific. The case analysis in this section will also help improve the ASEAN cruising network resilience management from a comprehensive perspective, from which a cruise operator can better plan its fleet itinerary based on the COVID-19 impact on each involved cruise port.

By modelling the ASEAN cruise shipping network by UCINET, the global network-level vulnerability of the ASEAN cruise ports can be calculated and obtained by Equations (6)–(13). Then, the top 20 ports in terms of network-level vulnerability are obtained based on the assessment result. Then, a validation is done by taking the top cruise ports away from the network by one port at a time. By eliminating a port and observing its reduction in network efficiency, the global influence of the port can be observed to prove the accuracy of the result. It is assumed to see a trend of enhanced network efficiency if the port removal process starts from the first port to the twentieth port.

### 4.4. *Vulnerability assessment with COVID-19 impact*

The chosen local port-level COVID-19 vulnerability indicators, CPIs are presented in Table 2. They are imparted into Equations (14) and (15) to provide a new network-level vulnerability by Equations (1)–(13). As an international route often links two or more ports of different CPIs, the lowest CPI among the involved ports is further analysed as the new capacity of ships and risk studies are normally based on the worst scenario. Then, as a local port-level vulnerability, CPI is exhibited to facilitate the comparative analysis with the new network-level vulnerability assessment score for visualising the impacts of local vulnerabilities on the whole ASEAN cruise shipping network. Finally, the vulnerability is successfully done, and the statistical result is presented in Section 5.

Here, the network for the COVID-19 period is firstly modelled. The network for the normal period can also be developed similarly to conduct the comparative analysis between the COVID-19 and normal periods. The detailed discussions are seen in Section 5.3.

## 5. Results

Based on the explanation in Section 4, the result without COVID-19 impact during the COVID-19 period and the validation for the network are presented in Section 5.1. Then, the COVID-19 impact analysis result during the COVID-19 period and the comparative analysis between the two sets of results with and without CPI during the COVID-19 period are presented in Section 5.2. Finally, the comparative analysis of the COVID-19 and normal periods is conducted to investigate further the impacts of COVID-19 on the cruise shipping network in ASEAN countries.

### 5.1. *Results without COVID-19 impact*

The top 20 ports against each of the three centrality degrees are summarised in Table 3 by Equations (1)–(5). Singapore is at the top of all three ranks. Penang, Klang, Malacca, Kuching, Langkawi, Tioman Island, and Kotakinabulu are the seven Malaysian ports on the list. Vietnam has four ports on the list, including Ho Chi Minh City, Da Nang, Halong Bay, and Nha Trang. There are eight ports from Thailand on the three lists: Phuket, Ko Samui, Laem Chabang, Ko Tao, Ko Kood, Ko Mak, Ko Samet, and Pattaya. Apart from the famous Bali, there are seven other ports Lombok, Komodo Island, Semarang, Surabaya, Pulau We, Jakarta, and Pulau Bintan. The other ports on the list are Manila, Busuanga Island, Myanmar, and Bandar Seri Begawan.

Considering the ranks in Table 4 and Equations (6)–(11), scores for the combined centralities of all 81 cruise ports are calculated, and the Top 20 ports are listed in Table 4. Singapore and Phuket are the first and the second ones. Moreover, Ho Chi Minh City and Penang are listed as the third ones. Thus, the score represents the level of centralisation of each cruise port in the ASEAN network. In other words, the score means the global vulnerability of the port for the whole network.

The top 20 cruise ports are taken away from the network accordingly and independently to observe the changes (as the impact), as shown in Fig. 3. By removing Singapore, about a 10% reduction in the global network efficiency is achieved. Apart from Singapore, only Phuket, Ko Samui and Bali provide a significant decrease of more than 1%. The remaining cruise ports have a negligible variation of less than 1%. Therefore, it proves the network is valid based on the correlation between the top cruise ports and network efficiency.

For validating the weighting of Equation (13), it is necessary to provide different weight distributions for $S_D(i)$,$S_c(i)$,and$S_B(i)$. Sensitivity analysis is a method for such implications by adjusting Equation (16) to Equation (18) (Poo et al., 2021) to investigate the impact of such

