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RESEARCH ARTICLES

Analysis of the Ferry Service Network in Hong Kong

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Ferry transportation enhances urban mobility and connectivity across the Hong Kong region. This study analyses the ferry network in Hong Kong using social network analysis. It has been found that the network consists of 31 piers linked by 28 maritime routes. Specific routes, particularly those departing from Hong Kong's Central Ferry Pier, serve as the network's backbone with its high service frequency. The existence of subnetworks within the broader ferry network indicates specialised clusters of maritime connectivity that cater to distinct geographic and operational domains. This study extends beyond network description to illuminate the implications of ferry network configurations for urban planning, sustainable transportation, and regional tourism development. That offers insights into strategies for optimising ferry services and infrastructure investment.

1. Introduction

Ferries serving as water-based transportation within local or regional areas have long been crucial in transporting people, vehicles, and goods across water bodies, especially for countries with long coastlines or many islands (Darzentas & Spyrou, 1996; Laird, 2012). Ferry transportation has evolved significantly, adapting to meet the changing needs of communities and supporting economic activities.

Ferries provide an essential mode of transport in coastal regions, islands, and areas with limited road or bridge infrastructure, connecting isolated communities (Baird, 1999). The ferry industry is influenced by the customers' demands and preferences, economic development, tourism, and city branding (Tanko & Burke, 2016). Ferries play an indispensable role in

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supporting trade and passenger transport. Unlike other transport modes, ferry services help to avoid or mitigate traffic congestion, a significant problem in large metropolitan areas (Lee & Leung, 2022).

Hong Kong, Macao, Japan, South Korea, and Indonesia benefit from ferry service due to their strong economies, quality of life, and attractiveness to visitors (Baird, 2000; Kim et al., 2022; Pham et al., 2020; Sihaloho et al., 2012; Verhaeghe et al., 2021; Weisbrod & Lawson, 2003). Ferry service supports economic growth, fosters trade, and links regions that rely on each other for commerce, taking into account the pier's efficiency, costs, and expenses. For instance, ferry service in Greece contends with significant operating expenses and routes designed to serve multiple islands with varying seasonal demand. There is no better method to maintain stable and uninterrupted itineraries, particularly for unpopular destinations than ferry service (Mitropoulos et al., 2022).

Ferry itinerary design must conform to strict constraints that include technical feasibility, safety issues, environmental impacts, and avoiding conflicts with ferries from neighbouring cities (X. Chu et al., 2020). Ferry operators design itineraries for efficient and reliable services by considering different factors, such as geographical features, population density, demand, and tourism patterns. For example, the Kowloon Ferry Company (also known as Star Ferry) provides ferry services between Hong Kong Island and Kowloon (Star Ferry, 2022a). Star Ferry now focuses on serving passengers and sightseeing tourists, with two primary routes, Hong Kong Central Harbour (henceforth Central)-Tsim Sha Tsui and Central-Wan Chai (Star Ferry, 2022b). Cotai Water Jet and TurboJet are high-speed ferry companies that sail between ports in Macao, Taipa, Hong Kong Island, and Hong Kong International Airport. Itineraries seek to optimise the ferry fleet, route reconfiguration, and passenger utility. A multi-stop itinerary with a single fleet reduces average passenger waiting time but increases average travel time (M. F. Lai & Lo, 2004). Ferry fleet optimisation seeks to be cost-effective during low-demand, off-peak periods. An itinerary should be direct lines to avoid unnecessary detours and increase service frequency (Sandell, 2017).

Ferry operators undertake many approaches to designing their itineraries and services, considering many factors. The initial step is conducting a demand analysis to determine passenger preferences, travel patterns, and cargo requirements. Schedule optimisation is used to minimise waiting times and maximise fleet utilisation, increasing service reliability and ensuring timely departures and arrivals. Cost and energy management is important to efficiently allocate operational resources (Banaei et al., 2020; Reddy et al., 2019). To enhance customer satisfaction, companies prioritise customer experience, evaluate environmental impact, and effectively respond to market competition.

The ferry services and networks in Hong Kong have been studied in many aspects, such as stochastic demand affecting ferry network design (H. K. Lo et al., 2013; Škurić et al., 2021), ferry services and community development

(Y. -y. Lau et al., 2023), reliability and risk analysis (Sasa et al., 2023; Yuan et al., 2023), and environmental sustainability, clean energy, green shipping, and waste management (Y. Y. Lau et al., 2021; Tsoi & Loo, 2021; Yu et al., 2023). Nevertheless, the characteristics and structural properties of the ferry service network are under-researched, notably in Hong Kong. The present study uses social network analysis to explore the ferry service network in Hong Kong and reflect on its operational design and services. Compared to other transport modes, ferries receive little government support. Therefore, the study may provide valuable insights for ferry operators to redesign routes to expand popular links. This may also spur the government to connect various outlying islands with land for urban development. This also creates a synergy effect of increasing local tourism in various outlying islands in a way that reconfigures tourist destinations to facilitate more sustainable and resilient tourism in response to negative incidents. As expected, the findings provide insight that may help ferry operators improve the overall quality of coastal shipping services, optimise the ferry service networks, and maximise resource allocation. The results may also support the sustainable development of ferry service for outlying islands.

This paper is structured as follows. Section 1 provides an introduction. Section 2 presents a literature review on ferry development, services, itinerary design, and network analysis. Section 3 presents the research methodology and data, while Section 4 provides an results and analysis. The discussion follows in Section 5 before the conclusion and future research directions in Section 6.

2. Literature Review

2.1. The evolution of ferry service in Hong Kong

The ferry system has played a pivotal role in shaping the city's connectivity and facilitating its economic progress. Ferry service started in the 19th century when the British colonial administration recognised the strategic importance of waterborne transport for linking the scattered islands and the mainland (Y. -y. Lau et al., 2023). Initial ferry operations primarily served as a means of local transportation.

As Hong Kong burgeoned into a thriving international trade hub, the ferry network underwent expansion and modernisation (Kai-Sun, 1997; Leung et al., 2017). In the early 20th century, there were advancements in ferry infrastructure, transitioning from simple wooden vessels to sophisticated steel-hulled boats equipped to accommodate growing passenger demands. The Star Ferry, which was established in 1898, exemplifies the transformation. The Star Ferry became a practical mode of transportation and a symbol of Hong Kong's resilience and continuity amid political changes (S. Y. -w. Chu, 2012).

