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Evaluation of Tranquility Improvement on Liner Ferry Service -Case Study on the Amami Islands in Japan-

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Abstract: This study deciphers the current status of marine transportation in the Amami Islands and presents the results of a cost-benefit analysis based on the number of vessel cancellations to reveal the importance of marine transportation in the region. First, the general situation of the islands is summarized, and the amount of cargo per capita and per value are examined. We found that the Amami Islands depend more on marine transportation than other regions. We then analyzed wave height data for Naze Harbor, comparing the current situation where vessels are canceled at four meters or higher with a hypothetical situation where vessels are not canceled up to five meters, thereby suggesting that the construction of a breakwater could produce benefits.

Keywords: Remote island, Liner ferry service, Tranquility improvement, Cancellation rate

1. INTRODUCTION

Sustainable Development Goals (SDGs) is one of the epoch-making policies of the last decade, with the iconic words “no one left behind” stated as the first term in the SDGs agenda. Although many matters need to be addressed in connection with SDGs, services for “minorities” must be discussed more. Benefits for small island developing countries/regions can be considered typical cases.

The International Civil Aviation Organization (ICAO) focuses on the service levels for small island countries/regions, especially those in the Pacific region. In 2019, the ICAO published the working paper “Pacific Small Island Developing States (PSIDS) Aviation Needs Analysis,” which discussed the current situation of PSIDS. PSIDS have limited market power, so they do not receive appropriate air service. Hooper (2020) examined the 2019 report and highlighted the significance of improving air services for small island developing states. In addition to air services, sea transport should also be improved. However, transport issues relevant to remote island areas can also be seen in developed countries such as Japan.

According to the Ministry of Land, Infrastructure, Transport and Tourism (2022), as of April 2022, there are 6,847 remote islands in Japan, 416 of which are inhabited. Remote islands play various roles, including the preservation of territorial waters and exclusive economic zones, maritime traffic safety, development and utilization of marine resources, protection of the marine environment, and territorial security. Therefore, the Japanese government has been implementing a promotion policy for remote islands since 1953. The Amami Islands, located on the fringes of mainland Japan, are no exception. Under the Amami Islands Promotion and Development Special Measures Law enacted in 1954, social infrastructure such as transportation, industrial infrastructure, and the living environment has been developed to steadily improve the standard of living on the islands. In particular, much support has been provided in marine transportation, which is essential for residents' livelihoods and industrial activities—mainly by reducing freight costs on shipping routes and transportation costs for shipping agricultural, forestry, and fishery products.

Thus, while it is true that the Amami Islands have received much aid based on the promotion policy, they face frequent flight cancellations as they are in a typhoon-prone area. We interviewed several people, including the president of Naze Koun Corporation, which manages Naze Port, a representative port in the Amami Archipelago, and were informed of the following challenges: (1) strong winds may cause ships to be canceled for up to four or five consecutive days; (2) the increased size of the ferries may have been offset by an increased emphasis on safety; and (3) the number of ports that can be entered is limited because of the large size of the vessels, and there are more significant restrictions on evacuation. Maruei Ferry Co., Ltd., with its main base of operations in southern Japan, also stated that many of its voyages were canceled due to typhoons because of increased safety awareness. From these incidents, it can be interpreted that the ports in the Amami Islands often experience cancellations due to weather phenomena such as typhoons and that support is inadequate.

This study analyzes the current status of marine transportation in the Amami Islands region. It highlights its importance by presenting the results of a benefit analysis based on the number of cancellations. Specifically, the profit that could be accrued when the number of days of ship cancellations is reduced from approximately 30 days is determined. As the only valid data available for analysis using wave height was from Naze Port, this analysis is limited to this port. However, Naze Port is important as it has a significant bearing on the country's interests and is an appropriate port to represent the Amami Islands. Therefore, the data from Naze Port is a perfect measure of the dependence of the Amami Archipelago on marine transport.

In addition, there are few examples of cost-effectiveness analyses of ports and harbors on remote islands in Japan, and the practice in the Amami Islands is particularly valuable. This study is intended to serve as a guide for future analysis.

2. LITERATURE REVIEW

2.1 Marine Transportation and Geographical Characteristics of Remote Islands

The main target of this study describes the dependence of the Amami Archipelago on maritime transport. As a case study similar to the Amami Islands, existing studies on marine transport in remote islands are summarized, focusing on cases in Southeast Asian countries. The Amami Islands, the subject of the study, are characterized by frequent typhoons. Because the geographic characteristics of these remote islands are an essential element in our analysis, we also collected existing studies on the characteristics of these islands.