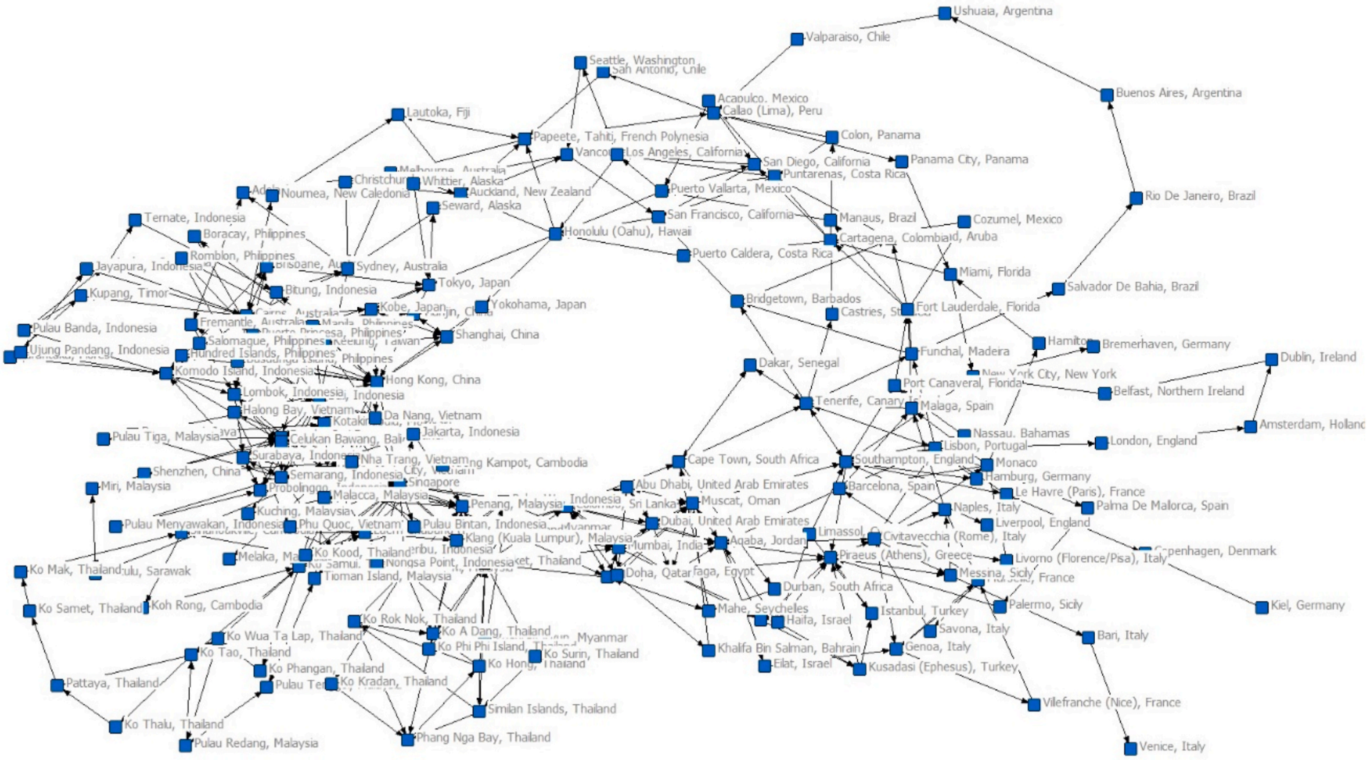

**Fig. 2.** Cruise shipping network of ASEAN region.

**Table 2**
CPI for ASEAN countries (Leng and Lemahieu, 2021).

| Country | Rank | Index | Latest update |
|---|---|---|---|
| Vietnam | 1 | 90.8 | 9th January 2021 |
| Thailand | 2 | 82.6 | 13th March 2021 |
| Singapore | 3 | 73.3 | 13th March 2021 |
| Malaysia | 4 | 69.9 | 13th March 2021 |
| Myanmar | 5 | 62.4 | 13th March 2021 |
| Other (Brunei and Cambodia) | 6 | 61.1 | 13th March 2021 |
| Philippines | 7 | 30.6 | 13th March 2021 |
| Indonesia | 8 | 25.8 | 13th March 2021 |

adjustment onto the final ranking. All the new ranks generated by Equation (16) to Equation (18) are presented in Table 5:

$$S_{ND}(i) = S_D(i) \times R_D + S_C(i) + S_B(i) \tag{16b}$$

$$S_{NC}(i) = S_D(i) + S_C(i) \times R_c + S_B(i) \tag{17}$$

$$S_{NB}(i) = S_D(i) + S_C(i) + S_B(i) \times R_B \tag{18}$$

First, $R_D$ is used to change the ratio of $S_D(i)$ in Equation (16). To observe its impact on the final ranking and validate the default weighting, a step of 0.1 is used to change the weight of $R_D$, and the rank is calculated again. The process is repeated until the $R_D$ value reaches 2. The sensitivity assessment for $S_D(i)$ is constructed, as shown in Table 5. The result reveals that Ho Chi Minh City relies more on degree centrality than Phuket. Ho Chi Minh City's ranking overtakes Phuket when the degree centrality becomes more important. This aligns with the degree centrality ranking of the two ports, verifying the proposed methodology. The same philosophy is applied to the ports ranked from 11th to 20th. It shows the rationale of the methodology again, while the non-abrupt ranking changes indicate the methodology's robustness too.

Next, $R_C$ is used to change the ratio of $S_C(i)$ in Equation (17). To observe its impact on the final ranking and validate the default weighting, a step of 0.1 is added to $R_C$, and the rank is calculated again. The process is repeated until $R_C$ is 2. The sensitivity assessment for $S_C(i)$ is constructed, as shown in Table 6.

Third, $R_B$ is used to change the ratio of $S_B(i)$ in Equation (18). To observe its impact on the final ranking and validate the default weighting, 0.1 is added to $R_B$, and the rank is calculated again. The process is repeated until $R_B$ is 2. The sensitivity assessment for $S_B(i)$ is constructed, is shown in Table 7.

It is noticed that the rank changes correspond to ranks of degree centrality, closeness centrality, and betweenness centrality in Equation (10) to Equation (12). For example, Manila's rank has been raised from 16 to 13 after doubling $S_D(i)$. It means that Manila has more connections with other ports. Laem Chabang (Bangkok) and Penang behave similarly to Manila, while Phuket and Semarang behave oppositely.

On the other hand, it is noticed that Da Nang is ranked 9 in closeness centrality, and its rank dropped to 12 if $S_C(i)$ is doubled. It means that Da Nang is close to most of the ports in the network. It is also observed that Langkawi and Yangon behave similarly to Da Nang, while Langkawi and Yangon behave oppositely.

Furthermore, Laem Chabang (Bangkok)'s rank has dropped from 8 to 10, after doubling $S_B(i)$. It means that it has the shortest path for most of the ports in the network. Nha Trang and Manila behave similarly to Laem Chabang (Bangkok), while Manila and Sihanoukville behave oppositely.

### 5.2. Results with COVID-19 impact

Table 8 shows the comparative results between the network-level vulnerability and the local port-level vulnerability. Therefore, new scores of the network-level vulnerability can be compared with the original scores of the network-level vulnerability. Also, local port-level vulnerabilities are listed for reference. Changes in Table 8 mean the variations of the ranks after implying the model by the COVID-19 impact.

It is expected that the countries (i.e., the Philippines and Indonesia) with lower CPI will become less centralised. Indonesian ports have

**Table 3**
Ranking of top twenty ports associated with three main disparate centralities.

| Degree centrality | | Closeness centrality | | Betweenness centrality | |
|---|---|---|---|---|---|
| Rank | Port | Rank | Port | Rank | Port |
| 1 | Singapore | 1 | Singapore | 1 | Singapore |
| 2 | Penang, Malaysia | 2 | Penang, Malaysia | 2 | Bali, Indonesia |
| 3 | Ho Chi Minh City, Vietnam | 2 | Phuket, Thailand | 3 | Ho Chi Minh City, Vietnam |
| 4 | Phuket, Thailand | 4 | Klang (Kuala Lumpur), Malaysia | 4 | Phuket, Thailand |
| 5 | Klang (Kuala Lumpur), Malaysia | 5 | Ho Chi Minh City, Vietnam | 5 | Ko Samui, Thailand |
| 6 | Laem Chabang (Bangkok), Thailand | 6 | Bali, Indonesia | 6 | Klang (Kuala Lumpur), Malaysia |
| 7 | Da Nang, Vietnam | 7 | Langkawi, Malaysia | 7 | Penang, Malaysia |
| 8 | Halong Bay, Vietnam | 7 | Yangon, Myanmar | 8 | Manila, Philippines |
| 9 | Ko Samui, Thailand | 7 | Pulau We, Indonesia | 9 | Komodo Island, Indonesia |
| 10 | Nha Trang, Vietnam | 10 | Laem Chabang (Bangkok), Thailand | 10 | Lombok, Indonesia |
| 11 | Bali, Indonesia | 10 | Semarang, Indonesia | 11 | Bandar Seri Begawan, Brunei |
| 12 | Lombok, Indonesia | 12 | Surabaya, Indonesia | 11 | Sihanoukville, Cambodia |
| 13 | Manila, Philippines | 12 | Malacca, Malaysia | 13 | Langkawi, Malaysia |
| 14 | Komodo Island, Indonesia | 14 | Bandar Seri Begawan, Brunei | 13 | Yangon, Myanmar |
| 15 | Sihanoukville, Cambodia | 15 | Ko Samui, Thailand | 13 | Da Nang, Vietnam |
| 16 | Semarang, Indonesia | 15 | Jakarta, Indonesia | 13 | Ko Tao, Thailand |
| 17 | Surabaya, Indonesia | 17 | Da Nang, Vietnam | 17 | Semarang, Indonesia |
| 18 | Malacca, Malaysia | 17 | Nha Trang, Vietnam | 18 | Tioman Island, Malaysia |
| 19 | Kotakinabulu, Malaysia | 17 | Lombok, Indonesia | 19 | Laem Chabang (Bangkok), Thailand |
| 20 | Busuanga Island, Philippines | 17 | Ko Kood, Thailand | 20 | Nha Trang, Vietnam |
| | | 17 | Pulau Bintan, Indonesia | 20 | Kotakinabulu, Malaysia |
| | | 17 | Tioman Island, Malaysia | 20 | Ko Mak, Thailand |
| | | 17 | Kuching, Malaysia | 20 | Ko Samet, Thailand |
| | | | | 20 | Pattaya, Thailand |

