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Optimizing Pioneer Vessel Efficiency: Empirical Insights and Mini-Container Integration in Remote Maritime Transport

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ABSTRACT

Pioneer vessels operating in the 3T regions of Indonesia (considered the most remote and underdeveloped areas) are a preferred mode of transportation among local communities. This preference stems from the comprehensive facilities offered by these vessels and their cost-effective voyage rates compared to other public maritime transport options. The affordability of these rates is largely attributed to governmental subsidies. However, optimizing the operational efficiency of these pioneer vessels is necessary, particularly in terms of vessel design and cargo handling, as there exists a discrepancy between the vessels' capacity and their actual utilization. Hence, this study aims to determine the optimal capacity of pioneer vessels based on empirical cargo transport data and improve cargo space efficiency through the implementation of a mini-container packaging system. The research adopts a quantitative approach, gathering data concerning passenger and cargo transport on the R-36 pioneer shipping route annually. Subsequently, this data is processed to forecast the vessel's capacity requirements for the upcoming five years. Upon acquiring these capacity estimates, the study progresses to the vessel design phase, incorporating a mini-container packaging system. The findings indicate an estimated optimal capacity of 160 passengers and 170 tons for cargo transport on the R-36 route.

1. Introduction.

Given Indonesia's extensive archipelago, a robust maritime transportation system is indispensable to interconnect every large and small island across its entirety [1]. One of the crucial modes of sea transportation that plays a significant role in connecting the islands of Indonesia is pioneer shipping [2]. Pioneer shipping itself is a transportation service on water routes designated by the Government to serve areas or regions that are not yet or not served by water transportation because they have not provided commercial benefits [3]. This pioneer shipping aims to connect the islands in Indonesia [4], especially in the 3T regions (frontier, underdeveloped, and outermost), so they can be linked with other major islands.

As the number of pioneer vessels increases, it is anticipated that the duration of a single voyage will become progressively shorter [5]. At present, numerous government-owned pioneer vessels are utilized to extend transportation subsidies to local communities. These subsidies are essential due to the relatively low-income levels in these regions. Without such support, the local populace might be unable to access the provided maritime transportation services. Consequently, the government must allocate funds for the operational requirements, maintenance, and personnel salaries associated with these vessels. This allocation is critical, as any financial challenges could lead to operational disruptions. This was exemplified in 2020 when nearly all pioneer shipping in Indonesia experienced budget reductions owing to the COVID-19 pandemic. These reductions resulted in the suspension of pioneer vessel operations in multiple locations [6]. To optimize the operational efficiency of pioneer vessels, a comprehensive analysis of passenger/cargo transportation and voyage durations across designated routes is essential. This study aims to align sailing schedules with regional

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demands, thereby ensuring cost-effective ship operations while adequately meeting the community's needs.

The establishment of pioneer shipping services is crucial and justifiable to support regional development and enhance transportation accessibility to small islands [7]. Furthermore, pioneer vessels play a crucial role in the distribution of goods in remote areas. The distribution of cargo within the 3T regions cannot utilize large container ships due to inadequate port facilities, which are not equipped to accommodate vessels with significant drafts. Consequently, the distribution system relies on smaller cargo ships that carry goods placed within the holds of the vessel. Presently, cargo is predominantly loaded in sacks or wooden packaging. The absence of standardized cargo protection measures can result in losses for both cargo owners and the vessels themselves. Poorly packaged items risk damage from being buried or coming into contact with other cargo, potentially reducing the ship's load due to irregular cargo placement.

Given the array of issues delineated earlier, there exists a necessity for a comprehensive study or investigation pertaining to the optimization of pioneer vessel design aligned with specific shipping routes. This aims to streamline both passenger and cargo transportation, thereby bolstering cost efficiency in the procurement and utilization of such vessels. Beyond the realm of ship design, the establishment of a standardized management system for pioneer vessel cargo transportation becomes imperative. This system is integral for the preservation and safeguarding of cargo, concurrently enhancing the efficacy of loading and unloading procedures aboard pioneer vessels.