Remote island countries/regions suffer from poor transportation services. Özcan (2014) addresses the significance of essential services for small islands and asserts that improving flight services could increase per capita income. Aminuddin *et al.* (2016) identify potential benefits and obstacles to interstate short-sea shipping (SSS) operations in the archipelagic Southeast Asian sub-region from a stakeholder perspective. According to the findings, experts expect that the enhanced trade and economic machinery brought about by the SSS connection will bring peace and stability through the gains made, thus strengthening political ties among the countries concerned. Aminuddin (2018) states that support is needed to narrow down and focus on the essential elements of the SSS project. The results of the Delphi survey and the analytic hierarchy process (AHP) lead to the conclusion that government support is necessary for the smooth introduction of Ro-Ro vessels. Peter *et al.* (2014) studied sustainable maritime transport in Oceania. They find that commercial banks do not finance island shipping due to low returns, high risk, and lack of adequate collateral, thus indicating that policies for maritime transport are still insufficient. In addition to the lack of groundbreaking policies, such as pushing for renewable energy, the conservative and risk-averse attitudes prevalent in the shipping industry have also been found to hinder development. Searcy (2017) presents a model that can be extended to Oceania and other regional shipping routes by developing a material flow management (MFM) frame for the routes used in monthly shipments to the Lau Islands. Implementing the MFM basic plan can overcome issues such as lack of capital and technical capacity; however, small remote islands with small populations and weak economic infrastructure require ingenuity to adapt. Amin *et al.* (2021) analyze the impact of maritime logistics on economic development in eastern Indonesia using a survey and stochastic frontier analysis. They find that high loading and unloading tariffs and ocean transport costs could lower the island's GRP per capita. Further, low cargo volumes and inadequate port facilities are the main causes of the inefficiency of maritime logistics on small islands. The scope of the study is limited to the province of North Maluku, and the need for a more extensive future study is identified. Rutz *et al.* (1996) examine the development of inter-island passenger transport in the Indonesian archipelago and focus on improvements in the transportation system since 1981. The decade beginning in 1986 has seen significant growth due to advances in the transportation network. Still, concerted efforts are required to improve the number of vessels and weekly sailings with minimal detours from all ports in Java and promote a national integration policy. Lekakou *et al.* (2011) investigated coastal shipping in Greece to determine whether coastal markets were becoming more concentrated and whether the accessibility of the islands was reduced by the high concentration of coastal firms and the absence of monitoring processes. They find that monitoring is necessary to ensure healthy competition and that it is essential to improve the status of shippers. Ng *et al.* (2019) develop a comprehensive coastal vulnerability index for the nine islands of the Azores archipelago. An understanding of the variation in the relative vulnerability of coastlines from the three perspectives of risk from the sea, biophysical characteristics, and socioecological characteristics can be applied to coastal development planning during the development process. They find that the soft erosion shoreline of the Azores Islands can predict the risk of disasters on remote islands. Chi *et al.* (2022) explore 26 islands in the Miaodao and Dongtou archipelagos of China to demonstrate their research on island development suitability. In the Miaodao archipelago, topography and soil factors are closely related to ecosystem conservation and urban construction. Moreover, the relationship between the sea and the earth is clear regarding agricultural production. In the Dongtou archipelago, soil factors affect ecosystem conservation, agricultural production, and urban construction.

2.2 Policies and Economic Efficiency of Remote Islands

The primary analysis of this study is based on the assumption that a measure to construct breakwaters in the harbor has been put in place. Therefore, existing studies were compiled to learn more about examples of such measures, such as the construction of breakwaters. We also collected existing studies on the economics of remote islands. The reason is that knowledge of the economic performance of other remote islands may provide hints for measures necessary for the Amami Islands.

Anckar (1996) describes the results of his research on the political life of the islands. He suggests that geographical conditions determine administrative and political institutions and states that constitutions need to include considerations of the unique geographical environment of the home country. Pacheco *et al.* (2022) run the energy transition process through its various stages on the island of Clatra, the southernmost point of mainland Portugal. They have designed solar power plants for public infrastructure, thus reducing their dependence on the grid by a third and helping them become energy self-sufficient. The results show that islands are likely pioneers for the mainland as places to experiment with new technologies. Ogden (1998) explains the need to avoid the disparity in information technology that remote islands suffer. Although the study is over 20 years old, island-derived economic disparity has not narrowed. The difficulty in developing long-term future strategies is familiar, and information disparity is more severe in the present world. Baldacchino (2006) conduct a comparative analysis of island governments' creative competitive strategies and governance practices. The study evaluates previous research regarding five economic and four political competencies and finds a thriving movement to promote creative development in jurisdictional districts that take advantage of different environments. Ridhwan (2021) focuses on the factors that explain spatial wage differentials across regions in Indonesia and examines whether agglomeration affects human capital externalities. Based on individual worker survey data from 440 districts in Indonesia between 2006 and 2015, they demonstrate that the wage gap is explained by individual characteristics, followed by industry and geographic factors. Spalding *et al.* (2015) present two case studies on the Pearl Islands and the Bocas de Toro archipelago to assess and document the evolution of maritime policy in Panama and compare the structural gaps in the institutions that enforce the law and the lack of integration between them. The lack of clarity in the marine and coastal property system is highlighted as a problem specific to Panama.

3. DATA

The population of the Amami Islands is quoted from the "Prefectural Population Census (Estimated Population)" on the official website of Kagoshima Prefecture, of which the Amami Islands are a part. The statistics summarize the population trends by age group. The data on cargo entering and leaving Japan by sea are taken from the "Annual Report of Port Statistics," which results from port surveys conducted by the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT). The Port and Harbor Survey is Japan's only institutional statistical survey that publishes data on the vessels entering ports, cargo entering and leaving the sea and the number of containers. Industry and commerce data are taken from the Survey of Industry and the Survey of Commerce, which are part of the Economic Census Activity Survey conducted by the Ministry of Economy, Trade, and Industry.