**Table 4**
Top 20 ports by multiple-centrality assessment.

| Port | Rank | Score |
|---|---|---|
| Singapore | 1 | 240 |
| Phuket, Thailand | 2 | 233 |
| Ho Chi Minh City, Vietnam | 3 | 232 |
| Penang, Malaysia | 3 | 232 |
| Klang (Kuala Lumpur), Malaysia | 5 | 228 |
| Bali, Indonesia | 6 | 224 |
| Ko Samui, Thailand | 7 | 214 |
| Laem Chabang (Bangkok), Thailand | 8 | 208 |
| Da Nang, Vietnam | 9 | 206 |
| Lombok, Indonesia | 10 | 204 |
| Semarang, Indonesia | 11 | 200 |
| Langkawi, Malaysia | 12 | 198 |
| Yangon, Myanmar | 12 | 198 |
| Bandar Seri Begawan, Brunei | 14 | 196 |
| Nha Trang, Vietnam | 14 | 196 |
| Manila, Philippines | 16 | 195 |
| Komodo Island, Indonesia | 17 | 191 |
| Sihanoukville, Cambodia | 18 | 185 |
| Surabaya, Indonesia | 18 | 185 |
| Pulau We, Indonesia | 20 | 183 |

significant drops, namely Semarang, Komodo Island, and Surabaya. However, it is also noticed that Bali and Manila, two essential ports in the region, remain in their critical roles in the network after the significant drop in weights. Langkawi, with less efficiency deduction, is raised significantly in rank. Besides, it is noticed that ports with higher CPI, Vietnam, Thailand, and Singapore, constantly increase the importance of the network. The changes among those countries with medium CPI are unpredictable. Langkawi from Malaysia has become more critical than before, but Klang has the opposite change. Furthermore, Yangon and Bandar Seri Begawan have become more centralised, with less CPI than ports in Malaysia. The result represents that network-level vulnerability and local port-level vulnerability of the whole network are changing differently. The complete picture of the COVID-19 impacts on the global cruise shipping network can be obtained by integrating the methodology.

### *5.3. Changes in network during the normal period after COVID-19*

Table 9 shows the comparative results between COVID-19 and normal periods. It is used to observe the network changes caused by the COVID-19 outbreaks. Southeast Asia welcomed its first port call after the pandemic in July 2022, and all ASEAN countries were included in cruise port calls in 2023 and 2024 (CRUISETIMETABLES, 2023). The ASEAN countries are gradually relieved from COVID-19 and relaxing their corresponding COVID-19 measures (Li et al., 2023). Therefore, *LI* is assumed as 100 for the normal period. Changes in Table 9 mean the variations of the ranks from COVID-19 period to the normal period.

The results reveal that the ports in large cruise cities, such as Singapore, Ho Chi Minh City and Klang (Kuala Lumpur), and Bali, have become more centralised. As a result, some smaller cities, such as Phuket, Penang, and Pulau We, have dropped in the ranks. It is reasonably believed that COVID-19's impact on large cruise ports is more significant. However, after the COVID-19, such large ports become more attractive to cruise lines, which is in line with the retaliatory consumption phenomenon in the tourism industry in ASEAN. Furthermore, in the countries of other concerns beyond the COVID-19 crisis, such as political conflict and severe crime issues, their cruise ports, such as Yangon and Sihanoukville, are heavily reduced in ranks.

## 6. Discussions

The paper creates a new dimension for studying cruise shipping by understanding network-level and local port-level vulnerabilities. It further successfully integrates them into a single assessment. Apart from studying each cruise port independently, this study establishes a weighted SNA to observe the network-level vulnerability changes based on local port-level vulnerability influences, such as COVID-19. There are different implications possibly backed by this study.

First, an ASEAN SNA has been implemented to facilitate the ASEAN cruising industry by indicating the centralised ports in the network. This paper highlights a standard procedure to extract all regions' cruising routes and construct a specific network for implementing the global SNA. The centralised cruise ports in the region are obtained by considering all cruise ports in the network and ranking cruise ports in different global regions for more network vulnerability assessments. As expected, more comparative analyses can be done based on the same procedures for specific theoretical and managerial implications.

Second, a weighted SNA methodology is designed to compare the

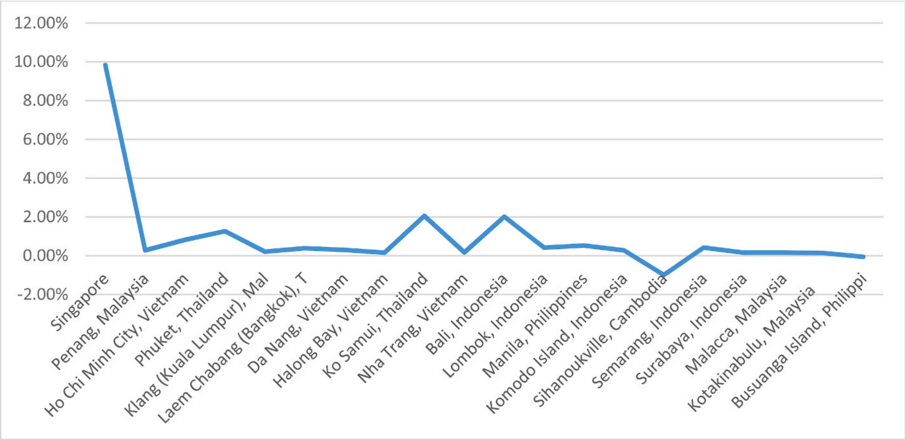

**Fig. 3.** Drop of network efficiency by removing an agglomeration for the assessment without COVID-19 impact.

**Table 5**
Weighting validation of $R_D$ for multiple-centrality assessment by Top 20 ports.

| Port | $R_D$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2 |
| Singapore | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Phuket, Thailand | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 |
| Ho Chi Minh City, Vietnam | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 |
| Penang, Malaysia | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| Klang (Kuala Lumpur), Malaysia | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Bali, Indonesia | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Ko Samui, Thailand | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Laem Chabang (Bangkok), Thailand | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Da Nang, Vietnam | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| Lombok, Indonesia | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Semarang, Indonesia | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 12 | 12 | 12 | 12 |
| Langkawi, Malaysia | 12 | 12 | 13 | 14 | 14 | 14 | 14 | 16 | 16 | 16 | 16 |
| Yangon, Myanmar | 12 | 12 | 13 | 14 | 14 | 14 | 14 | 16 | 16 | 16 | 16 |
| Bandar Seri Begawan, Brunei | 14 | 15 | 16 | 16 | 16 | 16 | 16 | 15 | 15 | 15 | 15 |
| Nha Trang, Vietnam | 14 | 14 | 12 | 12 | 12 | 12 | 12 | 11 | 11 | 11 | 11 |
| Manila, Philippines | 16 | 16 | 15 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| Komodo Island, Indonesia | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 14 | 14 | 14 | 14 |
| Sihanoukville, Cambodia | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| Surabaya, Indonesia | 18 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| Pulau We, Indonesia | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 21 | 21 | 21 | 21 |

