

Optimizing ferry route networks for sustainable island development using social network analysis: A study of Mokpo, South Korea

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Abstract: South Korea's over 3300 islands play vital roles in the nation's geography, economy, culture, and national security. Despite their importance, these islands face significant challenges, including population decline, aging demographics, and a severe lack of healthcare, childcare, and education facilities. With only 20% of inhabited islands connected to the mainland by bridges, coastal ferries are the primary transportation mode. However, the infrequent ferry services and numerous intermediate stops cause considerable inconvenience. This study conducts an analysis of the coastal ferry route connectivity within the Mokpo Area, focusing on proposing improvements to enhance access to community infrastructure for local island residents. This study analyzes the Mokpo Area's coastal ferry network, identifying Dochodo as a central hub island to improve connectivity for sustainable island development. By reorganizing routes around Dochodo with larger ferries for main routes and smaller ferries for local trips, the study aims to enhance service access and boost tourism for island communities.

Keywords: islands; social network analysis; connectivity; coastal ferry routes; sustainable development

1. Introduction

South Korea, situated in East Asia, is surrounded by the sea on three sides, creating a vast maritime boundary. The country boasts a total of 3382 islands, including 464 inhabited islands and 2918 uninhabited ones (Korea Island Development Institute, 2022c). These islands play crucial roles in maritime sovereignty, ecological preservation, and tourism development. They serve as vital reference points for defining territorial waters and establishing national boundaries (Kim and Lee, 2021). Given the importance of maritime security globally, South Korea faces significant challenges, such as the ongoing territorial dispute with Japan over Dokdo Island and rampant illegal fishing activities by Chinese vessels in the West Sea (Lee, 2017). Furthermore, the islands' unique natural beauty and characteristics have prompted South Korea to launch several tourism development projects, including the South Coast Marine Tourism Belt and the Attractive Island Tourism Development Project, aiming to leverage these natural assets for economic growth.

Despite their importance, South Korean islands are threatened by severe infrastructural deficits, leading to a decline in population and an aging demographic. Between 2009 and 2022, the number of inhabited islands decreased from 492 to 464, reflecting a worrying trend (Korea Island Development Institute, 2023). The population on these islands shrank by about 5% from nearly 835 thousand people in 2018 to over 790 thousand people in 2022. The Aging Index, which measures the ratio

of the elderly population to the younger population, is significantly higher on these islands at 291.5, compared to the national average of 152.0 (Korea Island Development Institute, 2022a). Additionally, while the national population is projected to decline by 3.5% from 2022 to 2042, the population decline rate on inhabited islands is expected to be much steeper at 18.1% during the same period (Korea Island Development Institute, 2022a). This rapid population decline leads to the inability to sustain essential community infrastructure, resulting in the closure of such facilities and discouraging further investment, which exacerbates the residents' discomfort and accelerates the islands' decline. Most of the 464 inhabited islands in South Korea lack healthcare, childcare, and education facilities (Korea Island Development Institute, 2022a). More than 62% of these islands do not have healthcare facilities, and over 76% lack childcare and education facilities (See **Table 1**). Consequently, residents are forced to travel off-island for healthcare and education, which can lead to further population outflow and the eventual extinction of these islands.

Table 1. Status of community infrastructure in islands.

Number of Healthcare facilities	Islands		Number of Childcare & Education facilities	Islands	
	Number	Percentage		Number	Percentage
0	289	62.3%	0	354	76.3%
1	133	28.7%	1	30	6.5%
2	9	1.9%	2	14	3.0%
3	12	2.6%	3	17	3.7%
4	4	0.9%	4	18	3.9%
5	1	0.2%	5	9	1.9%
6–10	9	1.9%	6–10	14	3.0%
Over 10	7	1.5%	Over 10	8	1.7%

Source: (Korea Island Development Institute, 2022a)

Transportation between South Korea's islands is predominantly dependent on coastal ferries, especially for the 80% of inhabited islands not connected to the mainland by bridges (Korea Island Development Institute, 2022b). However, the current coastal ferry services are fraught with challenges. These include infrequent operations due to high costs and adverse weather conditions, as well as relatively expensive fares. The average unit fare for coastal ferries is 362.9 KRW/km, which is approximately three times higher than that of intercity buses (116 KRW/km) and even more expensive than domestic airlines (210 KRW/km) (Korea Maritime Institute, 2017). Moreover, ferry routes are often determined by the revenue needs of the coastal shipping companies, leading to many intermediate ports of call and longer travel times (Korea Maritime Institute, 2020). These inefficiencies in the ferry services increase living and logistics costs, contribute to resident migration, and decrease the attractiveness of living on these islands, further leading to their decline (Ministry of Culture and Tourism, 2006). Improving the connectivity of coastal ferry routes is essential to enhance the convenience of island residents, strengthen island connectivity, and ensure the sustainable development of these islands. Based on 2022

data, coastal passenger ship transportation in South Korea amounted to approximately 14 million people, roughly 30% of the total population. South Korea has 104 coastal ferry routes, consisting of 77 regular routes and 27 subsidized routes (Korea Shipping Association, 2023).

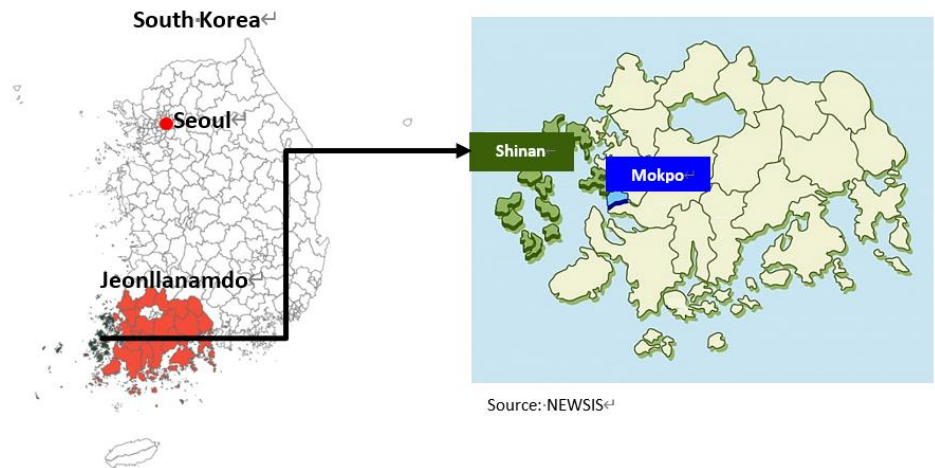


Figure 1. Location of Mokpo area (Mokpo-Shinan).