The wave height data necessary to determine the vessel cancellation rate were obtained from the Nationwide Ocean Wave Information Network for Ports and Harbours (NOWPHAS). It is a wave information network for Japan's coastline, constructed and operated under the cooperation of the Port and Harbor Bureau, Regional Development Bureaus, Hokkaido Development Bureau, Okinawa General Bureau, National Institute for Land and Infrastructure Management, and Port and Airport Research Institute.

The data on the number of ferry services and loading capacity were taken from the "Vessel Specifications 2022" and the "2020 Islands Statistics Annual Report CD-ROM Edition" The former is a compilation of Japanese-flagged vessels of 20 gross tons or more in operation as of June 30, 2021, and provides reliable information because of the cooperation of the MLIT. The latter lists 302 islands designated under the Remote Islands Development Law and other laws that have resident registration in the Basic Resident Registers as of April 1, 2019. As the 2020 version was the most recent, it is used in this study, but there is no significant change compared with the results of the interviews.

This study also refers to reports from field surveys on the Amami Islands. The destinations visited were Maruei Ferry Co., the Naze Port Transport Association, Amami City

Hall, Isen Town Hall, Tokunoshima Town, and Kyodo-Tsudo Unyu Co. The survey dates are November 24-26, 2022, and are used as the most recent information available.

4. CURRENT SITUATION IN THE AMAMI ISLANDS

The Amami Islands are a group of stepping-stone islands located 28 degrees 32 minutes 44 seconds north latitude, 27 degrees 01 minutes 07 seconds north latitude, 130 degrees 02 minutes 07 seconds east longitude, and 128 degrees 23 minutes 43 seconds east longitude. There are eight inhabited islands: Amami Oshima, Kakaroma Island, Uke Island, Yoro Island, Kikai Island, Tokunoshima, Okinoerabu Island, and Yoron Island. They are located in a particularly remote area from the Japanese mainland, with Kagoshima City 377 km from Kikai Island at the northeastern end of the archipelago and 594 km from Yoron Island at the southernmost point. The total area is 1,231.17 km^2. Amami Oshima, the largest of the archipelago, has a total area of 712.41 km^2. It is the second largest of Japan’s inhabited remote islands, to which special laws apply, after Sado Island. The figure below shows a general view of the Amami Islands.

The total population peaked in 1946 at 226,752; however, subsequent significant population outflow resulted in a total population of 110,147 by 2015. The number of cities, towns, and villages was 1, 5, and 14, respectively, when the islands were returned to Japan by the US in 1953. Subsequently, the area experienced changes such as municipal mergers and now comprises one city, nine towns, and two villages.

In this section, as a preliminary step to the main topic, i.e., the rate of vessel cancellations in the Amami Islands, we examine the volume of cargo per capita and per value of manufactured goods shipped to show how dependent the people of the Amami Islands are on ports. The equation used is one that we suggested for this study and is a simple equation that divides the amount of cargo handled at a port by the population or value of the cargo. Population data were taken from the official website of Kagoshima Prefecture, to which the Amami Islands belong. The data for the outgoing and incoming cargo volume are taken from the "Port and Harbor Survey and Port Statistics" conducted by the Ministry of Land, Infrastructure, Transport and Tourism. This is Japan's only statistical survey of ports and harbors, and its purpose is to clarify the actual conditions of ports and harbors and to contribute to their development, utilization, and management. The reason for defining " amount transferred out by marine transportation" and "amount transferred in by marine transportation" is that the ports in question are small and only move cargo domestically. The equations are as follows:

$$V_c = \frac{V_o or V_i}{T_p} \tag{1}$$

where,

V_o: volume transferred out by marine transportation (t)
V_i: volume transferred in by marine transportation (t)
T_p: population (people)
V_c: volume of cargo transferred out and in per capita (ton/person).