**Table 6**
Weighting validation of $R_C$ for multiple-centrality assessment by Top 20 ports.

| Port | $R_C$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2 |
| Singapore | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Phuket, Thailand | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Ho Chi Minh City, Vietnam | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Penang, Malaysia | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Klang (Kuala Lumpur), Malaysia | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Bali, Indonesia | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Ko Samui, Thailand | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Laem Chabang (Bangkok), Thailand | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Da Nang, Vietnam | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 12 | 12 |
| Lombok, Indonesia | 10 | 10 | 10 | 10 | 10 | 10 | 11 | 13 | 13 | 13 | 13 |
| Semarang, Indonesia | 11 | 11 | 11 | 11 | 11 | 11 | 10 | 12 | 12 | 11 | 11 |
| Langkawi, Malaysia | 12 | 12 | 12 | 12 | 12 | 12 | 11 | 10 | 9 | 9 | 9 |
| Yangon, Myanmar | 12 | 12 | 12 | 12 | 12 | 12 | 11 | 10 | 9 | 9 | 9 |
| Bandar Seri Begawan, Brunei | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 |
| Nha Trang, Vietnam | 14 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Manila, Philippines | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 18 | 18 | 18 | 18 |
| Komodo Island, Indonesia | 17 | 17 | 17 | 17 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| Sihanoukville, Cambodia | 18 | 20 | 20 | 20 | 20 | 20 | 20 | 21 | 21 | 21 | 21 |
| Surabaya, Indonesia | 18 | 18 | 18 | 18 | 17 | 18 | 18 | 17 | 17 | 17 | 17 |
| Pulau We, Indonesia | 20 | 19 | 19 | 19 | 17 | 17 | 16 | 16 | 16 | 16 | 16 |

**Table 7**
Weighting validation of $R_B$ for multiple-centrality assessment by Top 20 ports.

| Port | $R_B$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2 |
| Singapore | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Phuket, Thailand | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Ho Chi Minh City, Vietnam | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |
| Penang, Malaysia | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Klang (Kuala Lumpur), Malaysia | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Bali, Indonesia | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 5 |
| Ko Samui, Thailand | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Laem Chabang (Bangkok), Thailand | 8 | 8 | 8 | 8 | 9 | 10 | 10 | 10 | 10 | 10 | 10 |
| Da Nang, Vietnam | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 9 | 9 | 9 | 9 |
| Lombok, Indonesia | 10 | 10 | 10 | 10 | 10 | 9 | 9 | 8 | 8 | 8 | 8 |
| Semarang, Indonesia | 11 | 11 | 11 | 11 | 11 | 11 | 14 | 15 | 15 | 15 | 15 |
| Langkawi, Malaysia | 12 | 12 | 12 | 12 | 12 | 11 | 11 | 12 | 12 | 12 | 12 |
| Yangon, Myanmar | 12 | 12 | 12 | 12 | 12 | 11 | 11 | 12 | 12 | 12 | 12 |
| Bandar Seri Begawan, Brunei | 14 | 14 | 14 | 14 | 15 | 15 | 15 | 14 | 14 | 14 | 12 |
| Nha Trang, Vietnam | 14 | 16 | 16 | 16 | 16 | 17 | 17 | 17 | 17 | 17 | 17 |
| Manila, Philippines | 16 | 15 | 15 | 15 | 14 | 14 | 11 | 11 | 11 | 11 | 11 |
| Komodo Island, Indonesia | 17 | 17 | 17 | 17 | 17 | 16 | 16 | 16 | 16 | 16 | 16 |
| Sihanoukville, Cambodia | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| Surabaya, Indonesia | 18 | 19 | 19 | 19 | 19 | 19 | 20 | 20 | 20 | 21 | 21 |
| Pulau We, Indonesia | 20 | 20 | 20 | 20 | 20 | 19 | 19 | 19 | 19 | 19 | 19 |

**Table 8**
Top 20 ports about network-level vulnerability and port-level vulnerability with CPI.

| Port | Network-level vulnerability | | | | Port-level vulnerability | |
|---|---|---|---|---|---|---|
| | Rank | Change | Score | Change | Rank | CPI |
| Singapore | 1 | 0 | 240 | 0 | 3 | 73.3 |
| Phuket, Thailand | 2 | 0 | 233 | 0 | 2 | 82.6 |
| Ho Chi Minh City, Vietnam | 3 | 0 | 232 | 0 | 1 | 90.8 |
| Penang, Malaysia | 3 | 0 | 232 | 0 | 4 | 69.9 |
| Klang (Kuala Lumpur), Malaysia | 5 | 0 | 227 | −1 | 4 | 69.9 |
| Bali, Indonesia | 6 | 0 | 222 | −2 | 8 | 25.8 |
| Ko Samui, Thailand | 7 | 0 | 214 | 0 | 2 | 82.6 |
| Langkawi, Malaysia | 8 | ↑4 | 212 | +14 | 4 | 69.9 |
| Laem Chabang (Bangkok), Thailand | 9 | ↓1 | 208 | 0 | 2 | 82.6 |
| Da Nang, Vietnam | 10 | ↓1 | 207 | +1 | 1 | 90.8 |
| Yangon, Myanmar | 11 | ↑1 | 201 | +3 | 5 | 62.4 |
| Bandar Seri Begawan, Brunei | 12 | ↑2 | 200 | +4 | 6 | 61.1 |
| Lombok, Indonesia | 13 | ↓3 | 199 | −5 | 8 | 25.8 |
| Nha Trang, Vietnam | 14 | 0 | 196 | 0 | 1 | 90.8 |
| Semarang, Indonesia | 15 | ↓4 | 194 | −6 | 8 | 25.8 |
| Manila, Philippines | 16 | 0 | 193 | −2 | 7 | 30.6 |
| Sihanoukville, Cambodia | 17 | 0 | 188 | +3 | 6 | 61.1 |
| Komodo Island, Indonesia | 18 | ↓1 | 185 | −6 | 8 | 25.8 |
| Surabaya, Indonesia | 19 | ↓1 | 177 | −8 | 8 | 25.8 |
| Kotakinabulu, Malaysia | 19 | ↑2 | 177 | 0 | 4 | 69.9 |
| Malacca, Malaysia | 19 | ↑3 | 177 | +4 | 4 | 69.9 |

impacts of the network's traffic flow or shipping capacity, which are changed by integrating the network-level vulnerability assessment with the local port-level COVID-19 vulnerability assessment. CPIs for ASEAN countries are used as a local port-level COVID-19 vulnerability indicator to compare the network-level and local port-level vulnerability of different cruise ports, and the network vulnerability analysis is successfully enhanced from work by Poo and Yang (2022). The objective can be identified as a solid ground for a new vulnerability assessment for a network. In doing so, various local vulnerability indicators can be used to assess local vulnerabilities.