After World War II, a turning point in the ferry system's development, rapid urbanisation led to increased commuter needs and a shift in focus towards public transport. The 1960s witnessed the introduction of doubledecker ferries with improved capacity and efficiency, effectively catering to increasing population density (Chiu & Leung, 1991). The British colonial government initiatives played a significant role, proactively involved in constructing transportation infrastructure, such as ferry piers and bus terminals (L. W. C. Lai et al., 2011). These aligned with Hong Kong's urban planning strategies, ensuring a well-integrated transportation network sustaining economic growth.

The number of ferry passengers reached approximately 35.5 million in 2021, and nine ferry operators provide more than 20 routes connecting outlying islands with main-island harbours (Hong Kong Transport Department, 2023). In 2022, Star Ferry serviced more than three million passengers, while daily passengers reached over 17,000 (Star Ferry, 2022b). Combined the companies average more than three million monthly passengers (Hong Kong Transport Department, 2023).

The Hong Kong government wields jurisdiction over 263 outlying islands, some of which are significant tourist destinations, for instance Cheung Chau, Lantau, and Lamma. The ferry industry links these islands with the urban core. This facilitates seamless transportation and fosters vibrant interactions between residents and visitors (Leung et al., 2017). Reliable transportation modes offer punctuality and safety, as prerequisites for travelling to outlying islands (Ip & Law, 2010). Natural resources, services, culinary experiences, and escape from routine life were crucial determinants to motivate tourists to visit the destination.

Since outlying islands have burgeoned into sought-after tourist hotspots, island residents grapple with challenges they had not imagined, such as rising restaurant prices. However, outmigration remains limited for the residents since they have strong connections with their home islands. Alongside concerns over tourist influx, ferry operators need to cater to a more select demographic, chiefly day trippers in Cheung Chau and tourists from other cities (Y. -y. Lau et al., 2023). The operators must keenly assess passenger demands when charting future development strategies.

The outbreak of the COVID-19 pandemic led Hong Kong residents to increasingly visit outlying islands as an alternative to other destinations (Tsui et al., 2021). In response, the frequency of ferry sailings increased (Lee & Leung, 2022). Nevertheless, the number of passengers declined because of subpar service quality, which was lower than other transport modes (Ceder, 2006). The inconvenience of reaching distant piers on foot contributed to the waning popularity of ferry usage. Thus, addressing service deficiencies and considering the accessibility factor is paramount for ferry operators to improve their service.

2.2. Ferry service design

A ferry service supports the mobility of people in large cities with harbours and rivers (Bell et al., 2020). This contributes to tourism growth by enabling visitors to explore scenic destinations and enhancing recreational opportunities. Ferry service is important in developing outlying islands, influencing urbanisation, economic growth, and social dynamics (Pilsch and Held, 1994). Service expansion facilitates urbanisation on outlying islands and catalyses population influx and urban development (Grydehøj & Zhang, 2020; Reddy et al., 2019; Tsoi & Loo, 2021). This fosters economic opportunities by facilitating trade, tourism, and commerce. Despite the ferry system providing an essential lifeline service to island communities, we cannot overlook the underlying challenges. Issues such as maritime ecology, over-tourism, and the contradiction between financial subsidies and inefficient operation demand greater attention. Existing ferry itineraries boost the development of outlying islands and communities, but careful consideration needs to be given to factors such as service frequency, affordability, and environmental sustainability.

Ferry itineraries and routes are designed considering demand and service reliability and quality. This is important to develop outlying islands by connecting them to the urban core and influencing commuting patterns and employment options (Leung et al., 2017). Ferry operators formulate a two-phase stochastic program to design regular and ad hoc services based on service reliability. The program also considers fuel efficiency, safety, passenger comfort, and demand uncertainty (An & Lo, 2014; H. K. Lo et al., 2013). Recently, the rise of autonomous ferry services encouraged operators to use optimisation models to design service routes and departure frequencies (Aslaksen et al., 2020).

Passenger waiting time is one of the determining factors in designing ferry services.

Waiting time influences the willingness of travellers to pay for reduced headway (time between departures), with the value of headway increasing with waiting time (Sandberg Hanssen & Larsen, 2020). As such, Lai and Lo (2004) developed a heuristic algorithm that solves the problem efficiently by exploiting the polynomial-time performance of shortest-path algorithms. This leads to the waiting time becoming shorter when a multi-stop service is employed. Passengers tend to adjust more to the scheduled departure as the time between ferry departures increases, decreasing the mean waiting time between departures (Andersen & Tørset, 2019). The waiting time for national highway routes is longer than for local ferry services. Queue psychology suggests that unexplained waits, uncertainty, and anxiety make wait times seem longer, highlighting the importance of understanding the relationship between vehicle position and wait time to inform and pacify passengers (Findley et al., 2018). Thus, Wang and Lo (2008) used a heuristic procedure to solve a multi-fleet ferry routing and scheduling problem, considering different operation characteristics and passengers' preferred arrival time windows. In other words, designing itineraries and services must consider waiting time to ensure a positive travel experience.

2.3. Ferry network analysis

Network analysis is a methodology employed to scrutinise intricate systems by representing them as networks (graphs), facilitating the exploration of connections and interactions among constituent elements or subsystems. This elucidates how these interconnections influence the overall dependability of the system (Zang & Fiondella, 2022). This approach finds notable application in the study of public transportation systems, contributing to the analysis of geographic spatial communication and network characteristics (Háznagy et al., 2015; Rajput et al., 2020). For instance, the maritime network in Greece exhibits characteristics of the absence of economies of scale and susceptibility to seasonal tourism. Tsiotas and Polyzos (2015) harnessed network analysis to redesign a low-density, neighbourhood-centric maritime network, effectively connecting ports to a significant portion of Greece's population.