About 60% of South Korea's inhabited islands are situated in Jeollanamdo Province, with Shinan County being distinctive as it consists entirely of islands. Shinan County alone is home to 73 of South Korea's 464 inhabited islands. Most of these islands are connected to Mokpo City in the **Figure 1**, which boasts better community infrastructure. Located in the southwestern part of South Korea, Mokpo and Shinan are central to the region's coastal ferry operations, making the Mokpo area the busiest hub for such services (Pham et al., 2020). However, the ferry system in this area faces significant challenges. The Mokpo area has 26 coastal ferry routes, including 8 subsidized ones, with routes often featuring numerous intermediate stops. For example, the Mokpo-Yulmok route has 28 intermediate ports, causing extended travel times. Some routes operate infrequently, with only one trip per day, while others offer two to four round trips daily. Routes such as Mokpo-Jeju and Mokpo-Hongdo, which have high proportions of non-island visitors, are heavily used, indicating their importance. As of 2022, 100% of passengers on the Mokpo-Jeju route are visitors, and 73% on the Mokpo-Hongdo route are also visitors. Among the 79 inhabited islands in the Mokpo area, 51 are not connected by bridges, relying solely on coastal ferries for transportation. Passengers typically encounter about three intermediate stops on average for regular routes, and subsidized routes often have even more, with an average of 9 intermediate stops, which further complicates and lengthens travel.

Adding to these transportation issues are significant deficiencies in community infrastructure on the islands, such as inadequate healthcare, childcare, and education facilities. These gaps create substantial barriers to sustainable development, exacerbating the challenges posed by declining and aging populations on the islands. The lack of essential services and the inefficiencies of the ferry system hinder residents' quality of life and slow down potential economic and social growth. Addressing these issues, this study focuses on analyzing the connectivity of coastal ferry routes in the Mokpo area and identifying local hub islands that could serve as

central points for transportation and community infrastructure. By improving ferry connectivity through these hub islands, it is hoped that island residents will benefit from enhanced access to community services, which could also stimulate tourism and support sustainable development.

The paper is organized as follows: Section 2 provides a review of existing studies related to islands in South Korea and coastal ferry routes. Section 3 presents social network analysis (SNA) methodology utilized in this research. Section 4 explained the results of the study. Lastly, section 5 summarizes the results of study and present limitations and future research directions.

2. Literature review

Sustainable development, as defined in many studies, refers to achieving a balance between economic growth, environmental conservation, and social well-being (Chansanam et al., 2024; Yang and Solangi, 2024). In the context of islands, this concept is crucial due to their isolation, limited resources, and vulnerability to environmental changes (Ghina, 2003). Various studies have underscored the significance of sustainable practices in island ecosystems, emphasizing that the geographic and economic challenges faced by island populations require long-term, integrated planning strategies. Previous researches have highlighted the socioeconomic disparities faced by islanders, including education gaps, inadequate welfare systems, and insufficient infrastructure, which make sustainable development all the more necessary (Kim and Lee, 2021; Yun, 2017).

The role of transport systems, particularly maritime transport, is essential to sustainable development in island regions (Currie and Falconer, 2014; Vallega, 2007). Ferry networks are critical to ensuring access to resources, facilitating trade, and promoting tourism. Efficient ferry services reduce operational costs, enhance island connectivity, and support the socio-economic structure of these communities. Studies, such as those by Park and Seo (2022), have shown that changes in ferry route networks directly affect the connectivity and economic stability of island regions. Pham et al. (2020) evaluated the inefficiencies in current ferry systems, which often result in high operational costs and infrequent services, hindering access to essential resources for island residents.

Maritime transport can have both positive and negative effects on small islands. While it connects islands with the mainland and promotes inter-island trade and mobility, the environmental impacts, such as greenhouse gas emissions and marine pollution, are concerning. Previous studies suggest that optimizing ferry routes and adopting cleaner technologies can mitigate these effects. For instance, it has been found that inefficiencies in ferry networks contribute to environmental degradation and disrupt mobility. Therefore, understanding and optimizing network connectivity and operational efficiency is crucial for reducing these impacts and promoting sustainable development.

To provide a comprehensive understanding of port connectivity and operational efficiency, researchers have increasingly applied network-based approaches to maritime logistics. Among these, Social Network Analysis (SNA) has emerged as a powerful tool, enabling the examination of complex interactions within maritime

networks. This method focuses on analyzing nodes, such as individual ports, and edges, representing the shipping routes between them, revealing critical insights into the structure and relationships within the network (Nguyen and Kim, 2022; Nguyen and Woo, 2021). In transportation research, SNA helps visualize and assess the efficiency of transport systems, identifying bottlenecks and areas for optimization. Ko et al. (2015) used SNA to analyze changes in ferry routes over time, uncovering inefficiencies in the network and providing insight into how these changes affect both connectivity and ferry service reliability. SNA is particularly useful in the management and development of transport infrastructure, as it allows policymakers to identify strategic nodes and optimize network connections. For example, the application of SNA in Mokpo's ferry network has shown how inefficient connections increase travel times and reduce the accessibility of essential services for island populations. SNA can also inform long-term infrastructure investments, ensuring sustainable development by enhancing connectivity and reducing redundancy in transport networks.