**Table 9**
Top 20 ports changes between the COVID-19 period and the Normal period.

| Port | COVID-19 period | | Normal period | | | |
|---|---|---|---|---|---|---|
| | Rank | Score | Rank | Change | Score | Change |
| Singapore | 1 | 240 | 1 | 0 | 240 | 0 |
| Phuket, Thailand | 2 | 233 | 7 | ↓5 | 216 | −17 |
| Ho Chi Minh City, Vietnam | 3 | 232 | 2 | ↑1 | 230 | −2 |
| Penang, Malaysia | 3 | 232 | 9 | ↓6 | 212 | −20 |
| Klang (Kuala Lumpur), Malaysia | 5 | 228 | 3 | ↑2 | 229 | 1 |
| Bali, Indonesia | 6 | 224 | 4 | ↑2 | 228 | 4 |
| Ko Samui, Thailand | 7 | 214 | 16 | ↓9 | 198 | −16 |
| Laem Chabang (Bangkok), Thailand | 8 | 208 | 13 | ↓5 | 204 | −4 |
| Da Nang, Vietnam | 9 | 206 | 6 | ↑3 | 219 | 13 |
| Lombok, Indonesia | 10 | 204 | 11 | ↓1 | 211 | 7 |
| Semarang, Indonesia | 11 | 200 | 14 | ↓3 | 199 | −1 |
| Langkawi, Malaysia | 12 | 198 | 9 | ↑3 | 212 | 14 |
| Yangon, Myanmar | 12 | 198 | 33 | ↓21 | 150 | −48 |
| Bandar Seri Begawan, Brunei | 14 | 196 | 24 | ↓10 | 168 | −28 |
| Nha Trang, Vietnam | 14 | 196 | 5 | ↑9 | 226 | 30 |
| Manila, Philippines | 16 | 195 | 12 | ↑4 | 208 | 13 |
| Komodo Island, Indonesia | 17 | 191 | 8 | ↑9 | 215 | 24 |
| Sihanoukville, Cambodia | 18 | 185 | 25 | ↓7 | 167 | −18 |
| Surabaya, Indonesia | 18 | 185 | 20 | ↓2 | 176 | −9 |
| Pulau We, Indonesia | 20 | 183 | 29 | ↓9 | 154 | −29 |

### *6.1. Theoretical implications*

This study uses COVID-19 as a case study of the impact of such public social events on the development of the cruise industry. The theoretical implications of this study extend beyond the immediate findings, introducing novelty approaches that reshape the assessment of maritime transportation network vulnerabilities. One significant advancement is introducing a weighted shipping network incorporating local port-level vulnerability indicators. This novel approach goes beyond traditional network models by accounting for the specific vulnerabilities of individual ports. Also, the framework gains depth and sophistication by incorporating local risk indicators, as Poo et al. (2021) demonstrated. Analysing how the weighted network responds to these local inputs introduces a groundbreaking method for assessing the potential impacts of various events on maritime shipping networks. This intricate understanding allows stakeholders to formulate targeted strategies for risk mitigation and network resilience enhancement.

Another theoretical contribution lies in the framework's adaptability to incorporate multiple local port-level vulnerability indicators. This adaptability is pivotal, enabling a comprehensive analysis considering various port vulnerability dimensions. The framework paints a holistic picture of network susceptibilities by accommodating diverse indicators that capture distinct vulnerabilities. Such a multifaceted perspective is essential for developing resilient strategies that address the interplay of different vulnerabilities.

The versatility of this methodology is not confined to cruise shipping networks alone. Instead, its principles can be extended to diverse transportation sectors, such as container shipping, railway, and aviation networks. By using the same methodology, these industries can assess the impacts of various disruptions, including armed conflicts, economic downturns, cyber attacks, and climate change. This adaptability underscores the framework's potential to revolutionise how transportation sectors approach disruption assessments, providing a comprehensive toolkit for proactive risk management, crisis management, and contingency planning.

Furthermore, integrating big data technologies, particularly machine learning, holds promise for enhancing the assessment's capabilities. As showcased by Cao et al. (2023), machine learning can process vast amounts of data efficiently, allowing for the evaluation of extensive networks encompassing multiple vulnerability indicators. By harnessing these technologies, stakeholders can gain more accurate insights into potential risks and their intricate relationships. This integration positions the framework at the forefront of resilience analysis, empowering decision-makers with real-time, data-driven insights that facilitate strategic planning and proactive risk management.

The theoretical implications of this study extend the boundaries of transportation network resilience analysis. By introducing weighted shipping networks, accommodating diverse vulnerability indicators, enabling cross-industry applicability, and embracing cutting-edge technologies, the framework presents a new paradigm for addressing disruptions in complex, interconnected transportation networks.

### 6.2. *Managerial implications*

Such advantages of the framework used in the study will undoubtedly contribute to significant managerial implications for cruise lines and port operators. They can tailor the proposed methodology in this paper and their fleet calls and the CPIs to develop a dynamic shipping network resilience model.

The framework outlined in the study offers profound managerial implications for cruise lines and port operators. These stakeholders can use this methodology alongside fleet calls and CPIs to create a dynamic shipping network resilience model. This model's real-time adaptability enables precise fleet deployment adjustments based on evolving COVID risk levels at cruise ports. This implication enhances passenger safety and optimises operational efficiency by minimizing fuel consumption and crew management costs.

Beyond individual cruise lines, cruise port states can leverage the model's benefits to coordinate information from various hosted cruise lines, yielding cost-effective safety management improvements. This collaborative approach ensures consistent safety protocols while minimizing redundancies. Moreover, the ASEAN cruising network vulnerability analysis is a foundational basis for these implications. International entities can formulate comprehensive resilience planning strategies by extending these results to the broader network. These strategies, backed by local and global adaptation measures and contingency plans, contribute to the industry's preparedness against unforeseen challenges.

Clustering the global cruise ship network into regions introduces further opportunities. This approach enables a comparative analysis that offers insights into distinct regional characteristics. For example, CLIA defined different market groups (CLIA, 2020), including The United States, Europe, and Asia, except for China. Therefore, providing the same assessment to observe and benchmark the network resilience of different clusters, known as the market groups, is beneficial for best practice learning. Such analysis can empower cruise lines and port operators to tailor strategies specific to each market group, aligning service offerings, marketing tactics, and operational decisions with regional preferences. In addition to strategic growth, this analysis paves the way for localized risk assessments and cost-benefit analyses, fostering innovative business planning.

Furthermore, the methodology's potential extends to fostering industry collaboration, optimising resource allocation, and enabling data-driven decisions. By considering an expanded network with multilevel vulnerabilities beyond COVID risks, stakeholders can create comprehensive strategies that safeguard operations against a broader spectrum of threats. Ultimately, the implications of this framework encompass collaborative resilience efforts, data-driven decision-making, regional strategy optimization, and holistic preparedness, shaping a more adaptable and resilient cruise industry ecosystem.