Moreover, topological and spatial descriptions are employed in network analysis to provide recommendations and solutions to enhance the robustness and efficiency of public transportation networks (de Regt et al., 2019; Jia et al., 2019). Although network analysis has rapidly evolved in recent decades, it remains crucial to explore network cellular structures for a deeper understanding of transportation systems, while considering geographical constraints, urban attributes, and fostering collaboration among different domains. Such efforts bridge the gap between theoretical research and practical transportation challenges (Lin & Ban, 2013). In the present study, network analysis is used to conduct an in-depth analysis of ferry itineraries connecting outlying islands with Hong Kong. Subsequently, we discuss the socio-economic development of the outlying islands and the associated challenges awaiting resolution.

In conclusion, this research aligns with previous studies in its use of network analysis to evaluate transportation systems, particularly to improve connectivity and efficiency. The Greek maritime network and Hong Kong's ferry network face geographic challenges and fluctuations in demand. This requires tailored solutions based on network structures. However, there are also crucial differences. The present study uniquely integrates network analysis with a socio-economic perspective specific to Hong Kong, going beyond the topological and efficiency-driven focus seen in earlier works. The study also offers a more detailed investigation into the role of ferry itineraries in local development which is an area less explored in broader national or continental studies.

By synthesising methodologies and findings from previous research, this study contributes to addressing the challenges facing the Hong Kong ferry network. It offers theoretical insights and practical recommendations to improve system resilience. The study supports local socio-economic growth and enhances connectivity between Hong Kong and outlying islands .

Table 1. Statistical measures for analysing the ferry network

Measure	Equation	Description
Network density	$\rho(G) = \frac{2m(G)}{n(n-1)}$	The fraction of the number of links that a network has and the possible number of links
Average clustering coefficient	$C = \frac{1}{n}\sum_{i=1}^{n}\frac{2E_i}{k_i(k_i-1)}$	The average of the fraction of the number of links between the nodes within its neighbour and the possible number of links between them
Average path length	$L = \frac{1}{n(n-1)}\sum_{i\neq j}^{n} d_{ij}$	The mean of the links along the shortest path for all possible node pairs
Degree centrality	$C_D(i) = \sum_{j=1}^{n} a_{ij}$	The sum of the links that a node has
Strength centrality	$C_S = \left\lvert \sum_{j=1}^{n} w_{ij}a_{ij} \right\rvert$	The absolute sum of a node's link weights
Betweenness centrality	$C_B(i) = \sum_{s\neq i\neq t}\frac{\sigma_{st}(i)}{\sigma_{st}}$	The proportion of the number of shortest paths from nodes *s* to *t* passing through node *i* to the number of shortest paths from nodes *s* to *t*
Closeness centrality	$C_C(i) = \frac{n-1}{\sum_{j\neq i} d_{ij}}$	The inverse of the shortest paths from node *i* to all others in the network

3. Methodology

The structural properties of the ferry network and piers in Hong Kong are analysed using social network analysis. The ferry network is considered a weighted network consisting of a set of piers (nodes) connected by a set of shipping routes (links). The weight of a link is referred to the shipping frequency of that link. Table 1 summarises the key statistical measures used in this study. Network density, average clustering coefficient, and average path length are used to analyse the network. Whereas, degree, betweenness, strength, and closeness centrality are used to analyse piers.

The equations of the measures mentioned below are made up of the following parameters:

> n = the number of piers, m = the number of links, E_i = the number of links between the neighbour of nodes i, d_{ij} = the number of connection steps between node i and node j, k_i = the number of links that node i has, a_{ij} = a constant, if one is a link connects between nodes i and j, if zero otherwise, σ_{st} = the number of shortest paths from nodes s to t and $\sigma_{st}(i)$ = the number of shortest paths from nodes s to t passing node i.

Network density is used to analyse the connectivity of the network. An average clustering coefficient is used to analyse the intra-connectivity among piers in the subnetworks. The average shortest path length is used to analyse the network's connectivity efficiency. The properties of piers are analysed using centrality measures. Degree centrality is used to analyse the pier's connectivity. Strength centrality is used to analyse the frequency of a link that connects to a pier. Betweenness centrality is used to identify the intermediate piers with high accessibility. Closeness centrality is used to analyse the

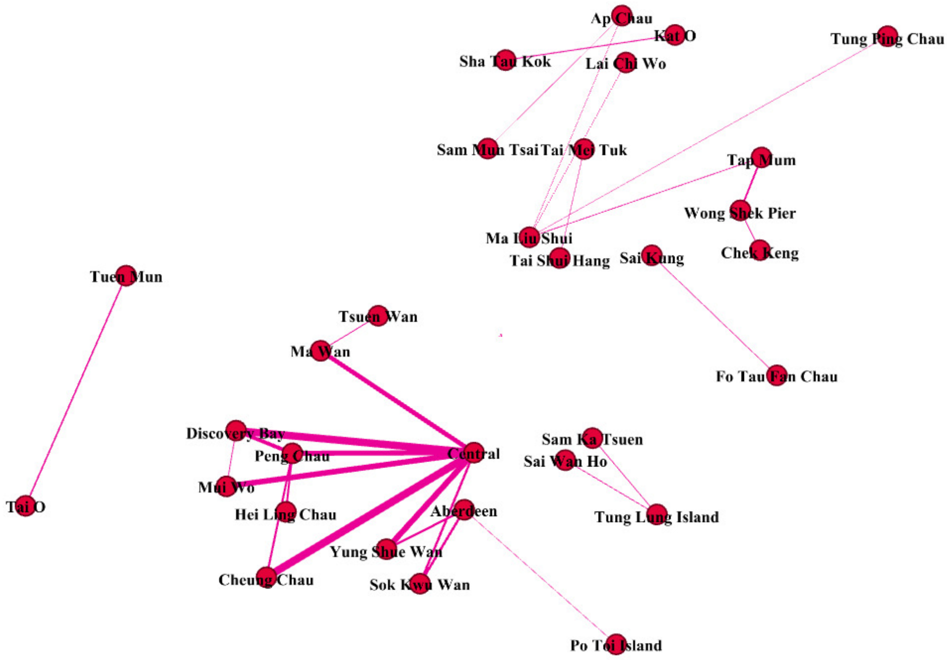

Figure 1. Graph of the ferry network in Hong Kong (line thickness denotes service frequency)

reachability of a pier. This study used the secondary data of the ferry network in Hong Kong collected from the website of the Hong Kong Transport Department in March 2023. The data consists of 4,295 itineraries serviced in a week. Analysis is conducted using the statistical software R.

