Article

Conceptualizing Floating Logistics Supporting Facility as Innovative and Sustainable Transport in Remote Areas: Case of Small Islands in Indonesia

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Abstract: Transportation is the main component that ensures the optimal distribution of goods in the maritime logistics system of small Islands. Therefore, this research developed a Floating Logistics Supporting Facility (FLSF) to overcome the logistics problems on small Islands by implementing sustainable operational systems. The research samples used were Nias, Kisar, and Sangihe Islands in Indonesia, with dimension, propulsion, operation, and mooring utilized as the four primary considerations. An FLSF was applied as a floating terminal capable of accommodating loading and unloading operations, ship mooring, cargo storage, stacking, and dooring services. The result showed that an FLSF can be applied to logistics activities while considering the safety aspects and related regulations. Based on the results, the FLSF can improve the quality of sustainable logistics operations and increase economic growth in remote islands.

Keywords: floating structure; transportation; remote island; logistics; sustainability

1. Introduction

The development of all sectors boosts economic growth and improves social welfare [1]. In certain instances, regional growth is often uneven. It causes economic disparities in some areas due to differences in each area’s abilities to support the development process [1,2]. In archipelagic countries such as Indonesia, Malaysia, and the Philippines, economic growth encounters several challenges mainly related to environmental conditions such as natural disasters, sea-level rise, and geographically isolated areas [3]. This causes some areas to experience less economic development, especially on remote and isolated islands.

Maritime logistics play a vital role in regulating the entry and exit of goods as well as maintaining local economic turnover in the development of archipelagic areas [4]. This concept applies the principles of logistics and supply chain management in the transportation system [5]. However, this is because maritime logistics is the main component that ensures that goods are distributed optimally. The quality of the supporting infrastructure critically...
ensures the efficiency of the logistics system in terms of providing added economic value and the ability to compete globally [6]. Its inefficiency tends to impact trade performance, resulting in additional costs that affect local economic development.

Several studies have been carried out to determine the characteristics of small islands in terms of the economic development related to maritime logistics. The isolation and remotes of an island lead to certain problems such as high transportation costs, the assessment of external goods, delays, and a reduction in the quality of information flow [7,8]. According to Kerr [9], high costs and irregular sea transportation, including unreliability, make the demand for the on-time delivery of goods challenging to achieve in modern supply chains.

As an archipelagic country, Indonesia has significant challenges associated with its logistics efficiency. Based on the World Bank (2018), it was ranked 46th in logistics performance globally and 4th in Southeast Asia. Although, it is still lagging behind several other Southeast Asian nations such as Singapore (Rank 7), Thailand (Rank 32), and Malaysia (Rank 41) [10]. This shows that logistics problems are a significant obstacle to increasing the competitiveness and distribution of goods among regions. Moreover, this inefficiency triggers the high cost of sea transportation and a lack of local economic development [4].

Currently, the research on logistics efficiency in Indonesia has become quite interesting. Zaman, Vanany, and Awaudin investigated port connectivity in Eastern Indonesia using the Gravity Method to determine its pattern in improving logistics efficiency [11]. Sutomo and Soemardjito assessed 18 ports in western Indonesia to determine the best ports that act as main hubs to support the national logistics system [12]. Gema, Arief, Tridoyo, and Nimmi proposed a strategy to create a competitive advantage in the Maritime Logistics Industry in Indonesia [13]. Romaji and Adiliya explored a scenario using the Tenau-Kupang port as a trans-shipment for maritime transportation connectivity in Eastern Indonesia [14]. Arianto et al. analyzed the country’s cost efficiency and CO2 emission in short sea shipping [15]. Logistics efficiency is important for economic development, although the research on maritime activities to boost the economy in remote islands is still limited. Therefore, it is paramount to carry out such related studies.

The development of maritime logistics is influenced by the availability of supporting infrastructure to increase the added value and competitiveness in trade [6]. One of such important facilities is the availability of ports. The development of port in remote islands has several limitations, such as shallow drafts, the fact that few ships that visit the islands, the number of loaded or unloaded cargoes, and the availability of loading and unloading equipment. These problems make it difficult for medium or large ships to send or receive cargo from the island, thereby causing few of them to either visit or leave the island, and this slows economic growth.

Optimizing maritime logistics led to the development of a floating infrastructure [16–19]. Currently, there is a high demand for the construction of such floating infrastructure because conventional types are costly, and the capacity is limited [20,21]. Floating infrastructure is usually based on converting ships or barges to moored platforms with various cargo commodities [19,22]. In principle, its application simply means that all logistics operations are carried out in the middle of the sea. This method can be a solution for remote islands via the possession of a floating port that functions as a logistics hub that connects it to other regions.

In the logistics process, sustainable development is needed to increase economic growth while still ensuring the maintenance of the environment for the next generation [23]. The sustainability of port activities is presently a vital issue due to the significant impact of this sector on the environment [24]. These port activities can have a negative impact on the environment due to water, air, and noise pollution along with the development of this infrastructure, including the maintenance of existing equipment and facilities.

Depending on its application, the implementation of port policies, such as improving management, strengthening the connectivity between land and sea transportation, and development of local economic supply chains, is an essential goal that needs to be achieved.
to improve logistics efficiency. Low efficiency disrupts the distribution of goods, resulting in high logistics costs [4]. In addition to improving its efficiency, implementing new policies and using environmentally friendly technologies are needed to protect the port from excessive emissions and to maintain its carrying capacity. Research on floating infrastructure to support maritime logistics in remote islands is still rarely performed.

Considering these problems, there is a need to construct a floating logistics infrastructure on a remote island. In this study, the barge principle, referred to as the Floating Logistics Supporting Facility (FLSF), was applied. The FLSF’s planning was carried out using both qualitative and quantitative approaches. Several small islands in Indonesia were selected as case studies. Determining the specifications of the FLSF considers the geographical conditions and the needs of the community.