The optimization of transport networks, especially in geographically fragmented areas such as island regions, is a critical area of study. Scholars have proposed various models, including Dijkstra's algorithm and linear programming, to optimize ferry routes by reducing travel times and operational costs. Research by Pham et al. (2020) revealed inefficiencies in ferry networks in Mokpo, identifying high operational costs and poor route planning as barriers to optimal transport services. Several methods have been used to optimize maritime transport, including algorithms and simulation models that aim to improve network performance while ensuring environmental sustainability. By applying these optimization techniques, researchers have improved ferry systems worldwide, ensuring that routes are both economically and environmentally sustainable. For example, Park and Seo (2022) explored how ferry route changes in port cities could optimize connectivity and foster economic growth. Numerous case studies have examined ferry network optimization in island regions, including the Mediterranean and Pacific Islands, revealing how network improvements can reduce environmental impact and foster sustainable development. In Mokpo, Ko et al. (2015) applied SNA to assess ferry routes and recommended optimizing key connections to improve service efficiency and enhance the socio-economic development of island communities.

Many studies have investigated the challenges faced by island communities in South Korea, particularly regarding transportation infrastructure and the implications of development policies. Research has highlighted various difficulties encountered by island residents, such as educational deficits, insufficient welfare services, and inadequate transportation (Kim and Kim, 2012; Kim and Lee, 2021; Park, 2018; Park and Lee, 2019). Among these, transportation inefficiencies, specifically concerning ferry networks, are crucial, as they directly impact residents' access to essential services and economic opportunities. Studies have shown that despite efforts to improve connectivity, many islands remain underserved by existing ferry routes, which complicates access to healthcare, education, and other critical needs. Since the early 2010s, research on improving ferry systems has gained momentum. Kim et al. (2019) conducted a comprehensive review comparing South Korea's island policies to Japan's Island Promotion Act, stressing the importance of developing tailored

strategies to meet the unique needs of island communities. Kim et al. (2013) explored the perceptions of island residents and experts in Jeollanam-do, offering insights into how policy initiatives are received and pointing out areas for improvement, particularly in transportation services.

Tourism revitalization has also been a focus of island development, with the ferry network playing a key role in connecting islands to tourism markets. Research shows that efficient ferry systems can bolster island tourism, enhance economic vitality, and integrate tourism with local development efforts (Ha, 2020; Kang et al., 2021; Lee and Lee, 2022; Jo et al., 2021). Ferry services are not only vital for tourism but are also essential for ensuring that residents can access opportunities related to tourism growth. Studies recommend that strategic improvements in ferry routes, including increasing service frequency and reducing travel times, could help alleviate current transportation deficiencies. In terms of ferry network optimization, several researchers have focused on identifying inefficiencies and proposing solutions. Pham et al. (2020) used data envelopment analysis (DEA) to assess ferry route efficiency in Mokpo City, revealing issues such as high operational costs and infrequent services. Park and Seo (2022) explored how changes in ferry route networks impact port cities, emphasizing the need for route optimization to maintain connectivity. Ko et al. (2015) applied social network analysis to trace changes in ferry routes, finding that network disruptions could severely affect island accessibility.

While existing research has thoroughly examined various aspects of island development, tourism, and ferry services, a significant gap persists in studies that focus on optimizing ferry route networks to improve connectivity between islands and the mainland, particularly for enhancing access to essential infrastructure. Current research often addresses isolated components of island development without adopting a comprehensive approach to optimizing ferry routes for greater efficiency and connectivity. This study aims to fill that gap by analyzing Mokpo's coastal ferry route network through the lens of social network analysis (SNA). The objective is to identify ways to enhance the connectivity between islands, ensuring more streamlined access to critical services and infrastructure.

By optimizing ferry routes, this research seeks to improve not only the mobility of island residents but also the integration of these islands into broader economic and social frameworks. Enhanced ferry connectivity is expected to foster sustainable island development, stimulate tourism, and ensure more resilient socio-economic outcomes for South Korea's island communities. This study will contribute to a deeper understanding of how transportation improvements, particularly through route optimization, can be leveraged to achieve sustainable development goals, helping unlock the full potential of island communities in South Korea.

3. Data and method

This research focuses on analyzing the connectivity of coastal ferry routes, optimizing these routes, and identifying key hub islands. The data used includes ferry routes and nodes, sourced from reports. The study employs social network analysis with some indexes, such as degree centrality to assess how well-connected a node is; weighted degree centrality to factor in the importance of each route; closeness

centrality to measure how quickly a node can reach others; and betweenness centrality to identify nodes that act as bridges within the network in the **Figure 2**. This approach ensures a comprehensive understanding of ferry operations and helps improve route efficiency.

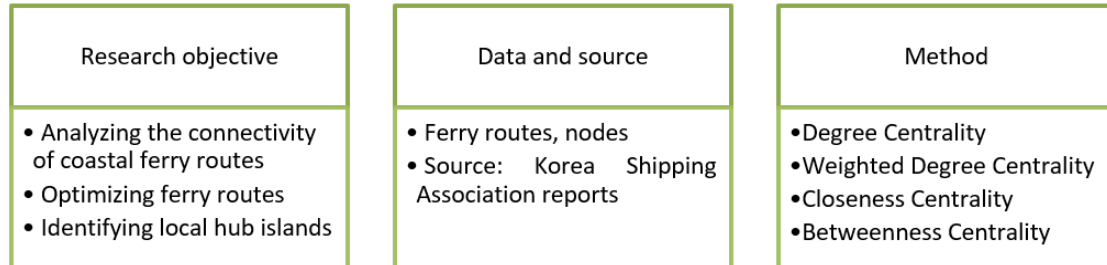


Figure 2. Illustration the methodology and data used in the study.