### 6.3. *Policy recommendations*

Based on the methodology provided in this study, the fleet management teams of the cruise lines can overview the changes caused by COVID-19. By updating the CPI, teams can foresee the changes given by the updated values of CPI. It is recommended that cruise lines update the routes based on the COVID-19 developments. In 2022, it seems that this round of the COVID-19 pandemic wave is nearly over, and the fleet management teams can use the same mindset to prevent the next round wave, if any, due to the virus evolving or other impacts on cruise networks.

Policy recommendations can be implicated for network vulnerabilities by investigating various impacts requiring forecasting results. For example, Arctic cruise ships can be a popular trend in the coming years (Lau et al., 2022a). Forecasting the potential network resilience changes on the cruise ship networks regionally and globally is possible. Then, further adaptation and resilience plans should be suggested to enhance the safety of the whole network in different sectors.

Furthermore, the centralisation of ports in large cities such as Singapore, Ho Chi Minh City, Klang (Kuala Lumpur), and Bali reflect an increasing focus as the cruise lines planned to choose large ports to resume operations first. Also, reduced rankings for the ports in countries with political conflict and severe crime issues, like Yangon and Sihanoukville, reflect the priority of safety and security in the cruise industry after COVID-19. Port facilities in these areas face challenges in attracting investment and maintaining operations due to political stability or security concerns. Therefore, apart from maintaining safety and security for shipping operations, it is also necessary to investigate the possibilities of improving infrastructure and capacity in small ports to minimise both network-level and port-level vulnerabilities.

Moreover, decentralisation from central hubs such as Singapore, Phuket, and Ho Chi Minh City is recommended for the top destinations listed in Table 5. It is imperative to develop more hubs with air traffic connections and larger cruise port facilities throughout ASEAN countries. For instance, beyond Ho Chi Minh City, Vietnam could consider the development of ports in Hanoi, Danang, and Nha Trang to create a network of cruise hubs across the country. Likewise, the Philippines boasts numerous beautiful islands and coastal areas that have the potential to become thriving cruise hubs, including Palawan, Cebu, and Davao. Investing in cruise port infrastructure in these regions would undoubtedly attract cruise operators.

Finally, smaller ships show more advantages, such as greater flexibility in itinerary planning and the ability to visit smaller, less crowded ports less affected by COVID-19. Smaller ships also typically have fewer passengers, making implementing social distancing and other health and safety protocols easier during a pandemic crisis. In addition, it can scatter the external risks and maintain the stability of the cruise shipping network.

## 7. Conclusion

In conclusion, this paper presents a pioneering approach to comprehensively evaluate vulnerabilities in the cruise shipping industry by integrating network-level and local port-level considerations. The study successfully bridges the gap between individual port analysis and network-wide impacts, offering insights into the complex dynamics brought about by events like the COVID-19 pandemic. The study fulfils its objective by merging these perspectives, advancing interdisciplinary knowledge and practical knowledge in the field.

Implementing an ASEAN cruising SNA highlights the central ports within the network, facilitating the regional cruising industry. The paper introduces a standardized procedure for constructing specific networks, enabling global SNA implementation. This approach allows for central port identification across various regions, fostering potential for comparative analyses with theoretical and managerial implications.

The weighted SNA methodology developed in this study offers a robust means of assessing the impacts of network traffic flow and shipping capacity. The paper enhances the foundation laid by prior research by integrating network-level vulnerability assessment with local port-level COVID-19 vulnerability analysis. The methodology's effectiveness is demonstrated by applying CPI as a local COVID-19 vulnerability indicator. This accomplishment solidifies the groundwork for new network vulnerability assessments, extending the application to various local vulnerability indicators.

From a theoretical standpoint, this study's contributions are twofold. Firstly, incorporating local port-level vulnerability indicators into a weighted shipping network is a novel contribution, guiding the identification of central ports. Secondly, developing a shipping network vulnerability analysis framework offers a groundbreaking approach to assessing the impact of events on shipping networks. The methodology can be adapted for various transportation networks, encouraging interdisciplinary applications and promoting a broader understanding of network resilience.

Practically, the outcomes of this research carry significant implications for cruise lines and port operators. The proposed methodology enables the creation of dynamic shipping network resilience models, empowering cruise lines to adjust fleet deployment according to real-time COVID-19 risk levels at various ports. Additionally, coordination among cruise lines and port states is facilitated, enhancing safety management while optimising resource allocation. The ASEAN cruising network vulnerability analysis insights provide a solid basis for these practical implications, guiding the industry's resilience planning and adaptation measures for other events.

Moreover, the potential for global cruise ship network clustering opens avenues for comparative analysis across different market groups. This approach offers insights into the distinct characteristics of various regions, aiding in risk assessment and business strategy formulation. Addressing the centralisation of ports and prioritising safety and security underscores the necessity to invest in infrastructure and capacity for small ports, minimizing vulnerabilities across levels.

Policy recommendations stemming from this study encompass various aspects, from anticipating external changes through fleet management to forecasting network resilience changes due to emerging trends such as another global pandemic. These recommendations suggest climate change adaptation and resilience plans to enhance network safety. The necessity of infrastructure improvements in politically unstable or insecure regions underscores the multifaceted nature of vulnerability reduction strategies.

The research method and outcomes offer a pioneering perspective on the vulnerability of cruise shipping networks to COVID-19 disruptions in particular, and other possible disruptions (e.g., climate change) in a broad sense. By elucidating interconnected vulnerabilities, cruise lines are equipped with actionable insights to navigate the complexities of global challenges. In the future, the study can be further extended to incorporate an actual number of cruise passengers to evaluate its impact on the findings. Secondly, the current study has not considered the impact of economic and political factors. For example, one of the leading cruise lines in the world, Royal Caribbean, changed its hub in Pacific Asia from Hong Kong to Singapore because of the slow relaxation of COVID-19 control policies (Yeo, 2022). If it happens, the network can be changed to a more considerable extent by the COVID-19 influences. Thus, the scale of COVID-19's impact on each port could be extended to reflect the whole picture better in case there is massive restructuring in the companies, fleets, and schedules. Thirdly, local port-level COVID-19 risk assessments rely on the port state CPI values based on the port city pandemic risk. Hence, a new thorough risk analysis of each cruise port's COVID-19 vulnerability will improve the soundness of the findings in the future when the relevant data becomes available or can be feasibly collected. To a certain extent, the availability also depends on the development of the COVID-19 pandemic. However, the mindset can be used for other safety-critical issues on the port, including climate change and economic depression.

This paper's comprehensive approach to cruise shipping network vulnerability assessment offers valuable insights for academia, industry, and policymaking. Integrating network-level and local port-level perspectives enhances understanding of vulnerability dynamics caused by various events. The methodology developed here is not only applicable to COVID-19 but also sets a foundation for addressing a broad spectrum of challenges. This study paves the way for optimising resource allocation, promoting safety and resilience, and fostering innovation in the cruise shipping industry.