The FLSF will be a floating terminal that accommodates loading and unloading operations, including cargo storage or stacking. It acts as a logistics terminal hub that can facilitate cargo distribution in and out of small islands. Its smooth distribution in remote archipelagic areas is expected to increase economic growth. In its application, the FLSF tends to implement sustainable policies and is perceived as the initiator in promoting and supplying more environmentally friendly fuels. Based on these functions, it will improve the quality and efficiency of sustainable logistics.

2. FLSF as an Innovative Approach to Maritime Logistics

Maritime logistics is a concept that applies the principles of logistics and supply chain management to the transportation system [5]. This is perceived as the main component that ensures that goods are optimally distributed. Currently, sea transportation is the primary means of distributing goods, accounting for 89.6% and 70.1% of international trade’s total volume and value, respectively. It is in demand because it has the lowest transportation costs and is highly efficient [25]. The quality of the supporting infrastructure is critical in terms of ensuring the efficiency of the logistics system and providing additional economic value towards global competition [6]. Figure 1 shows the general maritime logistics supply chain that is broadly utilized.

![Figure 1. Existing Maritime Logistics Supply Chain.](image)

Generally, the maritime logistics supply chain is an activity that results in the movement of cargoes and related service facilities between two substantial locations by sea transportation [26,27], as shown in Figure 1. These cargoes are moved from an area that acts as a supplier using a land route to the port. After it has been collected at the port, the delivery process involves shipment to the destination island. As soon as cargoes arrives at the destination port, the cargo will be transported to the recipient or consumer. The larger the ship’s dimensions, the cheaper the logistics costs [28]. Its application in remote islands encounters many obstacles such as draft limitations, a lack of port infrastructure, the unavailability of cargo loading or unloading facilities, communication problems, and remote access that make logistics costs expensive [4,7,9]. These issues result in economic disparities between remote islands and other regions [2].

This research applies FLSF as a floating terminal that accommodates loading and unloading operations, including cargo storage or stacking. It acts as a logistics terminal
hub that facilitates cargo distribution in and out of small islands, as shown in Figure 2. In accordance with FLSF development, cargo from the main island, or the producer of goods, can be sent using larger ships to increase efficiency and reduce operating costs [28]. These are stored and distributed to small islands using a feeder ship (a small ship). The FLSF tends to assist in cargo storage and overcoming barriers related to its delivery in remote islands, such as a lack of port infrastructure, shallow draft limitations, and warehouse availability. As a logistics terminal hub, it promotes using environmentally friendly fuels by providing bunkers with renewable energy sources to supply the operational needs of ships and the population. By promoting the use of renewable fuels, the FLSF tends to participate in supporting IMO regulations intended to reduce GHG emissions by at least 50% in 2050 [29].

Figure 2. FLSF as Part of Maritime Logistics.

FLSF development aids in curbing certain obstacles in maritime logistics operations, such as the limitation of draft ships going to the island, the availability of loading and unloading facilities, and limited communication [4,7,9], resulting in lower costs. This is in line with Bensasi et al. [6], who state that the quality of the supporting infrastructure critically ensures the efficiency of the logistics system in terms of providing additional economic value, including the ability to compete globally. With lower logistics costs, the purchasing power of people in remote islands increases [4], thereby ensuring the availability of goods in the local market. These phenomena increase the growth of local industries and absorb a high amount of labor because several new sectors can be developed [2]. Therefore, FLSF development indirectly stimulates economic growth in remote islands.

3. Consideration of FLSF Development

According to Gunther and Kim [30], three main factors are generally considered when designing a terminal: layout, operation plan, and real-time monitoring. Similar considerations will be used in this study in the development of the FLSF, which is at the core of the strategic planning of a facility and its operations. Several studies have reported that strategic optimization approaches were carried out during the development of floating terminals. This approach analyzed and evaluated the design layout based on technical and economic aspects [22,31]. It also aimed to determine the appropriate storage capacity and equipment to minimize a floating terminal’s capital and operating costs. Operational planning includes preparing and scheduling several terminal logistics problems, including berthing allocation, crane assignment, and stowage planning [20]. In terms of real-time monitoring, the application will be directly related to operations at the terminal, where an approach is taken to overcome several logistics problems. These include transportation distribution, loading and unloading equipment, scheduling, and vehicle routing to load cargo [20] for optimal operations at the terminal.

Several variables must be considered when designing an FLSF, including platform dimensions, propulsion, operational functions, mooring, safety, suitability, environment, etc. In this study, the design considerations are broadly divided into four modules, namely, dimension, operation, propulsion, and mooring, to produce a suitable FLSF design for the
implementation area. Figure 3 is a diagram of the modules considered in the development of the FLSF.

![Figure 3. FLSF Development Modules.](image-url)

Figure 3 shows that the determination of the module design is based on the logistical requirements and the geographical conditions in the area of the FLSF’s application. The dimension module analyzes the appropriate dimensions of the FLSF and the types of cargo to be handled based on the supply and demand needs of people on remote islands. The mooring module analyzes the mooring system requirements of the FLSF. Hence, it is applicable in the middle of the sea and has become a solution to overcoming the draft limitations that often occur on large ships on remote islands. The mooring analysis considers six degrees of freedom in the FLSF to ensure that ship-to-ship cargo handling operations run safely. The operations module addresses the lack of logistics infrastructure on remote islands. This module also analyzes the needs of cargo gear, storage, and logistics supporting infrastructure to support the smooth operation of the distribution of goods. The Propulsion Module determines the ability of the FLSF to move in the event of an emergency or to be placed to another island.

By implementing the dimension, mooring, operation, and propulsion modules, the FLSF can adapt to the environmental conditions of the application area, perform operations safely and efficiently, and change locations to support logistics on other islands when needed.

4. Analysis Method

This study is a combination of qualitative and quantitative methods. The Qualitative approach was used to determine the needs of the FLSF specifications and select the appropriate operating design to be applied to the implementation area. On the other hand, a quantitative approach was used to design the FLSF using software analysis. A flow chart of the analysis method is shown in Figure 4.