Data in this study was collected from the Korea Shipping Association’s “Status of coastal passenger shipping companies in 2023” and “Status of coastal passenger shipping companies in 2019” to examine changes in island connectivity according to passenger volume before and after COVID-19. The data encompasses information on coastal ferry routes in the Mokpo area, including passenger volumes, ports of call, travel time, and coastal shipping companies. The descriptive statistics for the sample are depicted in **Table 2**. This study analyzed the connectivity of islands in the Mokpo area based on coastal ferry routes using social network analysis (SNA) with NetMiner SNA analysis software.

Table 2. Descriptive statistics for the sample.

Data	Mean	STD	Min	Max
Frequency	1698	1412	14	5946
Number passengers (Person)	110,409	163,602	560	741,658
Distance (Km)	63	59	4	217
Travel time (Minute)	141	85	15	290

Source: (Korea Shipping Association, 2023).

Social network analysis

Social network analysis (SNA) is a method to analyze a network by nodes and links. SNA is used in various fields such as research trend analysis, maritime and airline networks, and sports analysis (Lusher et al., 2010; Nguyen and Kim, 2022; Zhao et al., 2020). In this study, the node is the islands, and the link is the coastal ferry routes. In SNA, there are centrality measures to determine which nodes play an important role in a network (Corlew et al., 2015; Partelow and Nelson, 2020). Representative centrality measures include degree centrality, closeness centrality, and betweenness centrality (Freeman, 1978). In this study, centrality measures were used to provide a comprehensive analysis of the ferry network structure, including degree centrality, weighted degree centrality, closeness centrality, and betweenness centrality. Social network theory emphasizes the importance of these centrality measures in understanding the roles of nodes within a network. Degree centrality indicates the number of direct connections each node has, reflecting local connectivity

and showing which nodes are locally well-connected. Weighted degree centrality expands on this by considering the strength or frequency of these connections, offering insights into the intensity of interactions between nodes and highlighting those that are frequently accessed or have high interaction volumes. Closeness centrality measures a node's average distance to other nodes, helping to identify nodes with efficient access to the entire network, as suggested by social network theory. This centrality measure is useful for pinpointing nodes that can reach others in the network with minimal steps, acting as efficient points of access. Finally, Betweenness centrality indicates nodes that act as bridges, connecting different parts of the network and maintaining overall connectivity. This measure was prioritized for identifying key hubs, as it best represents the network's structural dependency on certain nodes. By capturing nodes that hold pivotal positions in the overall network flow, Betweenness centrality serves as a critical tool in understanding the ferry network's structure and the dynamics of connectivity among the islands.

Degree centrality is the number of connected nodes. Degree centrality is expressed as an Equation (1). This study's degree centrality indicates how many other islands are connected to the target island.

$$D_i = \sum_{j=1}^N \frac{Z_{ij}}{N-1} \quad (1)$$

D_i = Degree centrality of island i .

Z_{ij} = Direct connection from island i to island j .

N = Number of islands in whole coastal ferry routes network.

This study used weights to reflect passenger volume in the degree centrality. The passenger volume per coastal ferry route was used as a weight. The coastal ferry routes pass through many islands in a single route but each island has no passenger volume data. Therefore, the passenger volume of each island on a route is assumed to be proportional to the population of that island. The population of the island was referenced from the current data provided by the Korea Island Development Institute. In cases where there was too much variation in the population of each island for the ratio to be appropriate, passenger performance ratios were obtained by interviewing the employee of the shipping company. Therefore, there are some differences from the actual data. The following equation can be used to consider passenger volume as a weight. The weighted degree centrality can be calculated by dividing the total number of passengers going to target island by the total number of islands in whole coastal ferry routes network.

$$D_{W.i} = \sum_{j=1}^N \frac{W_{ij}Z_{ij}}{N-1} \quad (2)$$

$D_{W.i}$ = Weighted degree centrality of island i .

Z_{ij} = Direct connection from island i to island j .

W_{ij} = weight (= passenger volume).

N = Number of islands in whole coastal ferry routes network.

Closeness centrality is calculated by aggregating the minimum steps one node takes to reach the other from all nodes in the network. Closeness centrality is expressed as Equation (3). Closeness centrality indicates how few steps the target island needs to go through to reach other islands in the coastal ferry routes network.

$$C_i = \left[\sum_{j=1}^N X_{ij} \right]^{-1} \quad (3)$$

C_i = Closeness centrality of island i .

X_{ij} = Direct/indirect connection from island i to island j .

Betweenness centrality is a measure that quantifies the extent to which one node is located between pairs of other nodes in the network. Betweenness centrality refers to how well an island can mediate between other islands. Betweenness centrality is expressed as an Equation (4).

$$B_i = \sum_{j=1}^N \frac{X_{iMj}}{X_{ij}} \quad (4)$$

B_i = Betweenness centrality of island i .

X_{iMj} = Number of cases where island M is located on the shortest path between island i and island j .

Of these centrality measures, this study considered betweenness centrality is the most important measure for identifying the local hub islands. Because the local hub island should be a central hub for transportation and should be able to mediate between the small islands in the area.

4. Results and discussion

This study first analyzed the connectivity of coastal ferry routes in the Mokpo area in 2022 using the social network analysis (SNA) methodology. Data from 26 coastal ferry routes, including 8 subsidized routes, were utilized for this analysis. The network comprises 120 nodes, representing ports of call (islands), and 138 links connecting these nodes. The coastal ferry routes in the Mokpo area are not only connected to Mokpo and Shinan but also extend to nearby islands within Jindo and Yeonggwang County. As a result, the number of analyzed nodes exceeds the actual number of nodes within Mokpo and Shinan alone.