4. Results

4.1. Network structural properties

Figure 1 illustrates the ferry network in Hong Kong, consisting of 31 piers connected by 28 shipping routes (links). The network appears to have seven subnetworks (groups) that are not connected to each other. The thickness of the lines connecting piers indicates ferry service frequency (weight) of links. Table 2 presents the popular routes connecting between two piers. The popularity is measured by the service frequency of a route. Central-Cheung Chau is the most popular route with the highest weight, followed by Central-Discovery Bay, Central-Yung Shue Wan, Central-Mui Wo, and Central-Peng Chau. Interestingly, all popular routes connect to Central, indicating that Central is located at the optimal location among the outlying islands where it provides the shortest route between the main city and outlying islands.

The network has a network density of 0.0602, indicating the possibility that piers can connect to others. Therefore, the network is sparse, with less cohesive piers. This phenomenon happens because ferry operators do not design services so that all piers can connect to all others. In addition, the location limitation of piers makes them unable to connect to others. A low network density also signifies that ferry shipping can face difficulties. The network's clustering coefficient is 0.1875, reflecting a low intra-connectivity among piers. This is because piers in the network tend to cluster together less.

Table 2. Top five links with a high service frequency

Rank	From	To	Service frequency
1	Central	Cheung Chau	301
2	Central	Discovery Bay	293
3	Central	Yung Shue Wan	224
4	Central	Mui Wo	214
5	Central	Peng Chau	192

Network efficiency can be reflected by average path length. The network has a very low efficiency with a large average path length of 200.82. This means connecting two piers has to take 200 connection steps on average, making mass ferry transportation less efficient.

The sparse network limits connectivity and flexibility, making it difficult to connect all piers efficiently. This can be fixed by increasing the number of direct ferry routes to reduce the sparseness of the network. Focus on connecting major piers to improve accessibility and reduce reliance on multiple transfers. Smaller vessels, for instance, water taxis can be introduced to connect more isolated piers to major hubs. This would increase density without requiring large-scale infrastructure changes. Implementing demand-based or seasonal routes to boost connectivity during peak periods or in areas with fluctuating demand would improve overall network flexibility.

The low clustering coefficient reflects poor connectivity among piers in the same groups, with isolated piers forming few highly connected groups. Grouping geographically close piers into clusters with frequent and direct services between them would increase their connections. By enhancing local connectivity, passengers could travel between piers within a region more easily without needing to pass through central hubs. Adding smaller, faster ferry services that act as "feeders" to connect clusters of piers would reduce the isolation of piers and help increase the overall clustering coefficient by improving connections within outlying areas. Creating different layers within the network, such as express routes between major piers and local routes connecting nearby piers though a hierarchical approach would enhance both regional and long-distance travel.

The large average path length indicates a highly inefficient network, where passengers need to make multiple transfers to travel between two destination piers. Prioritising increased direct connections between high-demand piers would reduce the number of transfers required for passengers to reach their destinations. This would significantly reduce the average path length. Introducing express ferries that bypass intermediate piers on popular routes would reduce travel time for long-distance passengers and minimise the number of connection steps between piers. Improving transfer facilities at major hubs and reducing waiting times by better synchronising ferry schedules for efficient transfers would reduce the effective path length experienced by passengers.

4.2. Pier Analysis

Table 3 presents the centrality values of all the piers in the network.

Degree centrality

Degree centrality reflects the importance and popularity of a pier in terms of its connectivity. Central has the highest degree centrality of 7, followed by Peng Chau and Ma Liu Shui (4 degrees) and Aberdeen and Discovery Bay (3 degrees). Nine piers have a degree centrality of 2, and 17 piers have a degree centrality of 1. These indicate that Central is the most essential pier since it has the highest connectivity, while others are less important.

With the highest degree centrality, Central serves as a key hub in the network. Operators should prioritise resources here, such as optimising schedules, increasing capacity, and offering premium services, as it is a high-traffic node essential for connectivity. Peng Chau, Ma Liu Shui, Aberdeen, and Discovery Bay (3-4 degrees) act as secondary hubs. Operators can target these locations for expansion, offering more frequent services or connecting them to additional destinations to ease congestion at Central. Piers with lower degree centrality (1-2 degrees) might serve niche routes or cater to specific local needs. Operators can adopt a more tailored approach for these piers, offering specialised services, possibly with smaller vessels or flexible schedules, to meet the local demand efficiently. With 17 piers having a degree centrality of 1, there might be opportunities to create new connections between less-connected piers and more central piers. This could enhance network efficiency and offer more direct routes for passengers.

The high degree centrality of Central suggests it should be prioritised for infrastructural investments, such as terminal upgrades or introducing new ferry technologies, to maintain its role as the network's central hub. For piers with lower connectivity, operators can employ flexible pricing, scheduling, or multi-modal transport options to enhance their attractiveness, possibly improving their centrality in the network over time. These strategies can help ferry operators optimise their networks, improve service quality, and potentially increase ridership.

Strength centrality

Strength centrality illustrates the strongness of a link connecting to a pier. A pier with the highest value of strength centrality means that it has the most vital connections. A pier with the lowest value of strength centrality is reasonably unimportant, which could be a deactivated pier. Central has the highest strength centrality of 1,480, indicating that it has a strong connection, and the links connecting to it provide 1,480 ferry services. Peng Chau ranks second with a strength centrality (469), followed by Discovery Bay (454), Cheung Chau (371), and Yung Shue Wan (301). Four piers have strength values between 101 and 200, and four piers have strength values of 51-100. A large number of piers (19 piers) have a low strength centrality of less than 51. Among these, Lai Chi Wo, and Sam Mun Tsai have the lowest value of two, indicating that the links that connected them provide two ferry services in a week. To reduce the operation cost, ferry operators should stop providing services for these routes. Ferry operators should move ferries to service the routes with high demand, such as routes that connect to Central, Peng Chau, and Discovery Bay.