Figure 1. Location of the Amami Islands

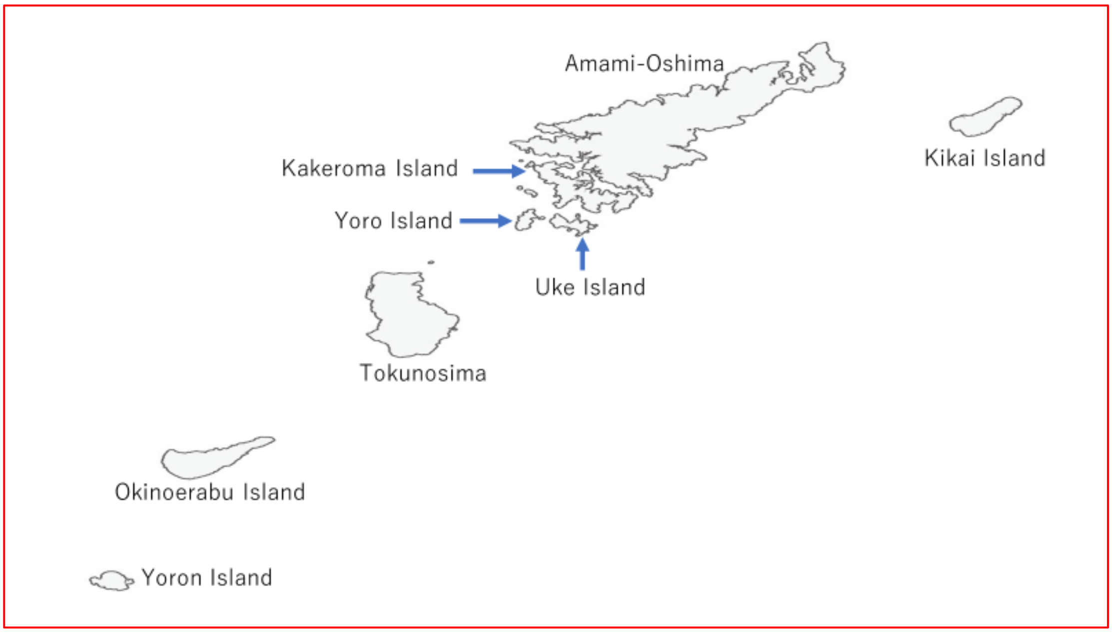

Figure 2. Map of Amami Islands

The data for the year 2020, the latest data available, were used to compare the amount of cargo transported in and out of the Amami Islands, Okinawa Prefecture, Tokyo Metropolis, and the whole of Japan. The reasons for each comparison are stated in Table 1. The ports, cities, towns, and villages analyzed in this study are listed in Table 2. Although Setouchi Town straddles four islands, Amami-Oshima, Kakeroma Island, Uke Island, and Yoro Island, only the data for the entire Setouchi Town was provided in the population data. Therefore, we assumed the population of Setouchi Town by distributing the population as of 2015, based on census data from the Ministry of Internal Affairs and Communications collected in 2015. The details are shown in Table 3, and the analysis results are shown in Table 4.

Table 1. Reasons for each comparison

Okinawa Prefecture	Similar location and circumstances and because of the implementation of promotion policies.
Tokyo Metropolitan	The extensive transportation network other than marine transportation.
Japan Nationwide	for comparison with mainland levels.

Table 2. Islands, ports and municipalities

Islands	Ports	Municipalities
Amami	Naze	Amami City
	Yannma	Yamato Village
	Koniya	Uken Village
	Yuwan	Setouchi Town
	Yamato	Tatsugou Town
	Tatsugou	Tatsugou Town
	Akakina	Tatsugou Town
	Sinokawa	Tatsugou Town
Kakeroma	Kakeroma	Setouchi Town
Kikai	Wan	Kikai Town
Okinoerabu	Ienn	Wadomari
	Wadomari	China
	Sumiyoshi	China
Tokunoshi	Kametoku	Tokunosima
	Hetono	Isenn Town
		Amagi Town
Uke	Uke	Setouchi Town
Yoro	Yoro	Setouchi Town
Yoron	Yoron	Yoron

Table 3: Setouchi Town Population Distribution

Amami Oshima	7,614 inhabitants, comprising approximately 84% of the total population.
Kakeroma Island	1,262 inhabitants, comprising approximately 14% of the total population.
Uke Island	82 inhabitants, comprising approximately 0.9% of the total population.
Yoro Island	84 inhabitants, comprising approximately 0.9% of the total population.

Table 4. Per capita transfers out and transfers in 2020

	tons/person	
	Out	In
Amami City, Yamato Village, Uken Village, Setouchi Town	11.57	12.22
Setouchi Town (Kakeroma Island)	119.24	113.15
Setouchi Town (Uke Island)	253.53	123.29
Setouchi Town(Yoro Island)	184.62	78.21
Kikai Town(Kikai Island)	3.70	8.01
Tokunoshima Town	4.97	14.68
Wadomari Town+China Town(Okinoerabu Island)	9.57	16.96
Yoron Town(Yoron Island)	7.54	16.36
Tokyo	1.03	1.47
Okinawa	6.19	9.51
Overall Japan	5.50	5.47

These results indicate that most of the islands in the Amami archipelago are more dependent on marine transportation than the national average. Kakeroma Island and Uke Island are particularly dependent and exceed 100 tons per capita. The difference in the number of airports may explain why most islands depend more on marine transportation than Okinawa Prefecture, which is in a similar situation. There are 12 airports in Okinawa Prefecture, while only 5 airports exist on the Amami Islands. It can be inferred that many airports facilitate cargo handling by air transportation and that the means of transportation are more dispersed. Subsequently, the number of cargo tons per thousand yen was examined to illustrate the dependence on marine transportation in terms of value. The formula is as follows:

$$C_t = \frac{V_o or V_i}{S_h} \tag{2}$$

where,

V_o : volume transferred out by marine transportation (t)
V_i : volume transferred in by marine transportation (t)
S_h : value of manufactured goods shipped (JPY)
C_t : volume of cargo transferred out and in per production (t/JPY)

The monetary data is obtained from the value of shipments of manufactured goods in the Survey of Industrial Statistics, a part of the Economic Census of Japan conducted by the Ministry of Economy, Trade and Industry to clarify the actual status of economic activities in Japan as a whole on a nationwide and regional basis, and is defined as follows. The value of manufactured goods shipped is the sum of the value of manufactured goods shipped, processing wage income, other income, and the value of scrap and waste from the manufacturing process during the year. Therefore, it provides reliable data on the total monetary value of cargo. The latest year is 2019, and unlike the population, there is no way of separating the amount of money in Setouchi Town, so the four islands of Amami Oshima, Kakeroma Island, Uke Island, and Yoro Island are analyzed together. Again, most of the islands of the Amami archipelago had larger values than those of the regions they were compared with. It is not an overstatement that the Amami Islands depend on marine transportation.