Centrality measures were employed to identify key nodes within the network, prioritizing Betweenness Centrality due to its ability to capture the bridging functions of nodes. While degree centrality highlights Mokpo as a highly connected node with numerous direct links, betweenness centrality emphasizes its role as a crucial bridge connecting otherwise distant nodes. As a result, Mokpo is identified as the primary hub, while Dochodo emerges as a secondary hub. The analysis involved comparing several centrality measures, including betweenness centrality, degree centrality, weighted degree centrality, and closeness centrality. Passenger volume on coastal ferry routes in 2022 served as a weight factor in calculating weighted degree centrality. The results, illustrated in **Table 3**, indicate that Mokpo port, Dochodo, and Paengmok port rank high in terms of betweenness centrality due to their frequent appearances

between routes connecting different islands. However, Mokpo and Paengmok ports were excluded from consideration as local hub islands, given their direct connectivity to the city via roads and bridges. Additionally, Jejudo and Chujado were excluded for their distant locations outside the Mokpo area. Thus, Dochodo is identified as a potential local hub island, which could serve as an effective bridge between other nearby islands. **Figure 3** and **Table 3** further highlight that while both Mokpo and Dochodo have high centrality scores, Mokpo’s betweenness centrality is greater, underscoring its critical role in maintaining network connectivity. Consequently, it is suggested that larger coastal ferries operate from hub ports like Mokpo to local hub islands such as Dochodo, and subsequently to nearby smaller islands, aligning with passenger demand. This operational strategy would involve more frequent trips over shorter distances, enhancing connectivity to and from small islands and ultimately improving overall accessibility within the region.

When examining other centrality measures, Mokpo port ranked first in all of them, as it serves as a major hub port where many routes depart and arrive. In terms of degree centrality, Mokpo port, Dochodo, and Hajodo displayed high rankings, while Jejudo and Chujado ranked lower compared to other measures. This suggests that while Jejudo and Chujado are not directly connected with other islands, they serve as intermediaries without having to route through multiple islands. In the degree centrality weighted by passenger volume, both Mokpo port and Jejudo ranked highly, likely due to the high passenger volume on the Mokpo-Jeju route. Dochodo ranked fourth. For closeness centrality, Paengmok port ranked relatively low, indicating that it takes several steps to reach other islands from Paengmok port in the network.

Overall, Dochodo ranked high on all centrality measures, indicating its important position in the coastal ferry route network in the Mokpo area.

Table 3. Top rank of centrality measures.

Port of call (Island)	Betweenness Centrality	Rank	Degree Centrality	Rank	Weighted degree centrality	Rank	Closeness Centrality	Rank
Mokpo port	0.442	1	0.067	1	9452	1	0.163	1
Dochodo	0.329	2	0.059	2	2663	4	0.147	4
Paengmok port	0.294	3	0.034	6	1238	9	0.139	10
Jejudo	0.271	4	0.017	27	7237	2	0.154	2
Chujado	0.267	5	0.017	27	1546	7	0.147	4
Bigeumdo	0.247	6	0.017	27	2476	6	0.153	3
Changyu (Haojodo)	0.185	7	0.059	2	1152	10	0.127	21
Songgong (Aphaedo)	0.141	8	0.017	27	286	33	0.129	17
Dangsado	0.13	9	0.017	27	413	28	0.116	34
Yuldo	0.127	10	0.034	6	347	30	0.146	6

* “do”: the suffix that is added after a noun to indicate the meaning of “island” ex) Jejudo = Jeju Island.

The network diagram of the Mokpo area’s coastal ferry routes is shown in **Figure 3**. The size of each node in the diagram is based on its betweenness centrality; the greater the betweenness centrality, the larger the size of the node. As illustrated in the diagram, Mokpo port acts as the hub port in the network, with Dochodo, Paengmok

port, Jejudo, and Chujado serving as key connectors between Mokpo port and other islands.

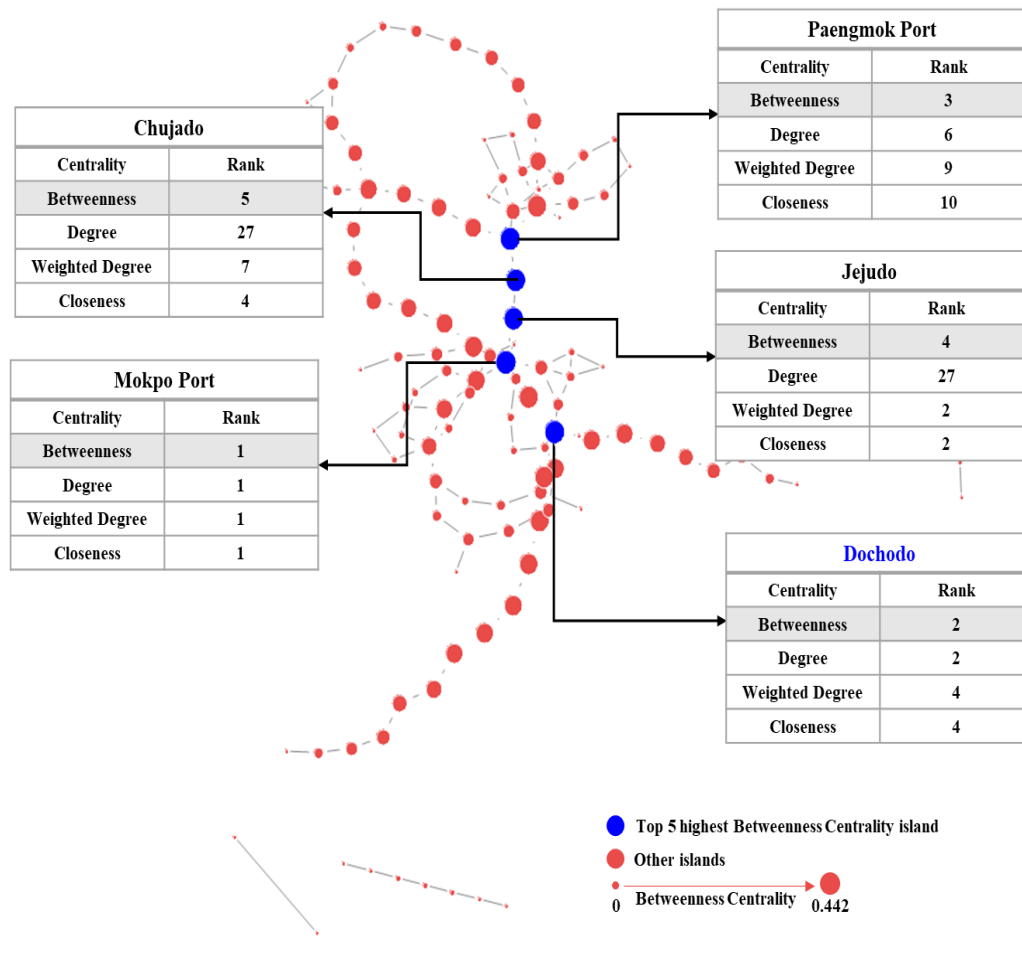


Figure 3. Network diagram of coastal ferry routes in Mokpo area.