Central, Peng Chau, and Discovery Bay, with the highest strength centrality values, represent routes with significant ferry demand. Operators should focus on these high-volume routes by increasing ferry frequency, offering larger or faster vessels, and enhancing passenger services to cater to higher traffic. By reallocating resources from low-demand routes (such as those to Lai Chi Wo and Sam Mun Tsai, which only have two weekly services) to high-demand routes, ferry operators can reduce operational costs and maximise profitability. Routes with strength centrality values lower than 51 should be re-evaluated to determine if the service is sustainable.

For piers with extremely low strength centrality, ferry services may be underutilised, which drives up operational costs. Operators could consider discontinuing or reducing the frequency of services to these piers unless there are strategic or social reasons to maintain them. For piers with moderate strength centrality (51-200), ferry operators could adopt a scalable approach, adjusting services based on seasonal demand fluctuations, special events, or tourism surges. This flexibility would help optimise capacity while meeting changing demand. While focusing on cost-effective routes is important, ferry operators should also consider accessibility for isolated or underserved communities. Even low-strength centrality piers might be strategically important for connecting remote areas, which can be addressed through government subsidies or alternative funding.

Betweenness centrality

Betweenness centrality reflects the accessibility of a pier standing between two others reflecting its intermediate role. Central has the highest betweenness centrality (38), followed by Peng Chau (19), Ma Liu Shui (17), Sok Kwu Wan (16), and Aberdeen (11). This indicates that they have high accessibility. They also have more control over the network because more services will pass through them. Therefore, they are intermediates of the network. About 23 % of total piers have a betweenness centrality of 1-10, reflecting fewer services passing through them. 19 piers are peripheral piers with a betweenness centrality of zero, signifying no ferry service passing through them. Central plays a crucial role in the network with the largest degree and betweenness centrality values. Therefore, it is a network hub.

Piers with high betweenness centrality serve as key intermediaries in the ferry network. These piers facilitate connections between other piers, making them essential for network flow and transit efficiency. Operators should ensure that these hubs have robust infrastructure, efficient schedules, and sufficient ferry capacity to handle high passenger volumes and transit traffic. Since these hubs have more control over the network, any disruption at piers like Central or Peng Chau could have significant ripple effects. To mitigate this possibility, ferry operators should prioritise service reliability at these locations, ensuring backup ferries, redundancy in schedules, and efficient coordination across routes.

Piers with lower betweenness centrality (1-10) may offer opportunities for route optimisation or new services. Operators could explore creating direct connections between these piers and key hubs to improve accessibility, potentially increasing the overall network efficiency. The 19 peripheral piers with a betweenness centrality of zero play no intermediary role in the network. These piers are likely served by point-to-point routes only, without transfers. Ferry operators could consider whether maintaining service to these peripheral piers is cost-effective or necessary. If passenger demand is low, reducing or restructuring service to these piers could help cut costs.

The piers with high betweenness centrality could also serve as strategic points for implementing premium pricing, as they have more influence over the flow of passengers. Ferry operators could consider adjusting ticket prices or offering additional services, such as express ferries or premium seating, at these key transit points. The centrality of piers like Central offers opportunities for better integration with other transport networks (e.g., buses, trains, or taxis), enhancing the overall connectivity and convenience for passengers. Ferry operators could collaborate with other transport providers to offer seamless connections, making these key piers even more attractive transit points.

Closeness centrality

All piers have a very low closeness centrality (less than 0.5), indicating that they are difficult to connect to all others in the network. This is because itineraries are always designed to have piers connecting to others nearby. The location limitation of a pier is another factor that makes a pier unable to connect to all others. However, Tai Shui Hang and Tai Mei Tuk have the highest closeness centrality of 0.125. The rest have a closeness centrality of less than 0.10. Therefore, these two piers have a higher reachability than others. The low closeness centrality of piers also reflects that shipping between all pairs of piers cannot be reached directly. It needs to depend on one other intermediate pier.

Since no pier has high reachability, ferry routes heavily depend on intermediate piers to connect different parts of the network. Operators need to ensure that these key transit piers (with higher betweenness centrality) are optimised for smooth transfers. Efficient scheduling, minimising waiting times, and ensuring reliable services at these key points are essential. The fact that most piers have low closeness centrality suggests that there are gaps in direct connectivity. Ferry operators could explore opportunities to introduce new direct routes between piers that are currently poorly connected, particularly in high-demand areas. This could reduce travel times and improve the overall efficiency of the network.

With the highest closeness centrality, Tai Shui Hang and Tai Mei Tuk are more reachable than other piers. Operators can leverage this by offering more services or expanding connections from these piers, as they have the potential to act as important hubs for further development of the network. The low closeness centrality of most piers reflects that ferry routes are designed to connect nearby locations. Operators could focus on improving localised services, catering to the needs of passengers traveling between neighbouring piers. Expanding the frequency and capacity of local routes could enhance convenience for daily commuters and local communities.

The geographical constraints of some piers limit their ability to connect directly to others. For these piers, ferry operators may need to accept that they will always be more peripheral in the network. Instead of attempting direct connections, they could focus on strengthening connections to key intermediary hubs, ensuring that passengers can easily transfer between routes. Given the limitations in direct connectivity across the ferry network, operators might consider working closely with land transport services (buses, trains, etc.) to offer better-integrated transport solutions. This could compensate for the low closeness centrality by providing more seamless connections beyond the ferry routes themselves.

5. Discussion

The ferry network is not the primary daily transportation mode for all members of the public. The entire network is discrete, but it also includes potential developments. Analysis revealed hubs including Central, Peng Chau, Ma Liu Shui, Aberdeen, and Discovery Bay. We developed suggestions for managerial implications from our findings. There is an strong opportunity to introduce new tourist destinations. The recovery of Hong Kong from the setbacks of COVID-19 is proving difficult (Liu et al., 2023). With rental prices soaring, the city must transform strategically to regain its position as a leading city in Asia, compared to Tokyo and Singapore. It is crucial to utilise its unique geography, which provides straightforward access to stunning coastal areas. Intensifying efforts to promote the less familiar islands of Hong Kong is essential. Additionally, contemplating upgrades to current ferry infrastructure could significantly boost its allure, which could be a turning point in targeting new tourism markets.