4.1. Qualitative Method

A survey of the implementation site is required to determine the specifications and facilities provided by the FSLF to obtain data on the type of cargo and packaging used in ships. The site survey for the application of FSLF also aims to determine the potential and conditions of the application area. The FSLF is designed according to the surrounding community’s needs, which function to support economic activities, facilitate the transportation of local trade, and enhance the efficiencies of goods logistics and ship operations in remote islands.

The most suitable FLSF operation scenario to be applied in the application area is determined using the analytical hierarchy process (AHP) method. This approach is applied to produce accurate judgments and perspectives of respondents from various fields of expertise [32]. The AHP analysis is also used to determine the weighting criteria and sub-criteria in several scales. This importance intensity scale is used in the process of pairwise comparisons.
4.2. Quantitative Method

In this study, the determination of the quantitative evaluation criteria is analyzed using numerical calculations and software analysis following applicable requirements and regulations. The hydrostatic analysis and stability of the FLSF are analyzed under the assumption that it is fully loaded. This analysis aims to determine the characteristics of the FLSF’s hull and its stability when loaded under IMO regulation A.749(18) Ch3 [33] to ensure safe cargo operation.

A resistance analysis was conducted to determine the minimum main engine power of the FLSF, with the main engine specifications adjusted to the environmental conditions in the application area. The KR Barge Resistance Method was used to analyze the resistance and determine the minimum power for the main engine. This method was chosen because of the barge-like design of the FLSF.

The determination of the cargo capacity was adjusted to the needs of the application area. After obtaining the cargo capacity requirement, the cargo space and the general arrangement were designed according to the requirements and regulations of the BKI (Indonesian Classification Society).

A mooring analysis was carried out to ensure that Ship to Ship operation for cargo loading and unloading was in a safe condition. In this analysis, the type of mooring and its specifications are first defined according to the oceanographic conditions in the implementation area. The results are the maximum tension, load direction, minimum breaking load, and safety factor. The quantitative analysis was carried out systematically to produce an FLSF design capable of operating proficiently in the application area.

5. Selection of Implementation Area

Several islands in Indonesia were selected as research samples in connection with implementing the FLSF in remote areas. Indonesia was chosen as the sample because, apart from the fact that it is still a developing country, it is also the largest archipelagic country in the world. Three islands were used as samples, namely, Nias, Kisar, and Sangihe. These islands were chosen because they are located on the Indonesian border, have a relatively
small landmass, small population, and have low economic growth. Figure 5 shows the location of Nias Island, Kisar Island, and Sangihe Island.

The FLSF is a floating terminal that will accommodate loading and unloading operations, ship mooring, cargo storage, stacking, and doorng services. The need for ship mooring will be a supporting facility for the FLSF while still meeting the level of stability due to the external influences and acceptable loading design in accordance with the planned capacity. The characteristics of each island are shown in Table 1.

Table 1. Characteristics of Implementation Area.

| Criteria          | Sangihe Island | Kisar Island | Nias Island |
|-------------------|----------------|--------------|-------------|
| Island Area       | 736.98 km²     | 81.83 km²    | 853.44 km²  |
| Population        | 139,262        | 15,296       | 147,794     |
| Sea Depth         | 262 m          | 430 m        | 542 m       |
| Wave Height (Hs) | 1.65 m         | 2.62 m       | 1.25 m      |
| Wave Period (Ts)  | 6.57 s         | 9.38 s       | 5.53 s      |
| Max Wind Speed    | 7.72 m/s       | 7.69 m/s     | 7.47 m/s    |
| Max Current Speed | 0.25 m/s       | 0.25 m/s     | 0.25 m/s    |

6. Results: Implementation of FLSF in Indonesian Small Islands

6.1. Site Survey and Interview

Site surveys and interviews were conducted to determine the implementation area’s environmental and logistical conditions on each island. Data were collected at this stage regarding the flow of goods, types of commodities, existing logistics facilities, superior products for each island, and population demographics. The data obtained were then processed and considered in producing FLSF in the selected areas. Table 2 summarizes the results of the survey and the interviews.
Table 2. Survey and Interview Result.

| Parameter          | Nias       | Kisar     | Sangihe   |
|--------------------|------------|-----------|-----------|
| Population         | 139,262    | 15,296    | 147,794   |
| Port facility      | Poor       | Poor      | Poor      |
| Shore crane        | Not available | Not available | Not available |
| Draft              | Up to 9 m | 5 m       | 4 m & 13 m|
| Ship logistics frequency | 36 ship/year | 12 ship/year | 12-16 ship/year |
| Local production   | Fishery and plantation | Fishery and plantation | Fishery and plantation |
| Port warehouse     | Limited    | Limited   | Limited   |

Table 2 shows the same logistics problems between Nias, Kisar, and Sangihe Islands. Many port facilities on all the islands are damaged and do not have loading and unloading facilities; hence, they rely on ship cranes. A shallow draft limit prevents medium or large-sized vessels from berthing in port. The frequency of ships coming to the island is dominated by ferries for public transportation, while ships for logistics activities are rare. Nias Island has better logistics activities than others due to the effectiveness of the “Sea Toll” program. Generally, the commodities produced from the three islands are fishery and plantation products with no commodity processing system to increase the added value of the goods.

Based on the needs in the implementation area, it was concluded that the main functions to be considered in the development of the FLSF are ship-to-ship (STS) cargo handling, storage, accommodation, and bunkering. The FLSF will have one crane with an SWL of 25–30 tons to support ship-to-ship (STS) cargo operations. This system also facilitates temporary cargo storage in containers, reefer, and general cargo. The handling facilities and residents’ domestic production can be collected at the FLSF, which eases the exchange of cargo with the main ship carrying goods to the island. The FLSF also provides bunker facilities for biodiesel and fresh water to facilitate sustainable fuel oil for marine operations in Indonesia. These facilities can meet the needs of ships carrying out operations. Biodiesel storage in the FLSF can also function as fuel storage capable of meeting the fuel needs of residents in the implementation areas to support a sustainable logistics system. Accommodation facilities are also provided to ensure the ship crews can easily obtain food supplies and other necessities.