A comparative analysis was conducted on the rankings of degree centrality, weighted by passenger volume before and after the COVID-19 pandemic, with a focus on islands showing high betweenness centrality rankings. Passenger volumes for total, visitor, and island resident categories by route in 2018 (pre-COVID-19) and 2022 (post-COVID-19) were used as weights. This approach aimed to assess how island connectivity was affected by COVID-19 and to identify significant shifts in the weighted degree centrality of Dochodo, which was selected as a local hub island based on the 2022 coastal ferry network.

Weighted degree centrality, by accounting for passenger volume, provides a nuanced understanding of how vital each island is within the network, particularly under the pressures of an event like COVID-19. By using this metric, the analysis captures the changes in connectivity strength, highlighting islands that play critical roles in sustaining network flows for both residents and visitors, even when overall travel patterns are disrupted.

The results, shown in **Table 4**, reveal that Dochodo’s ranking in weighted degree centrality increased by four positions, rising to fourth place when considering total passenger volume compared to 2018. This upward shift indicates Dochodo’s increased

connectivity post-COVID-19, emphasizing its role in maintaining network resilience during disruptions. For visitor and island resident passenger volumes, Dochodo’s ranking improved by three and six positions, respectively, demonstrating its growing importance as a travel hub for both tourists and local residents. Mokpo port maintained its top rank in weighted degree centrality for total and visitor volumes before and after COVID-19, though it experienced a slight decline of one position in island resident volume rankings.

In the case of Paengmok port, all weighted degree centrality rankings improved significantly from 2018 to 2022. This increase aligns with the addition of a new coastal ferry route in 2022 connecting Paengmok to Chujado and Jejudo, resulting in higher passenger volumes for both visitors and residents. For Jejudo, degree centrality rankings in total and visitor volumes remained stable in second place, but rankings for island resident volumes slightly decreased by one position.

Dochodo, chosen as a local hub island based on its high betweenness centrality in 2022, consistently ranked high in weighted degree centrality across all passenger categories both before and after COVID-19. Despite the pandemic’s disruption, Dochodo’s stable position in connectivity rankings highlights its capability to maintain steady visitor and resident flows, even under conditions of substantial travel restrictions. This stability further supports Dochodo’s suitability as a robust local hub island, capable of adapting to potential future challenges similar to COVID-19. The analysis suggests that Dochodo’s consistent role as a key connector strengthens its status as an essential hub within the coastal ferry network, providing resilience against both environmental and economic shifts.

Table 4. Weighted degree centrality rank before and after the COVID-19.

Port of call (Island)	Weighted Degree (Total)			Weighted Degree (Visitor)			Weighted Degree (Island resident)		
	2018	2022	Change	2018	2022	Change	2018	2022	Change
Mokpo port	1	1	-	1	1	-	1	2	▼1
Dochodo	8	4	▲4	8	5	▲3	10	4	▲6
Paengmok port	20	9	▲11	17	8	▲9	25	15	▲10
Jejudo	2	2	-	2	2	-	33	34	▼1
Chujado		7			7			29	
Bigeumdo	6	6	-	6	3	▲3	9	5	▲4
Changyu (Haojodo)	12	10	▲2	10	10	-	13	9	▲4
Songgong (Aphaedo)	3	33	▼30	3	25	▼22	2	40	▼38
Dangsado	15	28	▼13	16	18	▼2	14	30	▼16
Yuldo	91	30	▲61	88	27	▲61	83	26	▲57

The island selected as a local hub island for this study, Dochodo, is an island in Shinan County and the 13th largest island in South Korea and is known for having the widest open field in Shinan County (Korea Tourism Organization). The location of Dochodo is shown in **Figure 4**. Dochodo is located approximately 54.5 kilometers southwest of Mokpo. Around Dochodo are small islands with less than 100 residents, such as Jangbyengdo, Gaedo, Daeyado, and Neungsando.