Table 5. The volume of transfers out and in per 1,000 JPY in 2019

	tons/1,000JPY	
	Out	In
Amami City, Yamato Village, Uken Village, Setouchi Town	7.3	8.2
Kikai Town (Kikai Island)	0.9	2.4
Tokunoshima Town	2.1	6.1
Wadomari Town, China Town (Okinoerabu Island)	6.8	14
Yoron Town (Yoron Island)	3.2	6.8
Tokyo	0.2	0.3
Okinawa	2.0	3.0
Overall Japan	0.2	0.2

5. CANCELLATION RATE OF LINER FERRY SERVICES

The previous chapter clarified that Amami Islands are heavily dependent on marine transportation. Therefore, as mentioned in the background section, we would like to illustrate the losses resulting from the number of vessel cancellations. The results of the interviews indicate that ships are canceled when wind speed is 15 m/s and wave height is 4 m and that the number of cancellations is approximately 30 times a year. As mentioned earlier, given that wave height data are only available for Naze Port, we counted the number of days wind speeds exceeded 15 m/s per year from the Japan Meteorological Agency data for Amami City, where Naze Port is located. Data were present for only one day for Amami City, based on meteorological data for 2020—the latest year for wave height data. The results indicate a few days when wind speeds exceed 15 m/s. Therefore, we can infer that vessels are often canceled based on wave height. We then investigated the number of times wave height and the number of days exceeded 4 m. We used wave height data every two hours, 12 times per day. If the height exceeded 4 m at least once per day, it was considered a day of exceedance for our statistics. Data were used from the 37 years from 1978 to 2020, excluding years in which unmeasurable data exceeded 1,000 out of a total of 4,380–4,392 per year. The waves were targeted at 1/10 wave heights. The results are shown in Table 6.

Wave heights were found to exceed 4 m on average 150 times per year, causing 32 days of ship cancellations. It is generally consistent with the information we heard during the interviews and can be considered reliable data. The wave heights exceeded 4 m for two consecutive days on eight occasions, three consecutive days on two occasions, and four consecutive days on one occasion. In other words, wave heights exceeding 4 m for four consecutive days occur approximately once a year, thus implying the need to store sufficient supplies for four days.

The number of days of flight cancellations was higher in August–September and December–February. August–September is due to the effects of typhoons, as mentioned earlier. Precipitation increases from December to February because the Amami Islands have a subtropical climate and belong to the westerly wind belt during winter. An increased number of voyages made at such times of the year may reduce the number of goods stored at the port. To observe changes over the years, the data were divided into 20-year periods and averaged to clarify differences in wave heights. The results are shown in Table 7.

This table suggests that there may have been a change in the data around 2000. Therefore, we assumed that the data for these 37 years follow a normal distribution. The data were then divided into 20-year intervals to test for differences in the population means. The test of difference in population means tests whether there is a difference in the means in the population based on the means obtained from the sample. Tests were performed on data for the number of times and days when wave heights exceeded 4 m from 2001 to 2020 and from 1981 to 2000, and they were found to be different. Table 8 depicts the results.

The average number of times and days of exceedances for the 2001-2020 period was 166 and 35 days, respectively, while the 1981-2000 averages were 137 and 31 days, respectively, a difference of 29 times and 4 days. It could imply stronger waves as the years progressed. According to the Japan Meteorological Agency, the sea level along the coast of Japan has been on an upward trend since the 1980s, with the sea level rising by 2.9 mm per year between 2006 and 2018. If the power of the waves continues to increase, the number of ship cancellations will likely also increase. Therefore, if the status quo is maintained, marine transportation will not be able to continue, and a critical situation may arise in which daily life may be disrupted. A possible option to reduce the number of days that vessels are canceled is to build breakwaters that can withstand higher waves than conventional breakwaters. Therefore, assuming that waves of 5 m or less are acceptable, the number of times the 1/10 wave heights exceeded 5 m was investigated in the same manner. All the conditions were the same as before, except for the wave height. The results of the comparison are shown in Table 9.

Table 6. The number of times and days wave heights exceeded 4 m at Naze Port

year	times	days	Number of consecutive days of ship cancellations						
			2	3	4	5	6	7	8
2020	175	32	9	2	1	0	0	0	0
2019	86	24	7	0	0	0	0	0	0
2015	131	33	10	1	0	0	0	0	0
2014	230	42	11	3	0	0	0	0	0
2013	164	32	6	3	0	0	0	0	0
2012	175	44	14	2	0	0	0	0	0
2011	165	36	4	3	1	1	0	0	0
2010	136	33	2	4	1	1	0	0	0
2009	162	33	10	0	0	0	0	1	0
2008	162	34	11	1	0	0	0	0	0
2007	100	25	3	4	0	0	0	0	0
2006	145	29	9	2	0	0	0	0	0
2005	246	40	3	5	2	0	0	1	0
2004	198	44	13	2	0	0	0	0	0
2003	201	39	7	2	2	0	0	0	0
2002	158	33	6	4	1	0	0	0	0
2001	181	37	10	2	1	0	0	0	0
2000	117	24	3	2	1	0	0	0	0
1999	151	34	9	3	1	0	0	0	0
1998	88	25	7	1	0	0	0	0	0
1997	126	27	8	1	1	0	0	0	0
1996	140	32	7	2	1	0	0	0	0
1995	151	33	11	1	0	0	0	0	0
1994	143	33	9	0	1	0	0	0	0
1993	154	36	6	4	0	0	0	0	0
1992	89	20	7	0	0	0	0	0	0
1991	154	31	6	0	2	0	0	0	0
1989	139	33	10	0	1	0	0	0	0
1988	161	32	9	0	0	0	1	0	0
1987	178	36	7	2	2	0	0	0	0
1984	118	30	8	2	0	0	0	0	0
1983	150	34	9	1	1	0	0	0	0
1982	118	25	7	0	1	0	0	0	0
1981	154	35	8	4	0	0	0	0	0
1980	153	32	5	1	0	0	0	0	1
1979	121	28	6	3	0	0	0	0	0
1978	146	30	7	2	1	0	0	0	0
Average	150	32	8	2	1	0	0	0	0