Numerous studies have extensively explored various aspects of pioneer shipping. These encompass research focused on the strategic planning of fleet requirements for pioneer vessels [8], redesigning pioneer vessels [9], creating designs tailored for specific routes [10], and addressing operational intricacies of pioneer shipping [11]. Among the conducted research, the realization of pioneer shipping according to actual data and conditions for a specific route is still rarely considered in ship design. Additionally, the concept of cargo packaging using mini-containers for use in pioneer shipping has not been widely discussed in existing literature. Therefore, this study aims to determine the optimal capacity of pioneer vessels based on empirical cargo transport data as empirical insight and improve cargo space efficiency through the implementation of a mini-container packaging system.

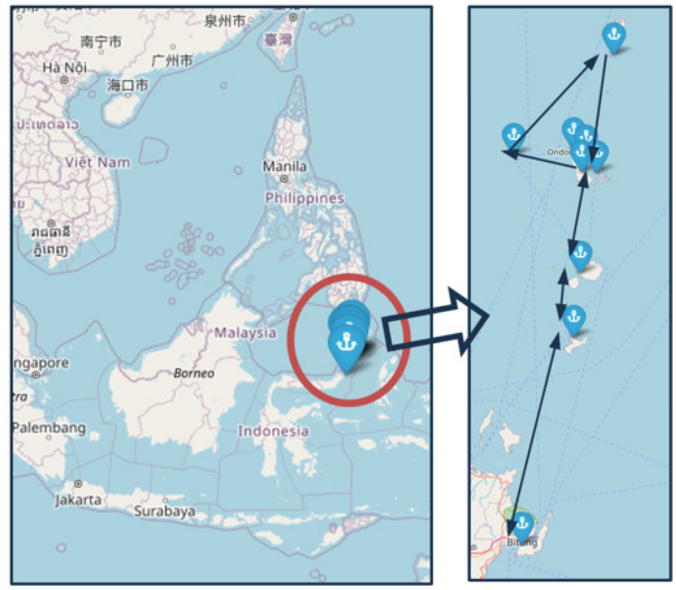
2. Methodology.

This study addresses existing issues by focusing on the design of a pioneering vessel tailored for a specific route, taking into account transport realization. The study focuses on the pioneer vessel route known as R-36, with Bitung Port serving as its main terminal (Figure 1).

The detail route is "*Bitung – Biaro – Tagulandang – Buhias – Sawang Siau – Ulu Siau – Makalehi – Pehe – Para – Ulu Siau – Buhias – Tagulandang – Biaro – Bitung*" [12].

The resultant design aims for optimality, aligning precisely with the stipulated requirements. The ship design process commences with the preliminary design phase, culminating in a proposed design compared against existing vessels. This design process includes the integration of packaging and cargo handling considerations. As a result, the proposed design not only matches optimal capacity or aligns with transport realization but also incorporates an efficient cargo system design. Subsequently, the resulting design will undergo comparative analysis with ships currently operating on the targeted sailing route. Should it meet the predefined design criteria, the subsequent stage involves determining the fleet configuration for the intended sailing route, encompassing considerations such as sailing frequency and fleet size. Upon completion of all stages, conclusive remarks will be drawn based on the outcomes derived from the design process.

Figure 1: Pioneer Vessel Route (R-36).



Source: Author.

3. Result and Discussion.

3.1. Transport Realization.

Dataset regarding transport realization along the R-36 route is crucial for determining the vessel's cargo capacity. This transport realization dataset encompasses the counts of boarding and disembarking passengers, as well as the quantity of loaded and unloaded cargo. Figure 2 & 3 and Figure 4 & 5 provided below illustrate the transport realization data spanning from 1996 to 2021 for the pioneer vessel route R-36.

Projections of transportation capacity requirements for the upcoming five years were derived through the utilization of exponential smoothing forecasting and linear regression methods applied to the existing transport realization data. The linear regression analysis involved the following computations:

$$a = \overline{y} - b\overline{x} \tag{1}$$

$$b = \frac{\sum (x - \overline{x})(y - \overline{y})}{\sum (x - \overline{x})^2} \tag{2}$$

where:

$\overline{y}$ = response variabel

$\overline{x}$ = predictor variabel

a = constant

b = regression coefficient

For exponential smoothing, the following calculation is employed:

$$F_t = \alpha A_{t-1} + (1 - \alpha) F_{t-1} \tag{3}$$

where:

F_t = estimated value

α = smoothing constant

A_{t-1} = previous period actual value

F_{t-1} = previous period estimated value

Validation of forecast using the Mean Absolute Percentage Error (MAPE) method [13]. Calculation of MAPE using the following equation:

$$MAPE = \frac{100\%}{n} \sum_{t=1}^{n} \left| \frac{A_t - F_t}{A_t} \right| \tag{4}$$

where:

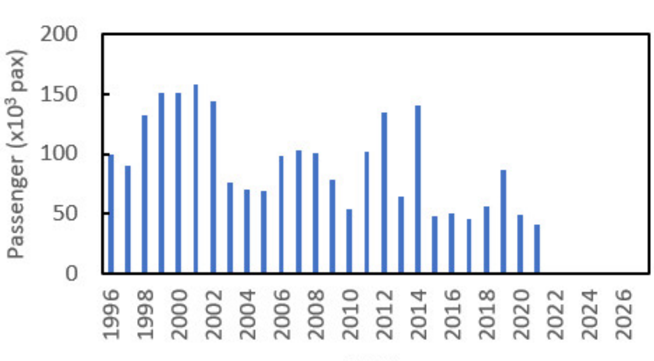
MAPE = Mean Absolute Percentage Error

n = number of data

A_t = actual value

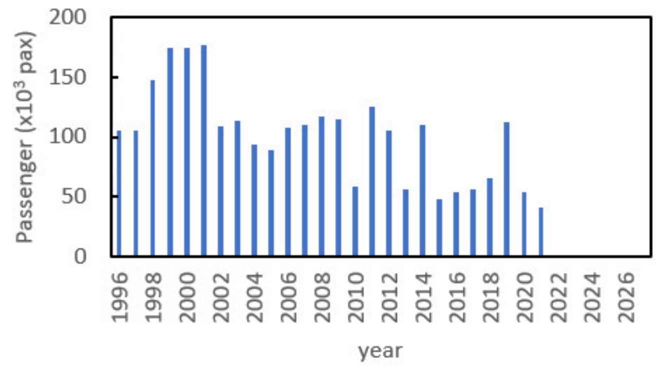
F_t = estimated value

Figure 2: Passenger transport realization (boarding).



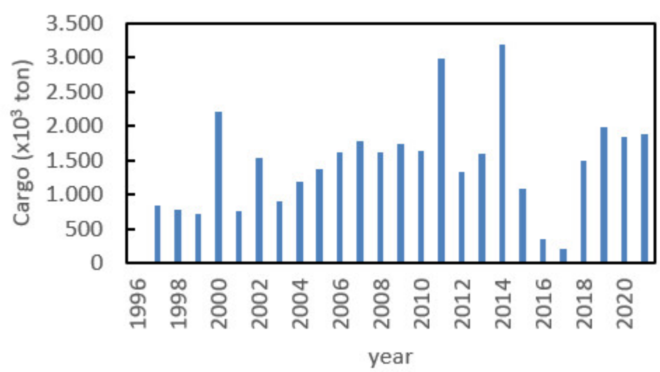
Source: Authors.

Figure 3: Passenger transport realization (disembarkation).



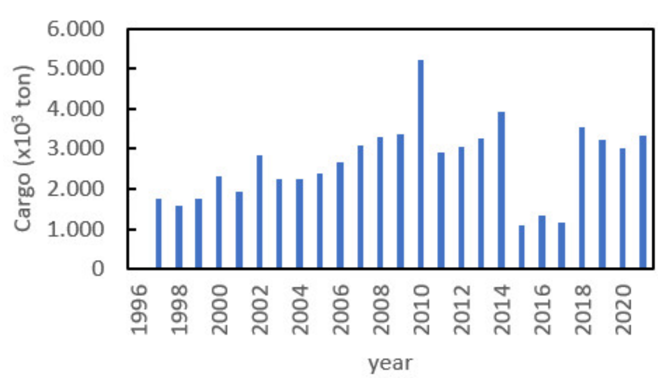
Source: Authors.

Figure 4: Cargo transport realization (loading).



Source: Authors.

Figure 5: Cargo transport realization (unloading).



Source: Authors.

Table 1 shows the MAPE values from the forecasting results.

3.2. *Ship Capacity Determination.*

Some shipping data for route R-36 is used to determine the capacity of the ship. These data is displayed in Table 2.