Figure 6 shows that there are three possible operation concepts of FLSF considered based on the survey results as follows:

1. **Fixed FLSF**: It has the function of loading and unloading service in the offshore area and serves both large and small ships for the destination area. FLSF moored at the sea near small island and becomes a central point for the ships to be served.

2. **Push/Tow FLSF**: It has the function of loading and unloading service in the offshore area and serves ships and small vessels. Furthermore, the FLSF is towed by a Tugboat from the loading and unloading region to the application area.

3. **Self-Propelled FLSF**: The scheme is fixed with its engine or propulsion for emergency needs, especially during very high waves or tsunamis. The FLSF can immediately perform emergency maneuvers.
6.2. Selection of FLSF Operation Concept using Analytical Hierarchy Process (AHP)

The selection of the operation concept of the FLSF was used to determine the optimal type capable of supporting logistics activities, which includes the flow of goods, services, efficiency, and effectiveness of operational activities. The Analytical Hierarchy Process (AHP) analysis was carried out at this stage to select the most suitable FLSF concept to be applied as a logistics support infrastructure. This process was used to determine the best combination of operating patterns by considering the set parameters and criteria.

During the planning of the AHP analysis, the main objective was to select the best FLSF operation concept based on the respondent’s point of view. There are three possible operation concepts: Fixed FLSF, Push/Tow FLSF, and Self Propelled FLSF. The criteria and sub-criteria used in the AHP Analysis are shown in Table 3:

| No. | Criteria | Sub Criteria |
|-----|----------|--------------|
| 1   | Dimension| Small (10 k ton), medium (20 k ton), big (30 k ton). |
| 2   | Function | Loading/unloading cargo, passenger terminal, loading/unloading and a passenger terminal. |
| 3   | Facility | Fuel station, Freshwater bunkering, cold storage. |
| 4   | Cost     | Infestation Cost, Operational Cost |
| 5   | Safety   | The level of design safety against currents, waves, wind, and tides. |

A hierarchy was created to facilitate calculations based on the criteria and sub-criteria determined. A comparison of the criteria was used to obtain the level of importance of each criterion against the objectives. The results from the selection of the best FLSF operation concept based on the AHP method were synthesized from the weighting results, as shown in Figure 7.

The most influential criteria in the development of the FLSF are the function and the safety, with values of 0.312 and 0.292, as shown in Figure 7. Based on the analysis, safety is the primary consideration because remote islands often experience bad weather and are prone to natural disasters, especially on Sangihe Island. The function of the FLSF is also a major consideration because the existing logistics facilities on each island are very limited and require supporting infrastructure to improve logistics. The other AHP criteria weights are 0.197, 0.108, and 0.090 for facility, cost, and dimension.

The AHP results in Figure 7 showed that the Self-Propelled FLSF design was more dominant than other designs for the FLSF applications in remote islands. The Self-Propelled
FLSF weighs 0.405, at a difference of 0.064 compared to the Push/Tow FLSF design, which weighs 0.341. The lowest is weight is the Fixed FLSF Design, at a value of 0.254.

The overall inconsistency in this study is 0.02, which is still within the allowable limit in the AHP analysis, with a maximum limit of 0.1 (10%) inconsistency [32,34]. Based on the analysis results, it can be concluded that the recommended FLSF design based on the AHP analysis is the Self-Propelled FLSF.

6.3. Hydrostatic Analysis

From the analysis of the survey results and interviews, three dimensions of FLSF at capacities of 30,000 tons, 20,000 tons, and 10,000 tons were applied to Nias, Kisar, and Sangihe Islands. The determination of the FLSF’s capacity is based on the need for supporting infrastructure and the existing logistics conditions in the implementation area, as shown in Table 4.

| Item         | Sangihe FLSF | Kisar FLSF | Nias FLSF |
|--------------|--------------|------------|-----------|
| Disp. (ton)  | 12.427       | 24.800     | 37.423    |
| LWL (m)      | 100.320      | 136.800    | 167.200   |
| B (m)        | 25.84        | 38         | 47.12     |
| H (m)        | 7            | 7.5        | 8         |
| T (m)        | 5            | 5          | 5         |
| Payload (ton)| 10.410       | 20.584     | 30.650    |

It is essential to know the characteristics of the FLSF’s design, especially the characteristics below the water surface, for its efficient operation. The hydrostatic data in Table 5 describe the shape and characteristics of the hull below the waterline at a full load for the Sangihe, Kisar, and Nias FLSFs.
Table 5. Hydrostatic Analysis of FLSFs.