Table 7. The number of times and days wave heights exceeded 4 m at Naze Port by decades

year	times	days	Number of consecutive days of ship cancellations						
			2	3	4	5	6	7	8
2001~2020	166	35	8	2	1	0	0	0	0
1981~2000	137	31	8	1	1	0	0	0	0

Table 8. Results of the test of difference of mother mean

	Difference in value	statistic value	P-value
times exceeded	28.038	2.620	0.013
days exceeded	4.206	2.500	0.017

Table 9. Comparison of average values in number of exceedances and number of days

Threshold	times	days	Number of consecutive days of ship cancellations						
			2	3	4	5	6	7	8
4.0m	150	32	8	2	1	0	0	0	0
5.0m	47	13	3	1	0	0	0	0	0
Differences	103	19	5	1	1	0	0	0	0

We found that, on average, 47 times a year, the height exceeded 5 m and that 13 days of the year, ships were canceled. We also found that wave heights that exceeded 5 m occurred on two consecutive days on three occasions and three consecutive days on one occasion. Table 7 shows a significant difference in the number of times and days when 4 m and 5 m are exceeded. If the current situation of canceling vessels at 4 m waves can be improved to allow waves up to 5 m, there would be 19 more days of uninterrupted operation than before, and the cancellation of vessels for four consecutive days would be virtually eliminated.

As these data are inaccurate, they were assumed to have a normal distribution, and the cumulative distribution function was calculated. They are illustrated in Figure 3 and Figure 4.