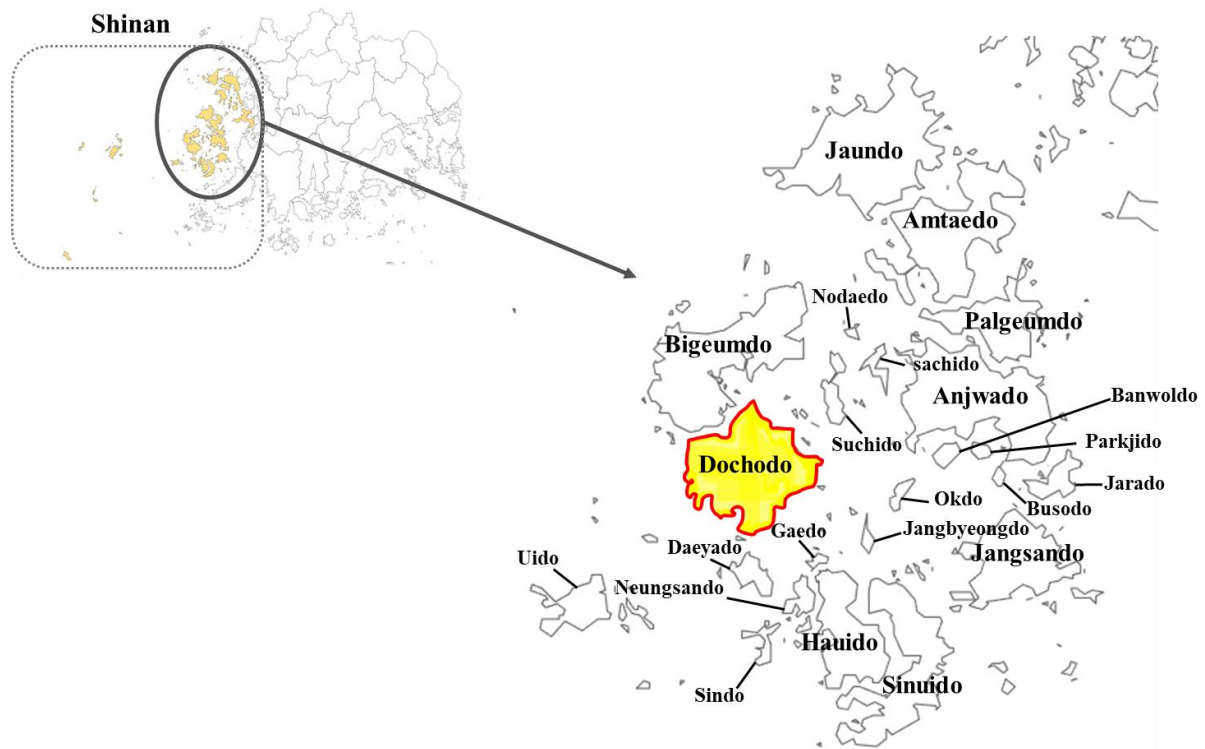


Figure 4. Location of Dochodo.

Figure 5 reflects the current coastal ferry routes that service Dochodo, which is a significant hub within the Mokpo area ferry network. It not only depicts the direct ferry connections to and from Dochodo but also illustrates its strategic location amidst a cluster of smaller islands, making it an essential node in the coastal transportation system. Dochodo is uniquely positioned between major routes connecting Mokpo port and the distant islands of Manjaedo and Heaksando, located to the southwest. This geographical positioning enhances Dochodo's role as a bridging point within the network, where ferries can efficiently facilitate travel between various destinations. By serving as a midpoint, Dochodo can significantly reduce travel times for passengers traveling between Mokpo and the islands further out to sea. It is clear that Dochodo is directly connected by coastal routes to several other islands within the Shinan group, including Uido, Aphaedo, Daeyado, and Bigeumdo. This direct connectivity is vital for local residents and visitors, as it allows for seamless travel between these islands and promotes greater mobility within the region. The visual representation highlights how Dochodo serves not just as a terminal but as a crucial access point for multiple destinations, enhancing the overall connectivity of the ferry network. It visually reinforces the findings of the analysis regarding centrality measures, particularly Betweenness Centrality, highlighting Dochodo's significance as a mediator that facilitates connections between islands that might otherwise be less accessible.

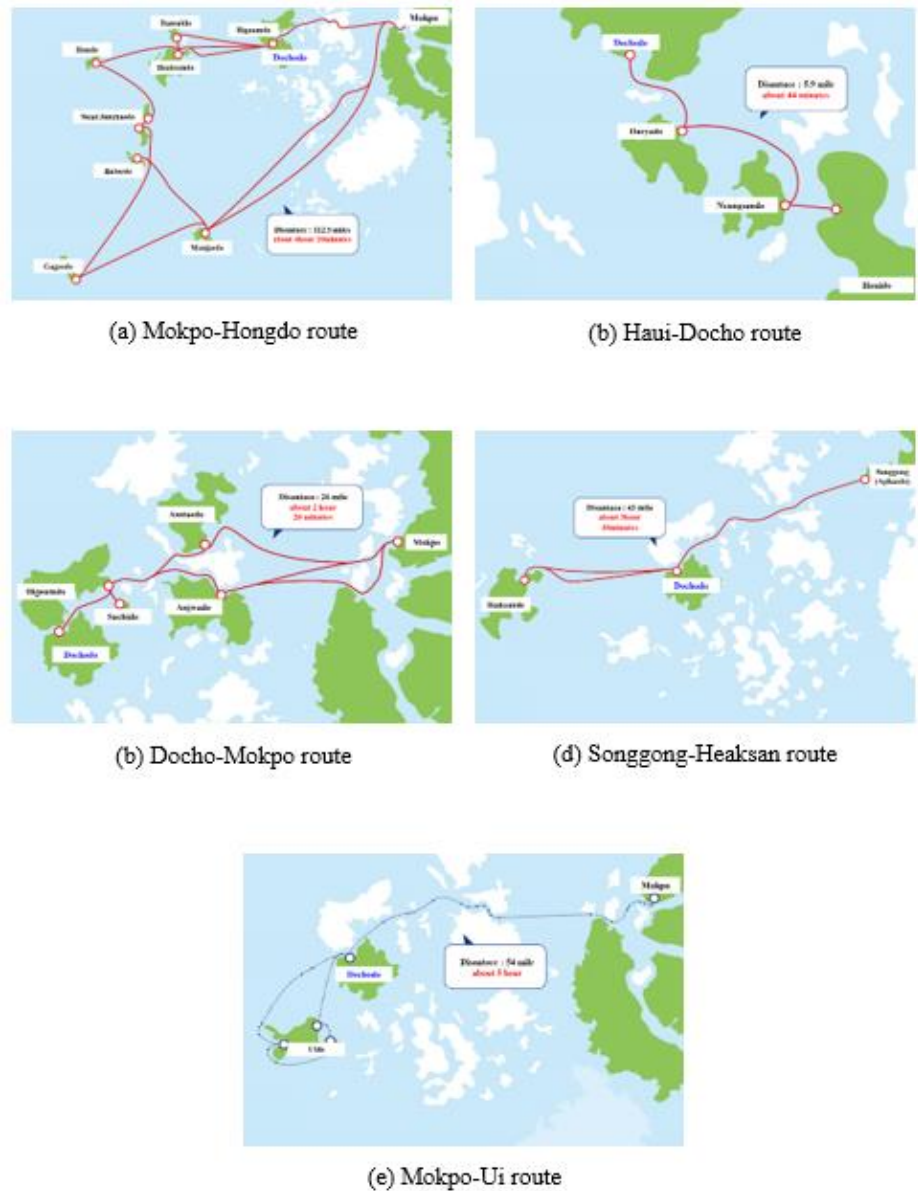


Figure 5. Current coastal ferry routes calling at Dochodo.