| Measurement                  | Sangihe FLSF | Kisar FLSF | Nias FLSF |
|------------------------------|--------------|------------|-----------|
| Displacement (ton)           | 12,429       | 24,804     | 37,448    |
| Volume (m$^3$)               | 12,125.480   | 24,198.790 | 36,534.800 |
| Draft Amidships (m)          | 5.000        | 5.000      | 5.000     |
| Immersed depth (m)           | 5.002        | 5.000      | 5.002     |
| WL Length (m)                | 99.930       | 135.760    | 165.390   |
| Beam max extents on WL (m)   | 25.840       | 37.990     | 47.110    |
| Wetted Area (m$^2$)          | 3495.380     | 6360.360   | 9225.710  |
| Max sect. Area (m$^2$)       | 128.140      | 188.270    | 233.400   |
| Waterpl. Area (m$^2$)        | 2580.030     | 5154.44    | 7790.530  |
| Prismatic coeff. (Cp)        | 0.947        | 0.947      | 0.946     |
| Block coeff. (Cb)            | 0.939        | 0.938      | 0.937     |
| Max Sect. area coeff. (Cm)   | 0.992        | 0.991      | 0.990     |
| Waterpl. area coeff. (Cwp)   | 0.999        | 0.999      | 1.000     |
| LCB length (m)               | 49.750       | 67.820     | 82.890    |
| LCF length (m)               | 49.980       | 67.900     | 82.680    |
| LCB %                        | 49.780       | 49.960     | 50.120    |
| LCF %                        | 50.020       | 50.020     | 49.990    |
| KB (m)                       | 2.590        | 2.590      | 2.590     |
| KG fluid (m)                 | 0.000        | 0.002      | 0.000     |
| BMT (m)                      | 11.830       | 25.620     | 39.430    |
| BML (m)                      | 176.820      | 326.680    | 485.870   |
| GMT corrected (m)            | 14.470       | 28.200     | 42.020    |
| GML (m)                      | 179.400      | 329.270    | 488.460   |
| KMt (m)                      | 14.420       | 28.200     | 42.020    |
| KML (m)                      | 179.400      | 329.270    | 488.460   |
| Immersion (TPC)              | 26.450       | 52.830     | 79.850    |

Table 5 shows some of the parameters in the hydrostatic analysis for each FLSF design, with similar shapes but different dimensions according to the needs in the implementation area. The FLSFs on Nias, Kisar, and Sangihe Islands have a draft of 5 m, which allows them to be anchored on piers to overcome draft limitations. A design optimization was carried out on the length, breadth, and the FLSF’s operation above the water’s surface to produce the same draft with varying payloads. This optimization produces different immersion levels with the same draft of 26.45 TPC, 53.83 TPC, and 79.85 TPC for Sangihe FLSF, Kisar FLSF, and Nias FLSF, respectively.

6.4. Resistance Analysis and Sustainable Propulsion System

A resistance analysis was carried out to determine the minimum engine power required to drive the FLSF at a speed of up to 4 knots. This speed was selected because the FLSF, under normal conditions, will stay in position and only move in an emergency or during docking.

The resistance calculation was carried out by creating a 3D model of the FLSF and then was calculated using the KR Barge Resistance method according to the characteristics of the barge [35]. Although the KR Barge method is proposed to estimate the towing force required for a non-propeller barge, it is widely used by naval architects in the early design stages for ships [36], mainly due to the lack of an adequate method [37]. The calculation
of the barge resistance uses the FLSF design model scenario with a propulsion system. Figure 8 is the result of calculating the FLSF resistance.

![Resistance Analysis](image1)

**Figure 8.** Resistance Analysis of FLSF.

Figure 8 shows that the resistances on the FLSF at a maximum speed of 4 knots on Sangihe, Kisar, and Nias FLSF are 196.6 kN, 310.3 kN, and 407.9 kN, respectively. The resistance chart illustrates a similar pattern due to the design’s similarity. Munoz et al. also generated a similar pattern in their research, which compared the results of the statistical model with the landing craft ships to estimate the ship’s resistance [37]. Based on the analysis, it was concluded that the dimensions of the FLSF will affect the resistance due to the difference in the surface area immersed in water. The resistance generated will be in a straight line with the minimum power required for the main engine to reach a speed of 4 knots. Figure 9 is a graph that illustrates the conversion from resistance to the power required for the FLSF to reach a speed up to 4 knots.

![Power Requirement Analysis](image2)

**Figure 9.** Minimum Power Requirement of FLSF.

Figure 9 shows that the minimum power required to achieve a maximum speed of 4 knots in Sangihe, Kisar, and Nias is 951.9 kW, 1502.47 kW, and 1974.96 kW. The minimum power referred to in this study is the maximum power produced by the propellers’ rotation. Therefore, the estimated power loss due to a decrease in the propulsion system and energy conversion must be added to determine the minimum specifications for the main engine.

The propulsion system needs to define the fuel and equipment required after determining the minimum specifications of the main engine for the FLSF’s mobility. The new system will use a diesel-electric propulsion system in which the main engine is an electric motor supplied with electricity by a generator. This propulsion system was selected because the main engine will only be used when there is an emergency or the FLSF docks. Based on this,
a generator can be used for the loading and unloading system and can supply the main engine’s electricity needs in an emergency. According to Hideki, Hiroaki, and Aiichiro (2011), the use of a diesel-electric system increases the propulsion efficiency. A significant increase was obtained for the energy-saving performance, which was enough to replace the energy loss due to the conversion of the diesel to the electric system [38].

In the development phase, the type of the main engine used was the electric deck-mounted azimuth thruster, which was selected due to its numerous advantages, such as the ability to move 360 degrees, its good maneuverability, efficient use of power, suitability for spatial ships, and low maintenance costs [39].

The generators in the FLSF will be designed to use biodiesel fuel as part of a sustainable floating logistics system. Biodiesel was selected because it is a fuel with lower emission levels than fossil fuels [40], and its availability is abundant in Indonesia, especially for palm oil biodiesel.

6.5. General Arrangement of FLSF

The general arrangement geometrically defines the ship as a total system by placing all the functional elements, producing unity, and allocating area and volume to all the components. The FLSF’s general arrangement was developed based on a survey conducted on the islands of Nias, Kisar, and Sangihe to improve logistics activities. Generally, the vessel constructions are calculated to explore the locations of the equipment and machinery needed to determine the capacity of the cargo storage area. In this research, the FLSF uses the BKI (Indonesian Classification Society) for classification society standards. Figure 10 is the general arrangement of the manufactured FLSF.

Figure 10. FLSF General Arrangement.
Figure 10 above shows that the designed FLSF is equipped with one crane of SWL 30 tons. This crane functions as loading and unloading equipment for feeder ships from remote islands and main ships. While supporting the cargo handling operations and crew needs, the FLSF will be equipped with three auxiliary generators as power plants.

Table 6 shows the dimensions and volume of the fuel tank of the FLSF. It has a fuel storage tank adjusted to the implementation area’s dimensions and needs.