## Author contribution statements

Y.L. and Z.Y. conceived of the presented idea. M.P. and Z.Y. developed the theory, and M.P. performed the computations. Y.L. and Z.Y. supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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## Appendix 1. Top Scheduled Port Calls by all cruising ships passing through ASEAN countries

| Rank | Destination | Port | Calls |
|---|---|---|---|
| 1 | Singapore* | Singapore | 400 |
| 2 | Taiwan | Keelung/Taipei | 284 |
| 3 | China | Baoshan/Shanghai | 276 |
| 4 | Hong Kong SAR, China | Hong Kong | 255 |
| 5 | Japan | Fukuoka/Hakata | 245 |
| 6 | Japan | Naha/Okinawa | 243 |
| 7 | Japan | Yokohama/Tokyo | 202 |
| 8 | Japan | Nagasaki | 198 |
| 9 | Thailand* | Patong Bay/Phuket | 188 |
| 10 | Malaysia* | Port Klang/Kuala Lumpur | 176 |
| 11 | Japan | Miyakojima/Hirara | 166 |
| 12 | China | Tianjin/Xingang/Beijing | 161 |
| 13 | Malaysia* | Georgetown/Penang | 158 |
| 14 | Japan | Ishigaki | 156 |
| 15 | Thailand* | Bangkok (Klong Toey & Laem Chabang) | 147 |
| 16 | India | Mormugao/Goa | 146 |
| 17 | Vietnam* | Ho Chi Minh City/Phu My | 144 |
| 18 | China | Xiamen | 129 |
| 19 | Japan | Kobe | 121 |
| 20 | Vietnam* | Da Nang/Hue/Chan May | 116 |
| 21 | Japan | Kagoshima | 110 |
| 22 | South Korea | Pusan/Busan | 110 |
| 24 | Malaysia* | Langkawi | 103 |
| 25 | China | Guangzhou/Nansha | 98 |
| 26 | Japan | Sasebo | 88 |
| 27 | Japan | Osaka/Sakai | 80 |
| 28 | Indonesia* | Benoa/Bali | 70 |
| 29 | Japan | Hiroshima | 69 |
| 30 | China | Shenzhen/Shekou | 64 |
| 31 | Vietnam* | Halong Bay/Hanoi | 63 |
| 32 | Malaysia* | Malacca | 62 |
| 33 | Thailand* | Koh Samui | 59 |
| 34 | Japan | Hakodate | 56 |
| 35 | Japan | Yonaguni | 55 |
| 36 | Cambodia* | Sihanoukville | 52 |
| 37 | Japan | Kanazawa | 51 |
| 37 | Indonesia* | Bintan | 51 |
| 39 | Japan | Shimizu | 50 |
| 40 | Japan | Sakaiminato | 49 |
| 40 | Philippines* | Manila | 49 |
| 40 | Sri Lanka | Colombo | 49 |
| 43 | India | Cochin | 47 |
| 44 | Japan | Nakagusuku/Okinawa | 46 |
| 45 | Indonesia* | Komodo/Slawi Bay | 44 |
| 45 | Indonesia* | Lembar/Lombok | 44 |
| 47 | Vietnam* | Nha Trang | 40 |
| 47 | India | Mumbai | 40 |
| 47 | Myanmar* | Rangoon (Yangon) | 40 |

Remarks: '*' indicates cruise port in ASEAN region Source: CLIA (2020).

## APPENDIX 2. ASEAN CRUISING PORTS FOR NETWORK ANALYSIS

| Country | Port | Country | Port |
|---|---|---|---|
| Brunei | Bandar Seri Begawan, Brunei | Malaysia | Pulau Tenggol, Malaysia |
| Cambodia | Koh Rong, Cambodia | Malaysia | Pulau Tiga, Malaysia |
| Cambodia | Sihanoukville, Cambodia | Malaysia | Sandakan, Sabah |
| Indonesia | Bali, Indonesia | Malaysia | Tioman Island, Malaysia |
| Indonesia | Ambon, Indonesia | Myanmar | Yangon, Myanmar |
| Indonesia | Banyuwangi, Java | Myanmar | Thahtay Kyun, Myanmar |
| Indonesia | Belawan, Indonesia | Philippines | Manila, Philippines |
| Indonesia | Bitung, Indonesia | Philippines | Boracay, Philippines |
| Indonesia | Celukan Bawang, Bali | Philippines | Busuanga Island, Philippines |
| Indonesia | Jakarta, Indonesia | Philippines | Hundred Islands, Philippines |
| Indonesia | Jayapura, Indonesia | Philippines | Puerto Princesa, Philippines |
| Indonesia | Kepulauan Seribu, Indonesia | Philippines | Romblon, Philippines |
| Indonesia | Kokas, Indonesia | Philippines | Salomague, Philippines |
| Indonesia | Komodo Island, Indonesia | Philippines | Subic Bay, Philippines |
| Indonesia | Kupang, Timor | Singapore | Singapore |
| Indonesia | Larantuka, Flores | Thailand | Ko Samui, Thailand |
| Indonesia | Lombok, Indonesia | Thailand | Laem Chabang (Bangkok), Thailand |
| Indonesia | Nongsa Point, Indonesia | Thailand | Phuket, Thailand |
| Indonesia | Padang Bay, Bali | Thailand | Ko A Dang, Thailand |

(*continued on next page*)

(*continued*)

| Country | Port | Country | Port |
|---|---|---|---|
| Indonesia | Probolinggo, Indonesia | Thailand | Ko Hong, Thailand |
| Indonesia | Pulau Banda, Indonesia | Thailand | Ko Kood, Thailand |
| Indonesia | Pulau Bawean, Indonesia | Thailand | Ko Kradan, Thailand |
| Indonesia | Pulau Bintan, Indonesia | Thailand | Ko Mak, Thailand |
| Indonesia | Pulau Menyawakan, Indonesia | Thailand | Ko Phangan, Thailand |
| Indonesia | Pulau We, Indonesia | Thailand | Ko Phi Phi Island, Thailand |
| Indonesia | Semarang, Indonesia | Thailand | Ko Rok Nok, Thailand |
| Indonesia | Surabaya, Indonesia | Thailand | Ko Samet, Thailand |
| Indonesia | Ternate, Indonesia | Thailand | Ko Surin, Thailand |
| Indonesia | Triton Bay, Indonesia | Thailand | Ko Tao, Thailand |
| Indonesia | Tual, Indonesia | Thailand | Ko Thalu, Thailand |
| Indonesia | Ujung Pandang, Indonesia | Thailand | Ko Wua Ta Lap, Thailand |
| Malaysia | Kotakinabulu, Malaysia | Thailand | Pattaya, Thailand |
| Malaysia | Langkawi, Malaysia | Thailand | Phang Nga Bay, Thailand |
| Malaysia | Bintulu, Sarawak | Thailand | Similan Islands, Thailand |
| Malaysia | Klang (Kuala Lumpur), Malaysia | Vietnam | Ho Chi Minh City, Vietnam |
| Malaysia | Kuching, Malaysia | Vietnam | Da Nang, Vietnam |
| Malaysia | Malacca, Malaysia | Vietnam | Halong Bay, Vietnam |
| Malaysia | Melaka, Malaysia | Vietnam | Krong Kampot, Cambodia |
| Malaysia | Miri, Malaysia | Vietnam | Nha Trang, Vietnam |
| Malaysia | Penang, Malaysia | Vietnam | Phu Quoc, Vietnam |
| Malaysia | Pulau Redang, Malaysia | | |