In 2018, the Hong Kong government introduced the Lantau Tomorrow Vision initiative, which promises significant changes, particularly impacting Peng Chau and Hei Ling Chau (S. S. H. Lo et al., 2021). It is critical to devise contingency plans for the residents of these islands to mitigate disruptions during the construction phase. Following the completion of this project, Peng Chau is poised to emerge as a crucial hub for waterborne transport. Positioned strategically between Hong Kong Island, Lantau Island, and Kowloon, its new geographical advantage could offer a viable solution to alleviate the high demand for metro services and road congestion. This could present an alternative for addressing urban mobility challenges.

Table 3. Centrality values of piers in the Hong Kong ferry network

Pier	Degree	Strength	Betweenness	Closeness
Central	7	1480	38	0.00046
Peng Chau	4	469	19	0.00036
Ma Liu Shui	4	23	17	0.00508
Aberdeen	3	168	11	0.00033
Discovery Bay	3	454	3	0.00031
Cheung Chau	2	371	0	0.00029
Mui Wo	2	233	7	0.00032
Yung Shue Wan	2	301	0	0.00028
Sok Kwu Wan	2	168	16	0.00040
Ma Wan	2	195	10	0.00028
Ap Chau	2	4	6	0.00488
Tap Mum	2	75	10	0.00437
Tung Lung Island	2	32	1	0.03126
Wong Shek Pier	2	79	6	0.00215
Hei Ling Chau	1	65	0	0.00029
Tuen Mun	1	45	0	0.02222
Tai O	1	45	0	0.02222
Tsuen Wan	1	21	0	0.00027
Po Toi Island	1	5	0	0.00032
Lai Chi Wo	1	2	0	0.00479
Tung Ping Chau	1	3	0	0.00465
Sai Wan Ho	1	16	0	0.02083
Sam Ka Tsuen	1	16	0	0.02083
Sai Kung	1	12	0	0.08333
Fo Tau Fan Chau	1	12	0	0.08333
Sha Tau Kok	1	28	0	0.03571
Kat O	1	28	0	0.03571
Tai Shui Hang	1	8	0	0.12500
Tai Mei Tuk	1	8	0	0.12500
Sam Mun Tsai	1	2	0	0.00461
Chek Keng	1	20	0	0.00171

The Guangdong–Hong Kong–Macao Greater Bay Area (also called the Greater Bay Area: GBA) consists of nine cities and two special administrative regions in South China. It will be a unified economic zone that aims to assume a leading position on the global stage by 2035 (H. Wang et al., 2024). A key strategy is bolstering the transportation network across the region to improve resilience and connectivity. Additionally, the strategy includes fostering tourism across cities within the area by encouraging a more integrated and cooperative regional tourism industry. For example, the ferry service between Hong Kong International Airport and Macao can be extended to other cities in GBA (Huang, 2024). New routes between Hong Kong and Zhujai islands nearby, such as Wailingding Island, can be proposed for local, regional, and international travellers (Z. Wang et al., 2024).

6. Conclusion

This investigation into Hong Kong's ferry network through social network analysis has uncovered a multifaceted system characterised by a series of interconnected subnetworks and pivotal routes, highlighting Central's predominant role as a network hub. Analysis reveals not only the structural and operational dynamics of the ferry network but also underscores its sparse density and the challenges associated with enhancing mass transport efficiency and pier interconnectivity. The strategic importance of Central-Cheung Chau and Central-Discovery Bay routes points to potential areas for focused development and service enhancement.

Identifying key piers with high centrality measures suggests avenues for targeted infrastructure and service improvements to bolster network efficiency and connectivity. The discussion extends to the broader implications of our findings for urban and transportation planning, emphasising the necessity of integrating ferry services into the larger context of public transportation systems and regional development strategies. This study's insights into the ferry network's configuration and critical nodes provide a foundation for future research aimed at comparative analyses with other regions and exploring innovative approaches to ferry service optimisation and urban mobility enhancement. The limitations of this study highlight the need for further research, incorporating qualitative insights from industry stakeholders and expanding the comparative framework to include international ferry networks, thereby enriching the global understanding of maritime transportation's role in urban and regional development.

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References

An, K., & Lo, H. K. (2014). Ferry service network design with stochastic demand under user equilibrium flows. *Transportation Research Part B: Methodological*, *66*, 70–89. https://doi.org/10.1016/j.trb.2013.10.008

Andersen, S. N., & Tørset, T. (2019). Waiting time for ferry services: Empirical evidence from norway. *Case Studies on Transport Policy*, *7*(3), 667–676. https://doi.org/10.1016/j.cstp.2019.04.006

Aslaksen, I. E., Svanberg, E., Fagerholt, K., Johnsen, L. C., & Meisel, F. (2020). Ferry Service Network Design for Kiel fjord. *Computational Logistics*. https://doi.org/10.1007/978-3-030-59747-4_3

Baird, A. J. (1999). A comparative study of the ferry industry in Japan and the UK. *Transport Reviews*, *19*(1), 33–55. https://doi.org/10.1080/014416499295664

Baird, A. J. (2000). The Japan coastal ferry system. *Maritime Policy & Management*, *27*, 16–13. https://doi.org/10.1080/030888300286644

Banaei, M., Boudjadar, J., Dragičević, T., & Khooban, M. H. (2020, September 28–October 1). Cost Effective Operation of a Hybrid Zero-Emission Ferry Ship. *2020 IEEE 11th International Symposium on Power Electronics for Distributed Generation Systems (PEDG)*. https://doi.org/10.1109/PEDG48541.2020.9244456

Bell, M. G. H., Pan, J.-J., Teye, C., Cheung, K.-F., & Perera, S. (2020). An entropy maximising approach to the ferry network design problem. *Transportation Research Part B: Methodological*. https://doi.org/10.1016/j.trb.2019.02.006

Ceder, A. (2006). Planning and Evaluation of Passenger Ferry Service in Hong Kong. *Transportation*, *33*(2), 133–152. https://doi.org/10.1007/s11116-005-3047-1

Chiu, W. K. S., & Leung, K. -p. B. (1991). *A social history of industrial strikes and the labour movement in Hong Kong, 1946-1989*.