Table 6. Dimension of FLSF Fuel Oil Tank.

| No | Fuel Oil Tank                          | Sangihe FLSF | Kisar FLSF | Nias FLSF |
|----|---------------------------------------|--------------|------------|-----------|
| 1  | Biodiesel Tank (P)                     | 32.48 m³     | 33.29 m³   | 38.88 m³  |
| 2  | Biodiesel Tank (S)                     | 32.48 m³     | 33.29 m³   | 37.58 m³  |
| 3  | Settling Tank (S)                      | 6.048 m³     | 9.072 m³   | 12.96 m³  |
| 4  | Settling Tank (S)                      | 6.048 m³     | 9.072 m³   | 12.96 m³  |
| 5  | Daily Oil Tank (P)                     | 4.536 m³     | 4.536 m³   | 5.04 m³   |
| 6  | Daily Oil Tank (S)                     | 4.536 m³     | 4.536 m³   | 5.04 m³   |

Figure 11 illustrates the cargo arrangement on the FLSF, designed to handle fuel, fresh water, containers, and general cargo. At the front of this device, a cargo hold provides general cargo loads capable of accommodating various types of packaging, and the cargo hold is equipped with a hatch cover for protection from rainfall. The general cargo hold was equipped with a twist-lock that can be used for container placement. The center and aft are divided into two types of payloads and used for the placement of a container and a bunker tank for fresh water and fuel. This tank will supply biodiesel and fresh water for ships operating around the FLSF and as emergency storage for islands in the implementation area. The existence of a renewable fuel bunker increases the use of renewable energy to support a sustainable logistics system. The FLSF was equipped with a 30 ton SWL crane to assist in loading and unloading cargo. Table 7 shows the tank dimensions and cargo hold for each FLSF.

Figure 11. FLSF Cargo Arrangement.

Table 7. Tank and Cargo Hold Dimension.

| No | Item                        | Sangihe FLSF | Kisar FLSF | Nias FLSF |
|----|-----------------------------|--------------|------------|-----------|
| 1  | Cargo Hold—General Cargo    | 3608.56      | 10,725.12  | 17,008.43 |
| 2  | Cargo Fresh Water Tank 1    | 1647.08 m³   | 2606.8 m³  | 2968.56 m³|
| 3  | Cargo Fresh Water Tank 2    | 1647.08 m³   | 2606.8 m³  | 2968.56 m³|
| 4  | Cargo Fresh Water Tank 3    | None         | None       | 2968.56 m³|
| 5  | Cargo Oil Tank 1—Biodiesel  | 1614.35 m³   | 2469.6 m³  | 2842.56 m³|
| 6  | Cargo Oil Tank 2—Biodiesel  | 1614.35 m³   | 2469.6 m³  | 2842.56 m³|
| 7  | Cargo Oil Tank 3—Biodiesel  | None         | None       | 2842.56 m³|
Generally, the FLSF can provide for the need of remote islands to increase the logistics activities in the implementation area. Local products can be collected before loading to main vessel and it will be deliver to other areas. The FLSF also acts as a logistics hub that receives cargo from the main vessel to the small islands around the implementation area. Accommodation facilities are also provided to ensure that the needs of ship crews are easily met, such as providing food supplies and other necessities. With cargo storage, loading, unloading, and logistics support facilities, the FLSF will reduce price disparities in remote islands by improving the logistics systems. This is in accordance with the research by Benassi et al. [6], who stated that the quality of the supporting infrastructure for maritime logistics is critical to ensure the efficiency of the logistics system and to provide additional economic value with the ability to compete globally. The fuel storage system is a promotion for ships operating around the FLSF and residents on remote islands to use renewable energy and as a contribution from supporting IMO policies to reduce Green House Gas (GHG) emissions [29].

6.6. Stability Analysis

During operation, the FLSF is likely to experience bad weather conditions, such as high waves and strong ocean currents, which may make it wobble in response to regular and random waves. This stability affects the angle of sway, which is important to ensure that the various goods to be traded are properly maintained. The poor stability of an FLSF would be very dangerous for cargo storage as well as loading and unloading operations.

Table 8 shows the results of the intact stability analysis for full load conditions, which is used to determine the ship’s condition, such as the possible leaking of the hull and compartments. The ship is expected to meet several stability criteria, including GMT (metacentric height), the area under GZ (righting lever), the range of stability, the trim, etc. Before running calculations on the software, numerous steps are taken by determining the position, defining the room space, and loading the case. Based on several analyzed criteria, all the FLSFs have met the criteria required by IMO A.749(18) Ch3 for stability [33]. Figure 12 shows the stability graph of each FLSF.

Based on Figure 12, the graph above shows the Maximal Righting Lever (GZ) on the Sangihe FLSF is 3725 m at 26.4 deg, the Kisar FLSF shows the Maximal Righting Lever (GZ) of 6302 m at 25.5 deg, while on Nias the FLSF shows the Maximal Righting Lever (GZ) of 8061 m at 25.5 deg.

The righting lever (GZ) and load distribution are related to the stability of the FLSF. Changes or differences in the distribution of shiploads lead to changes in the KG value and the resulting righting lever (GZ). Based on several criteria and the value of the righting lever, the FLSF has met the criteria required by IMO A.749(18) Ch3.