Source: Korea Maritime Transportation Safety Authority.

In addition to its role in transportation, this study investigated the status of Dochodo. The island, with an area of 44.04 million square meters, has a population of approximately 2737, making it the fifth largest population center in Shinan County as of 2020. Dochodo is equipped with a local public office and a police box, ensuring governmental and security presence on the island. The living environment on Dochodo is supported by healthcare services, including a hospital and a clinic, and two childcare facilities. Educational needs are met by two schools: Docho Elementary School and Docho High School. Docho High School, in particular, is attended by students from nearby islands such as Bigeumdo and other Shinan islands. This indicates that Dochodo has the potential to grow as a local hub island by providing community infrastructure to nearby smaller islands that lack such facilities.

Shinan County, to which Dochodo belongs, is known for having the highest number of islands in South Korea and has gained attention for island tourism. In 2021,

Purple Island (Banwoldo and Parkjido) in Shinan was designated as one of the United Nations World's Best Tourism Villages. Similar to Spain's Santiago de Compostela, the 12 Apostles Pilgrimage Route, which connects the islands of Shinan, is attracting an increasing number of tourists. Purple Island saw a significant increase in visitors, from 280,000 in 2021 to 380,000 in 2022.

To accommodate the growing number of tourists visiting the islands, improving coastal ferry route connectivity is necessary. Furthermore, if Dochodo develops community infrastructure for island residents along with tourism facilities, including accommodations and food and beverage services, it could help overcome the challenges of population decline on the islands and promote island tourism. This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

This analysis provides important insights into the roles of islands in the Mokpo coastal ferry network, particularly Dochodo, based on centrality measures from SNA. Dochodo stands out with high weighted degree centrality and serves as a critical bridge between surrounding islands. This aligns with theories on the role of hubs in transportation networks, as shown in prior studies such as Ko et al. (2015), which demonstrated how central hubs enhance connectivity and reduce traffic bottlenecks within networks. Using centrality measures such as betweenness and closeness in this study elucidates the structure of the ferry network and the role of specific islands. These measures have been applied in previous studies to optimize transportation systems in similar geographic settings, such as research on container port networks in Southeast Asia (Nguyen and Woo, 2021). Our study confirms that islands with high betweenness, like Dochodo, are crucial transfer points for connecting smaller islands, enhancing the efficiency of the overall network. The findings from this analysis contribute not only to improvements in the coastal ferry network of Mokpo but also offer important recommendations for other island regions. By identifying and optimizing central islands like Dochodo, policymakers can enhance access to essential services for residents of smaller islands, supporting sustainable development. This approach aligns with goals for sustainable transportation networks in island regions, contributing to reduced operational costs and an improved quality of life for local residents.

5. Conclusion

To prevent the extinction of islands due to population decline and promote their sustainable development, this study explored how to improve the coastal ferry route network, which serves as the primary mode of transport for the islands but currently has low frequency and many inefficient intermediate ports of call. Additionally, this study explored ways for islands without community infrastructure to easily access such infrastructure through improved connectivity of coastal ferry routes.

For this purpose, the study analyzed the coastal ferry route network in the Mokpo area, which has the largest number of islands in South Korea, using social network analysis (SNA). Based on betweenness centrality in SNA, Dochodo was identified as a local hub island capable of serving as a central point for transportation, connecting

islands in the area. The study also examined the rankings of Dochodo's weighted degree centrality, considering total, visitor, and island resident passenger volumes before and after COVID-19. The results indicated that Dochodo consistently held high rankings and was suitable as a regional hub island.

To improve the current coastal ferry route network, the study proposed reorganizing the routes around the local hub island. This approach suggests using larger coastal ferries to operate between major hub ports, such as Mokpo port, and local hub islands like Dochodo. Smaller coastal ferries would then connect Dochodo to smaller neighboring islands, offering frequent, short-distance trips according to passenger demand.

The study also investigated the status of Dochodo, which was selected as a local hub island. With a population of 2737, Dochodo is equipped with healthcare and educational facilities, indicating its potential to provide medical and educational services to surrounding small islands and become a local hub island.

Improved coastal ferry route connectivity can also revitalize island tourism, which is expected to grow in the coming years. Currently, many tourists spend only 2–3 hours on islands due to the lack of accommodation and food and beverage facilities. However, establishing such tourism infrastructure on local hub islands and connecting them with smaller islands through coastal ferry routes could encourage longer stays and increase island income.

The significance of this study lies in its analysis of the coastal ferry route network in the Mokpo area using SNA to identify local hub islands that can act as mediators between local islands. It also suggested ways to improve the use of community infrastructure by island residents without such facilities and to revitalize tourism by improving coastal ferry route connectivity.

However, the study has limitations. The analysis was limited to the Mokpo area, and when calculating weighted degree centrality considering passenger volume, there was no data on passenger volume by port of call. Instead, passenger volume was estimated by reflecting the population of the island and the percentage of passenger volume obtained from shipping companies. Additionally, route length and number of operations were not considered in the SNA. Therefore, to obtain more accurate results, it is necessary to secure actual data by port of call and consider various data related to coastal ferry routes.

In the future, a new coastal ferry route centered on the selected local hub island of Dochodo will be identified. This will involve exploring the expected passenger demand of island residents and tourists, the length of the route, and the appropriate vessel size and terminal facilities for the new coastal ferry route to present a more practical proposal.

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