Chu, S. Y. -w. (2012). Brand Hong Kong: Asia's World City as Method? In *Hybrid Hong Kong* (1st ed.). Routledge. https://doi.org/10.4324/9780203723296-5/brand-hong-kong-asia-world-city-method-stephen-yiu-wai-chu

Chu, X., Shao, S., Xu, S. X., & Kang, K. (2020). Data-driven ferry network design with candidate service arcs: the case of Zhuhai Islands in China. *Maritime Policy & Management*, *47*(5), 598–614. https://doi.org/10.1080/03088839.2020.1747650

Darzentas, J., & Spyrou, T. (1996). Ferry Traffic in the Aegean Islands: A Simulation Study. *Journal of the Operational Research Society*, *47*(2), 203–216. https://doi.org/10.1057/jors.1996.19

de Regt, R., von Ferber, C., Holovatch, Y., & Lebovka, M. (2019). Public transportation in Great Britain viewed as a complex network. *Transportmetrica A: Transport Science*, *15*(2), 722–748. https://doi.org/10.1080/23249935.2018.1529837

Findley, D. J., Anderson, T. J., Bert, S. A., Nye, T., & Letchworth, W. (2018). Evaluation of wait times and queue lengths at ferry terminals. *Research in Transportation Economics*, *71*, 27–33. https://doi.org/10.1016/j.retrec.2018.06.009

Grydehøj, A., & Zhang, H. (2020). Complementarity of island cross-sea transport links: Bridges, ferries, and mobility in Zhoushan Archipelago, China. *Journal of Marine and Island Cultures*. https://doi.org/10.21463/jmic.2020.09.2.04

Hong Kong Transport Department. (2023). *Ferry operators*. https://www.td.gov.hk/en/publications_and_press_releases/publications/index.html

Huang, W. (2024). Attracting Tourists to the Region: Analysis on Macau's Transportation System. *International Journal of Social Sciences and Public Administration*, *2*(1), 119–128. https://doi.org/10.62051/ijsspa.v2n1.16

Ip, C., & Law, R. (2010). Outlying Islands as a Tourist Destination for Local Residents: The Case of Cheung Chau in Hong Kong. *Asia Pacific Journal of Tourism Research*, *15*(4), 417–430. https://doi.org/10.1080/10941665.2010.520945

Jia, G.-L., Ma, R.-G., & Hu, Z.-H. (2019). Urban Transit Network Properties Evaluation and Optimization Based on Complex Network Theory. *Sustainability*, *11*(7). https://doi.org/10.3390/su11072007

Kai-Sun, K. (1997). Private participation with strong government control: Hong Kong. In *Infrastructure strategies in East Asia: the untold story* (pp. 51–68). World Bank.

Kim, H., Choi, J., Nam, Y., & Youn, J.-H. (2022). Characteristic Analysis of the Built Environment of Ferry Terminals: A Case Study of Mokpo, South Korea. *Sustainability*, *14*(4), 2115. https://doi.org/10.3390/su14042115

Lai, L. W. C., Davies, S. N. G., & Cheung, A. P. C. W. (2011). Government Transport Land-use Planning and Development by Implicit Contract for Franchised Buses and Ferries in Hong Kong, 1933–1972. *Planning Practice & Research*, *26*(4), 435–466. https://doi.org/10.1080/02697459.2011.582395

Lai, M. F., & Lo, H. K. (2004). Ferry service network design: optimal fleet size, routing, and scheduling. *Transportation Research Part A: Policy and Practice*, *38*(4), 305–328. https://doi.org/10.1016/j.tra.2003.08.003

Laird, J. J. (2012). Valuing the quality of strategic ferry services to remote communities. *Research in Transportation Business & Management*, *4*, 97–103. https://doi.org/10.1016/j.rtbm.2012.06.013

Lau, Y. Y., Kawasaki, T., Guan, J., & Not, C. (2021). An investigation into the attitude and behaviors of ferry passenger towards general waste management. *Ocean & Coastal Management*, *213*, 105879. https://doi.org/10.1016/j.ocecoaman.2021.105879

Lau, Y. -y., Tam, K. -c., & Ng, A. K. Y. (2023). Ferry services and the community development of peripheral island areas in Hong Kong: Evidence from Cheung Chau. *Island Studies Journal*. https://doi.org/10.24043/isj.402

Lee, H. Y., & Leung, K. Y. K. (2022). Island ferry travel during COVID-19: charting the recovery of local tourism in Hong Kong. *Current Issues in Tourism*, *25*(1), 76–93. https://doi.org/10.1080/13683500.2021.1911964

Leung, A., Tanko, M., Burke, M., & Shui, C. S. (2017). Bridges, tunnels, and ferries: connectivity, transport, and the future of Hong Kong's outlying islands. *Island Studies Journal*, *12*(2), 61–82. https://doi.org/10.24043/isj.24

Lin, J., & Ban, Y. (2013). Complex Network Topology of Transportation Systems. *Transport Reviews*, *33*(6), 658–685. https://doi.org/10.1080/01441647.2013.848955

Liu, H., Wu, P., & Li, G. (2023). Do crises affect the sustainability of the economic effects of tourism? A case study of Hong Kong. *Journal of Sustainable Tourism*, *31*(9), 2023–2041. https://doi.org/10.1080/09669582.2021.1966018

Lo, H. K., An, K., & Lin, W. -h. (2013). Ferry service network design under demand uncertainty. *Transportation Research Part E: Logistics and Transportation Review*, *59*, 48–70. https://doi.org/10.1016/j.tre.2013.08.004

Lo, S. S. H., Hung, S. C. F., Loo, J. H. C., Lo, S. S. H., Hung, S. C. F., & Loo, J. H. C. (2021). Populist Protesters, October 1 Confrontation and Opposition to Anti-mask Law. In *The Dynamics of Peaceful and Violent Protests in Hong Kong: The Anti-extradition Movement* (pp. 211–226). https://doi.org/10.1007/978-981-15-6712-4_6