**Table 8. Stability Analysis of Sangihe FLSF.**

| IMO Stability Criteria                      | MinValue | Sangihe | Kisar  | Nias   | Units |
|--------------------------------------------|----------|---------|--------|--------|-------|
| 3.1.2.1: Area 0 to 30                      | 3.1513   | 76.5266 | 140.5843 | 186.1437 | m.deg |
| 3.1.2.1: Area 0 to 40                      | 5.1566   | 112.2175 | 200.7027 | 263.9286 | m.deg |
| 3.1.2.1: Area 30 to 40                     | 1.7189   | 35.6909 | 60.1184 | 77.7849 | m.deg |
| 3.1.2.2: Max GZ at 30 or greater           | 0.200    | 3.725   | 6.302  | 8.061  | m     |
| 3.1.2.3: Angle of maximum GZ               | 25.0     | 26.4    | 25.5   | 25.5   | deg   |
| 3.1.2.4: Initial GMT                       | 0.150    | 12.143  | 25.806 | 37.648 | m     |
6.7. Mooring Analysis

The dynamic stability was also considered regarding the loading and unloading operations of the FLSF. During operation, it must remain stable, while FLSF mooring system is used to ensure the FLSF’s optimal operation in locations where natural and environmental conditions are unstable. The FLSF can carry out loading and unloading operations stably with a good mooring system to maintain its position even though it is exposed to environmental influences.

The application of spread mooring was used as a method to determine the FLSF’s dynamic stability. Its analysis was conducted under ULS conditions with collinear loadings, such as wind, current, and wave loads from the same direction. This is in addition to the variations in the direction of loading “inline” and “between the line” for three barge types with varying displacement magnitudes. The analysis was carried out using the same barge mooring system configuration. However, different mooring rope specifications determine whether each barge is safe to operate at its respective location, as shown in Table 9. In this case, the mooring specifications follow the BKI (Indonesian Classification Society) regulations [41].

| Criteria          | Sangihe FLSF | Kisar FLSF | Nias FLSF |
|-------------------|--------------|------------|-----------|
| Length            | 522.5 m      | 577.5 m    | 632.5 m   |
| Diameter          | 66 mm        | 76 mm      | 90 mm     |
| Chain type        | Stud link    | Stud link  | Stud link |
| Quantity          | 4 pcs        | 4 pcs      | 4 pcs     |
| Grade             | KI-R3        | KI-R3      | KI-R3     |
| MBL               | 3761 kN      | 4884 kN    | 6647 kN   |

The first step in the mooring analysis was the barge motion response with the inputted data consisting of the barge’s main dimensions, geometry, mass, moment of inertia, and the wave heading. This step analyzed the RAO (Response Amplitude Operator) tabulation of the barge motion in a six-degree of freedom (6-DoF) barge, namely, the surge, sway, heave, roll, pitch, and yaw as a function of the wave frequency.
The second stage was a mooring system analysis with a spread mooring configuration. It starts with modeling the barge and the entire configuration of the system, covering the overall dimensions of the rope, including the water depth, the wave and wind direction, and several hydrostatic parameters of the barge required for the analysis to be conducted.

The third stage analyzes the tension results on each FLSF, which is still within the allowable limit based on a predetermined reference. According to the planned design, the barge is feasible to operate from a safety perspective.

Table 10 shows the mooring system analysis for the Sangihe FLSF carried out with maximum tension values of 499,395 kN in Line 2 at a load direction of 90° and a minimum breaking load of 3761 kN. The mooring chain has a minimum actual safety factor of 7.53, which meets the criteria set by the BKI (Indonesian Classification Society). This result shows that the mooring chain can guarantee the safety of the FLSF in the implemented area.

Table 10. Mooring Analysis of Sangihe FLSF.

| Description          | Unit | Load Case | 1   | 2   | 3   | 4   | 5    |
|----------------------|------|-----------|-----|-----|-----|-----|------|
| Load Direction       | Deg  |           | 0°  | 45° | 90° | 135°| 180° |
| Heading              |      |           |     |     |     |     |      |
| Surge (X direction)  | m    |           | 0.516 | 0.562 | 0.005 | 0.605 | 0.537 |
| Sway (Y direction)   | m    |           | 0.000 | 0.961 | 1.325 | 0.959 | 0.000 |
| Line1                | kN   |           | 418.121 | 446.318 | 472.125 | 420.871 | 418.812 |
| Line2                | kN   |           | 418.130 | 430.361 | 499.395 | 447.351 | 418.819 |
| Line3                | kN   |           | 414.711 | 451.670 | 499.210 | 426.540 | 413.268 |
| Line4                | kN   |           | 414.717 | 420.938 | 477.064 | 434.941 | 413.260 |
| Minimum Breaking Load| kN   |           | 3761 | 3761 | 3761 | 3761 | 3761 |
| Actual Safety Factor |      |           | 8.99 | 8.33 | 7.53 | 8.41 | 8.98 |
| Min. Safety Factor   |      |           | 2.25 | 2.25 | 2.25 | 2.25 | 2.25 |
| Status               |      |           | Pass | Pass | Pass | Pass | Pass |

Table 11 shows the mooring system analysis for the Kisar FLSF carried out with a maximum tension of 603,287 kN in Line 2 at a load direction of 135° and minimum breaking load values of 4884 kN. The mooring chain has a minimum actual safety factor of 8.10, which meets the criteria set by the BKI (Indonesian Classification Society). This result shows that the mooring chain can guarantee the safety of FLSF when used in the implementation area.

Table 12 shows the mooring system analysis for the Nias FLSF carried out with maximum tension values of 1,339,795 kN in Line 3 at a load direction of 90° and a minimum breaking load of 6647 kN. The mooring chain has a minimum actual safety factor of 4.96, which meets the criteria set by the BKI (Indonesian Classification Society). This result shows that the mooring chain can guarantee the safety of FLSF when used in the implementation area.