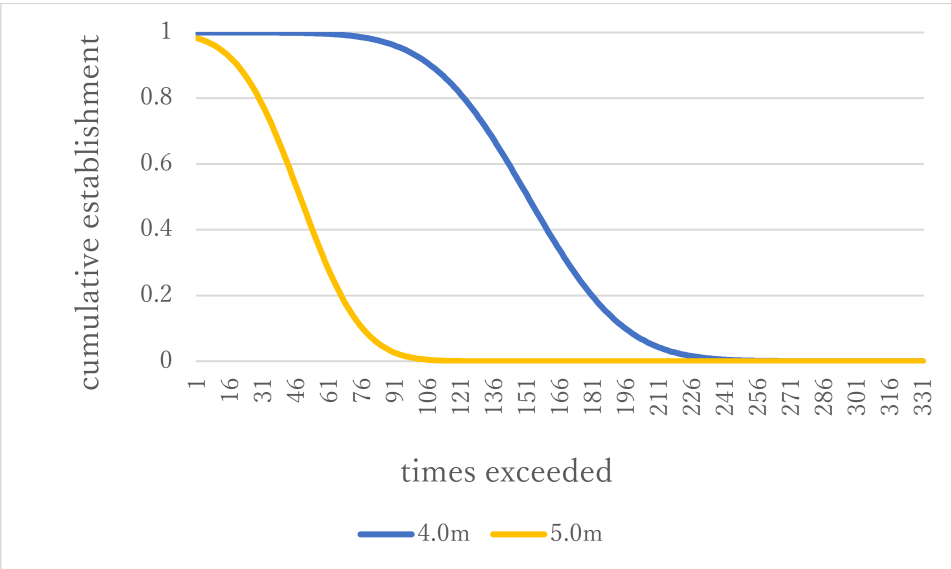

Figure 3. The cumulative distribution function of the number of exceedances

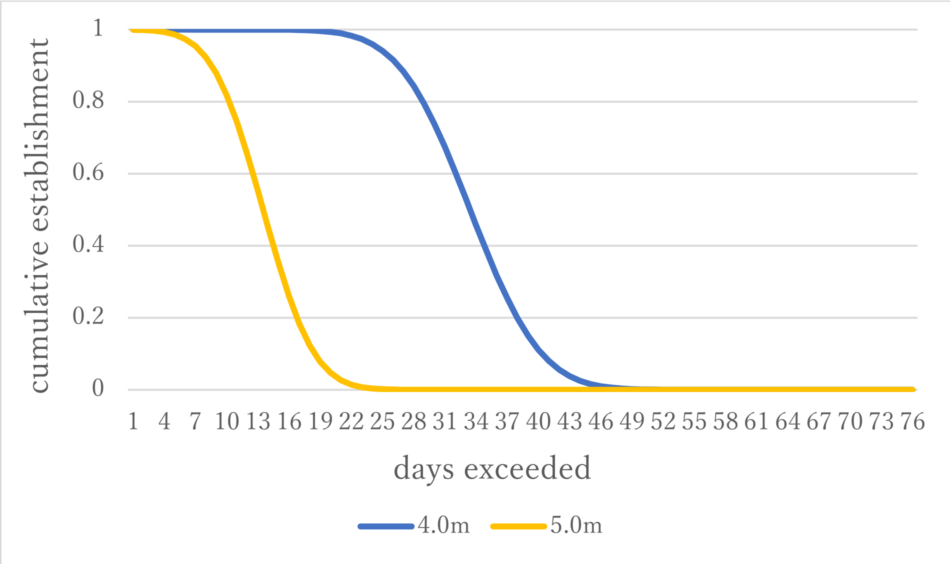

Figure 4. The cumulative distribution function of the number of days in excess

We observed a clear difference even in the normal distribution. The number of exceedances can be over 200 times in the conventional case but is likely less than 100 times if wave heights can be withstood up to 5 m. Likewise, the number of days shows that cancellations are unlikely to exceed 20 days, whereas conventionally, they may exceed 40 days. It means that the number of days of ship cancellation could be reduced by approximately 50%. In our simulation, 58% of the ship cancellation days were operable.

Based on these results, further analysis should be conducted to explore how the situation might improve if more days are available for operation.

6. BENEFIT ANALYSIS OF TRANQUILITY IMPROVEMENT

As discussed in the previous section, if wave heights of up to 5 m could be withstood, Naze Port could increase its service rate and profits. In this section, we discuss whether the construction of breakwaters to improve the percentage of ships in service of Naze Port is workable and present an equation in that respect. The cost of constructing, managing, and reinvesting in breakwaters was not analyzed in terms of cost this time because the cost of constructing, managing, and reinvesting in breakwaters was unclear due to a lack of data. In future analyses, we would like to prepare alternatives, such as estimating construction costs by referring to data from other ports rather than just sticking to data from the Port of Nase. Besides the above, the information required to conduct a cost-effectiveness analysis at the Port of Nase in this analysis was limited, making it difficult to follow the flowchart in the manual for cost-effectiveness analysis provided by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT). For this reason, we have used our flowchart for this analysis. The flowchart for determining the benefits is shown in Figure 5.

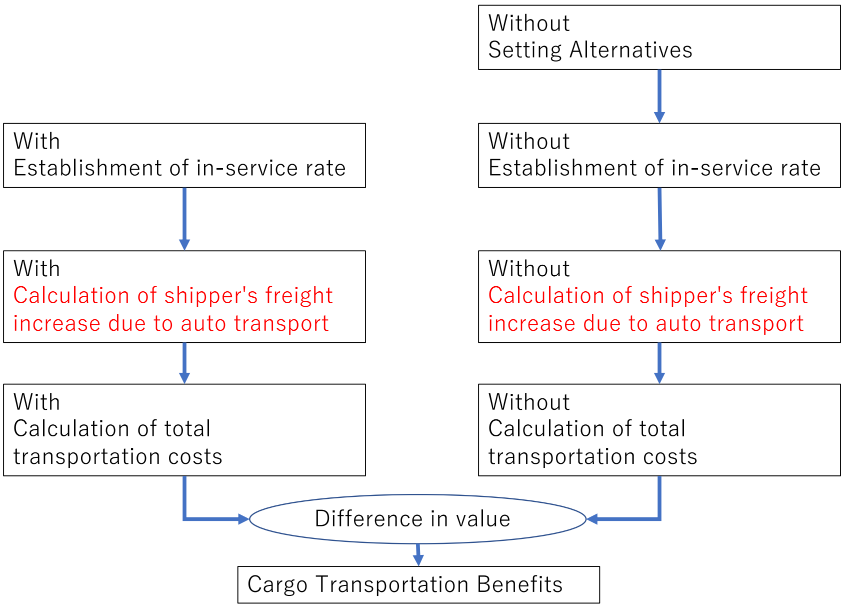

Figure 5. Flowchart for determining the benefits of the construction of breakwaters that will increase the rate of service

In this case, "with" refers to constructing a breakwater that can be used for sailing in waves less than 5 m. "Without" refers to cases where ships were canceled when waves of 4 m or higher occurred, as before. To set the in-service rate, the number of exceeded days determined in Section 5 was divided by the number of days a year. The transportation costs incurred by waiting are calculated from the tariffs for car transportation by ferry, as the tariffs for each cargo are not publicly available. In other words, we evaluated the increase in shippers' freight rates as a benefit. Therefore , we limited our target to the four ferries operated between Kagoshima and Amami by the Marix Line and Maruei Ferry Co to determine the benefits. The names of each ferry and the number of trucks they carry are shown in Table 10.