Mitropoulos, L., Antypas, A., & Kepaptsoglou, K. (2022). Transportation planning for ferry services by using a continuous approximation model: the case of the Aegean Islands, Greece. *Transportation Letters*, *14*(5), 512–523. https://doi.org/10.1080/19427867.2021.1901010

Pham, T. Q. M., Lee, G., & Kim, H. (2020). Toward Sustainable Ferry Routes in Korea: Analysis of Operational Efficiency Considering Passenger Mobility Burdens. *Sustainability*, *12*(21), 8819. https://doi.org/10.3390/su12218819

Rajput, N. K., Badola, P., Arora, H., & Grover, B. A. (2020). *Complex Network Analysis of Indian Railway Zones*. https://doi.org/10.48550/arXiv.2004.04146

Reddy, N. P., Zadeh, M. K., Thieme, C. A., Skjetne, R., Sørensen, A. J., Aanondsen, S. A., Breivik, M., & Eide, E. (2019). Zero-Emission Autonomous Ferries for Urban Water Transport: Cheaper, Cleaner Alternative to Bridges and Manned Vessels. *IEEE Electrification Magazine*, *7*, 32–45. https://doi.org/10.1109/MELE.2019.2943954

Sandberg Hanssen, T.-E., & Larsen, B. (2020). The influence of waiting time on the value of headway time on a ferry service in Norway. *Research in Transportation Economics*, *82*, 100879. https://doi.org/10.1016/j.retrec.2020.100879

Sandell, R. (2017). Network Design Strategies to Increase Efficiency and Usefulness of Urban Transit Ferry Systems. *Transportation Research Record*, *2649*(1), 71–78. https://doi.org/10.3141/2649-08

Sasa, K., Lee, S. W., Shimada, R., Takagaki, T., & Terada, D. (2023). Safety evaluation of lashed trailer motions in ferry operations under rough sea conditions. *Ocean Engineering*, *275*, 114114. https://doi.org/10.1016/j.oceaneng.2023.114114

Sihaloho, A., Wunas, S., Jinca, M., & Parung, H. (2012). Ferry transport of Trans Maluku interislands cluster in Indonesia. *Internasional Journal of Civic & Environmental Engineering*, *12*(5), 9–14.

Škurić, M., Maraš, V., Davidović, T., & Radonjić, A. (2021). Optimal allocating and sizing of passenger ferry fleet in maritime transport. *Research in Transportation Economics*, *90*, 100868. https://doi.org/10.1016/j.retrec.2020.100868

Star Ferry. (2022a). *Ferry Services*. https://www.starferry.com.hk/en/service

Star Ferry. (2022b). *The Company*. https://www.starferry.com.hk/en/theCompany

Tanko, M., & Burke, M. I. (2016). Transport innovations and their effect on cities: the emergence of urban linear ferries worldwide. *Transportation Research Procedia*, *25*, 3957–3970. https://doi.org/10.1016/j.trpro.2017.05.483

Tsiotas, D., & Polyzos, S. (2015). Analysing the Maritime Transportation System in Greece: a Complex Network Approach. *Networks and Spatial Economics*, *15*(4), 981–1010. https://doi.org/10.1007/s11067-014-9278-y

Tsoi, K. H., & Loo, B. P. Y. (2021). Cutting the loss: International benchmarking of a sustainable ferry business model. *Transportation Research Part A: Policy and Practice*, *145*, 167–188. https://doi.org/10.1016/j.tra.2021.01.007

Tsui, K. W. H., Fu, X., Chen, T., Lei, Z., & Wu, H. (2021). Analysing Hong Kong's inbound tourism: The impact of the COVID-19 pandemic. *IATSS Research*, *45*(4), 440–450. https://doi.org/10.1016/j.iatssr.2021.11.003

Verhaeghe, R., Halim, R. A., & Tavasszy, L. (2021). Chapter 6 - Optimising the efficiency of the future maritime transport network of Indonesia. In I. Kourounioti, L. Tavasszy, & H. Friedrich (Eds.), *Freight Transport Modeling in Emerging Countries* (pp. 109–134). Elsevier. https://doi.org/10.1016/B978-0-12-821268-4.00006-X

Wang, D. Z. W., & Lo, H. K. (2008). Multi-fleet ferry service network design with passenger preferences for differential services. *Transportation Research Part B: Methodological*, *42*(9), 798–822. https://doi.org/10.1016/j.trb.2008.01.008

Wang, H., Xue, H., He, W., Han, Q., Xu, T., Gao, X., ... Huang, M. (2024). Spatial-temporal evolution mechanism and dynamic simulation of the urban resilience system of the Guangdong-Hong Kong-Macao Greater Bay Area in China. *Environmental Impact Assessment Review*, *104*, 107333. https://doi.org/10.1016/j.eiar.2023.107333

Wang, Z., Yao, L., Yu, J., Chen, P., Li, Z., & Yang, W. (2024). Evaluation of the ecological carrying capacity of Wailingding marine ranching in Zhuhai, China by high-resolution remote sensing. *Frontiers in Marine Science*, *11*, 1354407. https://doi.org/10.3389/fmars.2024.1354407

Weisbrod, R. E., & Lawson, C. T. (2003). Ferry systems: Planning for the revitalisation of U.S. cities. *Journal of Urban Technology*, *10*, 47–68. https://doi.org/10.1080/1063073032000139697

Yu, M.-M., Chen, L.-H., & Hsiao, B. (2023). Simultaneously consideration subsidy allocation and target setting in low-volume offshore ferry routes: an empirical study of Taiwan companies. *International Journal of Sustainable Transportation*, *17*(5), 423–433. https://doi.org/10.1080/15568318.2022.2049402

Yuan, X., Zhang, D., Zhang, J., Wan, C., & Fan, L. (2023). A two-stage collision avoidance path planning approach for inland ferries under dynamic channel crossing risk conditions. *Ocean and Coastal Management*, *242*, 106692. https://doi.org/10.1016/j.ocecoaman.2023.106692

Zang, Y., & Fiondella, L. (2022, January 24–27). A Network Reliability Analysis Method for Complex Systems based on Complex Network Theory. *2022 Annual Reliability and Maintainability Symposium (RAMS)*. https://doi.org/10.1109/RAMS51457.2022.9893999