## APPENDIX 3. International CRUISING PORTS FOR NETWORK ANALYSIS

| Country | Port | Country | Port |
|---|---|---|---|
| Antigua and Barbuda | St Johns, Antigua | Japan | Yokohama, Japan |
| Argentina | Buenos Aires, Argentina | Jordan | Aqaba, Jordan |
| Argentina | Ushuaia, Argentina | Kenya | Mombasa, Kenya |
| Aruba | Oranjestad, Aruba | Maldives | Male, Maldives |
| Australia | Adelaide, Australia | Malta | La Valletta, |
| Australia | Brisbane, Australia | Mauritius | Port Louis |
| Australia | Cairns, Australia | Mexico | Acapulco, Mexico |
| Australia | Fremantle, Australia | Mexico | Cozumel, Mexico |
| Australia | Melbourne, Australia | Mexico | Puerto Vallarta, Mexico |
| Australia | Sydney, Australia | Monaco | Monaco |
| Bahamas | Nassau, Bahamas | New Caledonia | Noumea, New Caledonia |
| Bahrain | Khalifa Bin Salman, Bahrain | New Zealand | Auckland, New Zealand |
| Barbados | Bridgetown, Barbados | New Zealand | Christchurch, New Zealand |
| Bermuda | Hamilton, Bermuda | Norway | Bergen, Norway |
| Brazil | Itajai, Brazil | Norway | Oslo, Norway |
| Brazil | Manaus, Brazil | Norway | Tromso, Norway |
| Brazil | Rio De Janeiro, Brazil | Oman | Muscat, Oman |
| Brazil | Salvador De Bahia, Brazil | Panama | Colon, Panama |
| Brazil | Santos (Sao Paulo), Brazil | Panama | Panama City, Panama |
| Brunei | Bandar Seri Begawan, Brunei | Peru | Callao (Lima), Peru |
| Cambodia | Koh Rong, Cambodia | Portugal | Funchal, Madeira |
| Cambodia | Sihanoukville, Cambodia | Portugal | Lisbon, Portugal |
| Canada | Montreal, Quebec | Puerto Rico | San Juan, Puerto Rico |
| Canada | Quebec City, Quebec | Qatar | Doha, Qatar |
| Canada | Vancouver, Canada | Russia | St Petersburg, Russia |
| Canary Islands | Gran Canaria, Canary Islands | Senegal | Dakar, Senegal |
| Canary Islands | Tenerife, Canary Islands | Seychelles | Mahe, Seychelles |
| Chile | San Antonio, Chile | South Africa | Cape Town, South Africa |
| Chile | Valparaiso, Chile | South Africa | Durban, South Africa |
| China | Hong Kong, China | Spain | Barcelona, Spain |
| China | Shanghai, China | Spain | Bilbao, Spain |
| China | Shenzhen, China | Spain | Malaga, Spain |
| China | Tianjin, China | Spain | Palma De Mallorca, Spain |
| Colombia | Cartagena, Colombia | Spain | Seville, Spain |
| Costa Rica | Puerto Caldera, Costa Rica | Spain | Tarragona, Spain |
| Costa Rica | Puntarenas, Costa Rica | Spain | Valencia, Spain |
| Croatia | Dubrovnik, Croatia | Sri Lanka | Colombo, Sri Lanka |
| Cyprus | Limassol, Cyprus | St Lucia | Castries, St Lucia |
| Denmark | Copenhagen, Denmark | St Maarten | Marigot, St Maarten |
| Dominican Republic | La Romana, Dominican Republic | St Maarten | Philipsburg, St. Maarten |
| Dominican Republic | Santo Domingo, Dominican Republic | Sweden | Stockholm, Sweden |
| Egypt | Safaga, Egypt | Taiwan | Keelung, Taiwan |
| Fiji | Lautoka, Fiji | The Netherlands | Amsterdam, Holland |
| France | Bordeaux, France | The Netherlands | Ijmuiden, Holland |
| France | Cannes, France | The Netherlands | Rotterdam (Amsterdam), Holland |
| France | Fort de France, Martinique | Turkey | Antalya, Turkey |

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(*continued*)

| Country | Port | Country | Port |
|---|---|---|---|
| France | Le Havre (Paris), France | Turkey | Istanbul, Turkey |
| France | Marseille, France | Turkey | Kusadasi (Ephesus), Turkey |
| France | Rouen, France | United Arab Emirates | Abu Dhabi, United Arab Emirates |
| France | Villefranche (Nice), France | United Arab Emirates | Dubai, United Arab Emirates |
| French Polynesia | Papeete, Tahiti, French Polynesia | United Kingdom | Belfast, Northern Ireland |
| Germany | Bremerhaven, Germany | United Kingdom | Dover, England |
| Germany | Hamburg, Germany | United Kingdom | Edinburgh, Scotland |
| Germany | Kiel, Germany | United Kingdom | Liverpool, England |
| Germany | Travemunde, Germany | United Kingdom | London, England |
| Germany | Warnemunde, Germany | United Kingdom | Newcastle, England |
| Greece | Corfu, Greece | United Kingdom | Portsmouth, England |
| Greece | Iraklion, Greece | United Kingdom | Southampton, England |
| Greece | Piraeus (Athens), Greece | United States | Baltimore, Maryland |
| Guadeloupe | Pointe A Pitre, Guadeloupe | United States | Boston, Massachusetts |
| Iceland | Reykjavik, Iceland | United States | Charleston, South Carolina |
| India | Mumbai, India | United States | Fort Lauderdale, Florida |
| Ireland | Dublin, Ireland | United States | Galveston, Texas |
| Israel | Eilat, Israel | United States | Honolulu (Oahu), Hawaii |
| Israel | Haifa, Israel | United States | Jacksonville, Florida |
| Italy | Ancona, Italy | United States | Juneau, Alaska |
| Italy | Bari, Italy | United States | Los Angeles, California |
| Italy | Brindisi, Italy | United States | Miami, Florida |
| Italy | Cagliari, Sardinia | United States | Mobile, Alabama |
| Italy | Civitavecchia (Rome), Italy | United States | New Orleans, Louisiana |
| Italy | Genoa, Italy | United States | New York City, New York |
| Italy | La Spezia, Italy | United States | Norfolk, Virginia |
| Italy | Livorno (Florence/Pisa), Italy | United States | Palm Beach, Florida |
| Italy | Messina, Sicily | United States | Port Canaveral, Florida |
| Italy | Naples, Italy | United States | San Diego, California |
| Italy | Palermo, Sicily | United States | San Francisco, California |
| Italy | Ravenna, Italy | United States | Seattle, Washington |
| Italy | Savona, Italy | United States | Seward, Alaska |
| Italy | Trieste, Italy | United States | Tampa, Florida |
| Italy | Venice, Italy | United States | Whittier, Alaska |
| Jamaica | Montego Bay, Jamaica | Uruguay | Montevideo |
| Japan | Kobe, Japan | US Virgin Islands | St Thomas, US Virgin Islands |
| Japan | Tokyo, Japan | | |

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