Table 10. Name of the ferry to be covered and loading capacity of trucks

Name of ferry	Details of loaded trucks
Queen Coral Plus	26 12-meter trucks
Queen Coral Cross	30 12-meter trucks
Ferry HANOUE	48 units of 8t trucks
Ferry Akebono	50 units of 8t trucks

The data is accurate as of 2022. The tonnage of the trucks loaded on the Queen Coral Plus and Queen Coral Cross are not listed, but it can be assumed that they are 10-ton trucks based on the standard size of large trucks. The total transportation cost for one year was calculated by equation (3).

$$Ty = T \cdot P \cdot 365 \cdot Ns \cdot Nt \tag{3}$$

where,

T: transportation cost per truck (JPY)

P: the service rate

Ns: number of services (days)

Nt: number of trucks (vehicles)
Ty: total transportation cost per year (JPY)

This simulation is based on the maximum loading of trucks on the ferry. The number of flights is taken from the annual report of remote islands statistics published by the Japan Remote Islands Center, and 0.25 is substituted for the number of ships. First, the current total transportation cost is calculated. Note that the total cost value is not linear with respect to P and T because the number of trucks loaded by each ferry is different. The results are shown in Table 11.as follows:

Table 11. Current total transportation costs

Name of ferry	P	T(1,000JPY)	Total (1,000JPY)
Queen Coral Plus	333/365	158	341,991
Queen Coral Cross	333/365	158	394,605
Ferry HANOUE	333/365	124	494,465
Ferry Akebono	333/365	124	515,068

The total transportation costs for the four ferries were 1,746,128,790 JPY. As there are nearly 30 days of ship cancellations, it means a loss of 32/365, or 153,085,264 JPY, of the total transportation cost. The benefits calculated by reducing the number of days of flight cancellations by 19 days in this situation were examined. The results are as shown in Table 12.

Table 12. Total Transportation Cost of Alternatives

Name of ferry	P	T(1,000JPY)	Total Cost(1,000JPY)	benefit(1,000JPY)
Queen Coral Plus	352/365	158	361,504	19,513
Queen Coral	352/365	158	417,120	22,515
Ferry HANOUE	352/365	124	522,678	28,213
Ferry Akebono	352/365	124	544,456	29,388

The benefits were calculated for each ferry and ranged from approximately 20 to 30 million JPY per vessel. The total benefit for the four vessels was 99,628,970 JPY. A ferry carries less payload than the gross deadweight tonnage, and even more benefits would be calculated if cargo ships and tankers were included.

The benefits are likely to increase with each passing year. Due to the increase in containerized cargo volumes and soaring oil prices, ships are becoming increasingly more prominent, and their payloads are also increasing. The trend toward larger trucks is also expected to increase the cost of transportation per vessel. The Queen Coral Cross, a subject of this analysis, replaced the Queen Coral 8 in November 2021, increasing its gross deadweight tonnage by more than 2,000 tons. The trucks used for loading have also changed from 8-ton trucks to 10-ton trucks, indicating a shift to an era of mass transportation. In this analysis, it is assumed that there is no change in wave heights and wind speeds, which are the criteria for cancellation due to the increase in the size of the vessels. We interviewed Maruei Ferry Co., Ltd., one of the leading companies in the shipping industry in the Amami Islands. We found that the company has increased the number of cancellations due to heightened safety awareness. Shoji (2018) also stated that ships are difficult to handle due to their huge size and slow mobility and that highly accurate weather and marine weather information is essential over the long term.

In other words, the effect of increased performance due to larger vessels can be interpreted as being smaller than the effect of weather and sea conditions.

The benefits obtained here can be used to perform a cost-benefit analysis. It is calculated by evaluating the magnitude of the net benefits of project implementation by assessing the difference between the benefits and costs. This method is called the Net Present Value method (NPV). When the NPV obtained by this method is positive, the project can be evaluated as efficient from a socioeconomic perspective. The formula is as follows:

$$\mathrm{NPV} = \sum_{i=1}^{T} \frac{B_t - C_t}{(1+i)^t} \tag{4}$$

where,

B_t: nominal benefits in year t (JPY)
C_t: nominal costs in year t (JPY)
i: social discount rate
T: project duration (years)
NPV: net present value (JPY)

7. CONCLUDING REMARKS AND FUTURE DIRECTION

This study analyzed marine transportation in the Amami Islands region and discussed the workability of improving cancellation rates at Naze Port in terms of cost-benefit. Our results suggest that the in-service rate of ferries for the Amami Islands can enhance their economic status by approximately 100 million JPY in total. Accordingly, we can assume that maintaining a safe status at Naze Port can be crucial for stabilizing transportation for Amami; therefore, building a new breakwater can be considered essential. However, our research is based on limited information about the Amami Islands, and the reliability of our findings needs to be improved through comparison with other cases. Future work should conduct similar analyses, not only for the Amami Islands but also for different regions.

The analysis was not performed because the benefits are only for ferries, and the costs of constructing, managing, and reinvesting in breakwaters need to be clarified. Therefore, future work should include calculating the costs and benefits from vessels other than ferries and the cost of building breakwaters.

The cost of the breakwater is expected to be high, and it is highly possible that the benefits calculated in this study, equivalent to 100 million yen, will not be sufficient. Therefore, it can be interpreted that the construction could be more appropriate for analysis according to the manual. In addition to calculating the benefits for one year, we would also like to calculate the benefits from a reduction in the number of consecutive days of flight cancellations to determine the significance of the breakwater construction as a future goal. NPV dealt with at the end of Chapter 6, is another long-term analysis method. In the case of this paper, this method of analysis is necessary to know in how many years the benefits obtained exceed the cost of constructing the breakwater but could not be performed because the cost of constructing the breakwater is unknown.

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