Therefore, based on the analysis results, it can be concluded that all the types of FLSF with spread mooring configurations respective to their specifications are safe to operate. This is because the safety factor value for all mooring lines is above the minimum value of 2.25 based on the BKI criteria regarding the operating conditions for mooring lines [42].
Table 11. Mooring Analysis of Kisar FLSF.

| Description                  | Unit     | Load Case |
|------------------------------|----------|-----------|
| Load Direction               | Deg      | 0°  45°  90°  135°  180° |
| Heading                      |          |           |
| Surge (X direction)          | m        | 1.253 1.132 0.004 1.123 1.176 |
| Sway (Y direction)           | m        | 0.000 1.795 2.122 1.618 0.000 |
| Line1                        | kN       | 561.071 582.105 591.073 553.126 560.674 |
| Line2                        | kN       | 561.065 556.664 600.881 603.287 560.681 |
| Line3                        | kN       | 556.165 577.426 602.928 551.785 547.605 |
| Line4                        | kN       | 556.170 556.562 595.879 585.938 547.594 |
| Minimum Breaking Load        | kN       | 4884 4884 4884 4884 4884 |
| Actual Safety Factor         |          | 8.70 8.39 8.10 8.10 8.71 |
| Min. Safety Factor           |          | 2.25 2.25 2.25 2.25 2.25 |
| Status                       |          | Pass Pass Pass Pass Pass |

Table 12. Mooring Analysis of Nias FLSF.

| Description                  | Unit     | Load Case |
|------------------------------|----------|-----------|
| Load Direction               | Deg      | 0°  45°  90°  135°  180° |
| Heading                      |          |           |
| Surge (X direction)          | m        | 0.094 0.127 0.001 0.114 0.092 |
| Sway (Y direction)           | m        | 0.000 0.287 0.515 0.280 0.000 |
| Line1                        | kN       | 1154.050 1163.869 1280.484 1162.461 1161.172 |
| Line2                        | kN       | 1152.741 1172.292 1335.384 1173.776 1159.823 |
| Line3                        | kN       | 1150.168 1174.623 1339.795 1163.066 1151.578 |
| Line4                        | kN       | 1151.388 1164.234 1274.202 1159.948 1152.716 |
| Minimum Breaking Load        | kN       | 6647 6647 6647 6647 6647 |
| Actual Safety Factor         |          | 5.76 5.66 4.96 5.66 5.72 |
| Min. Safety Factor           |          | 2.25 2.25 2.25 2.25 2.25 |
| Status                       |          | Pass Pass Pass Pass Pass |

7. Conclusions and Recommendations

7.1. Conclusions

Transportation is the main component in the maritime logistics system that ensures that goods are distributed optimally. Transportation quality in supporting maritime logistics is critical in developing global economy, because majority of goods transported by sea freight. Similarly, developing a sustainable logistics system will likely improve economic while considering the environment’s carrying capacity. There is limited research on economic development in remote islands, despite its importance.

Based on the study case results for the Floating Logistics Supporting Facility (FLSF) operations in the Kisar, Nias, and Sangihe areas in Indonesia, this system can be the solution to improving the quality of logistics operations and increasing economic growth in remote
islands. The FLSF has four main functions: cargo loading and unloading facilities, water and fuel bunkering, passenger accommodation, and cargo storage. The FLSF will be used as a floating terminal that accommodates the loading and unloading operations of cargo and its storage. It also acts as a logistics terminal hub capable of facilitating cargo distribution in and out of small islands. This system is also designed to use propulsion with a speed up to 4 knots, equipped with one crane consisting of SWL 30 tons. There are three main sizes of FLSF design, with a payload capacity of around 10,000 tons, 20,000 tons, and 30,000 tons. The fuel bunker system will promote renewable and environmentally friendly energy for ships operating around residents on remote islands.

The analysis results showed that the FLSF can operate for logistics activities while considering safety and sustainability factors. The general arrangement and hydrostatic specifications of the FLSF meet the BKI (Indonesian Classification Society) requirements, which regulate the strength during the construction phase. Its stability has also met the requirements of IMO A.749(18) Ch3, which ensures safety when moving cargo. The FLSF’s mooring specifications have been defined to keep the mooring operation running safely and to ensure that it does not shift position. During an emergency, the FLSF also has an independent propulsion system that allows it to move away from the danger zone.

Based on the conducted analysis, FLSF’s suitable for application in the implementation areas and meets the safety, stability, mooring, and cargo capacity required by the surrounding communities. With the technical advantages of this FLSF, a solution for the availability of integrated sustainable logistics infrastructure in remote islands will be realized.

7.2. Recommendations for FLSF Implementation

Various models of FLSF management can be carried out on numerous patterns that can be determined based on the initiatives offered by the government, public institutions, or private entities. The following are some of the various schemes:

1. The FLSF was built by government initiative and operated as part of a public-obligation business entity.
2. It can be either fully or partially funded from private company as part of a business actor’s initiative and can be granted concessions to provide cargo and passenger services for a certain period. These include providing fleet with operational human resources through the central or local governments.
3. The government provides the pattern of Cooperation between the public and private companies in the scheme of asset management cooperation through joint operation (asset sharing).
4. The pattern of leasing private companies to the government or vice versa.

In general, the implementations of policies that support the realization of FLSFs in remote islands need to be carried out in three stages, namely, short (2022–2024), medium (2025–2030), and long (2030–2040) terms. Details of the achievement agenda for each stage are shown in Figure 13:

Figure 13 shows that several policies are needed to implement the provision of FLSFs to encourage the development of resource exploration, population mobilization, and trade in remote island areas. The FLSF support important sectors on remote islands, especially fisheries, aquaculture, mining, animal husbandry, plantations, and regional creative industries that are attractive to national and international markets. Furthermore, establishing good and efficient policies increases the regional connectivity between islands, districts, cities, and nearby provinces for regional economic development.

This research is still in the early stages of designing a sustainable floating logistics facility that can coordinate several remote islands and connect them with national and international trade routes. Therefore, several studies can be conducted to further improve the sustainable logistics systems in remote areas, such as making more complex technical designs to improve the features and quality of FLSF. Others include making technical regulations and policies related to floating infrastructure; creating integrated logistics
systems that connect land, water, and air logistics; and improving human resources for the future operation of the FLSF.

Figure 13. Plan of FLSF Implementation Policies.

By conducting continuous research in developing integrated logistics systems, and especially by manufacturing FLSFs, solution will be realized to overcome the limitations of the geographical conditions and thereby improve remote island populations’ economy and welfare in remote island.

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