Based on the input of these data, the calculation of the required capacity of the ship is carried out for both passenger capacity and cargo capacity using the following equations, where

Table 1: MAPE values from the forecasting results.

Forecast Method	Passenger transport (boarding)	Passenger transport (disembarkation)	Cargo transport (loading)	Cargo transport (unloading)
Exponential Smoothing	7.57%	5.83%	3.96%	5.13%
Regresi Linear	7.57%	20.88%	8.81%	6.18%

Source: Authors.

HPTR stands for Highest Passenger Transport Realization, and HCTR stands for Highest Cargo Transport Realization.

$$Passenger\ capacity = \frac{HPTR}{Total\ Voyage \times Number\ of\ Ship} \quad (5)$$

$$Cargo\ capacity = \frac{HCTR \times Load\ Factor}{Total\ Voyage \times Number\ of\ Ship} \quad (6)$$

Table 2: Shipping Data.

Data	Value	Unit
Voyage duration	22	Days
Average Docking Time	21	Days
Number of voyages in a year	15	Voyages
The forecasted number of passengers (total boarding next 5 years)	2,874	Pax
The forecasted number of passengers (total disembarkation next 5 years)	4,675	Pax
The forecasted number of cargo (total unloading next 5 years)	7,346	Ton/m3
The forecasted number of cargo (total loading next 5 years)	10,542	Ton/m3
Number of ships	2	Ship
Load factor	0.5	

Source: Authors.

Thus, the capacity of the ship is obtained in accordance with the realization of passenger and cargo transportation for the next 5 years, as shown in Table 3.

Table 3: Ship capacity according to realization of transportation.

Capacity	Value	Unit
Passenger	160	Pax
Cargo	170	Ton

Source: Authors.

3.3. Design of the Pioneer Vessel.

In the ship design process, the comparative ship method is employed to determine the main dimensions of a vessel. In this method, a similar ship, *KM. Sabuk Nusantara 58*, is used as a reference. The comparative ship factor formula is utilized to derive the main dimensions of the vessel, as illustrated in the following calculation:

$$Comparative\ ship\ factor\ (\lambda) = \sqrt[3]{\frac{\Delta 2}{\Delta 1}} \quad (7)$$

where:
λ = comparative ship factor
$\Delta 1$ = displacement of the reference vessel
$\Delta 2$ = displacement of the designed vessel

The displacement variable in the formula can be manipulated to represent cargo capacity, passenger capacity, ship dimensions, or ship weight. Consequently, data for the designed vessel is obtained, as shown in Table 4.

Table 4: Data for the designed vessel.

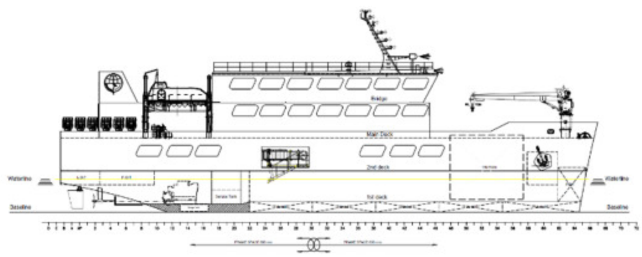
Item	Value	Unit
Displacement	640.491	ton
LOA	41.1	m
LWL	40.1	m
LPP	38.67	m
B	10.37	m
H	5.6	m
T	2.5	m
Prismatic coeff. (Cp)	0.738	-
Block coeff. (Cb)	0.615	-
Max Sect. area coeff. (Cm)	0.836	-
Waterpl. area coeff. (Cwp)	0.843	-
Speed	12	knot
	6.69	m/s

Source: Authors.

Subsequently, the hull design process was undertaken utilizing the Maxsurf Modeller software. Figure 6 depicts the general plan of the vessel's side view. Following the creation of the design, a comprehensive analysis was conducted to assess the ship's resistance, stability, and maneuverability. For a vessel operating at an efficiency of 46% and a speed of 13 knots, the calculated hull resistance was determined to be 52.3 kN, while the required power consumption amounted to 759.826

kW. To counteract this resistance, the vessel utilizes two YANMAR 6EY17W 480kW engines.

Figure 6: Vessel's side view.



Source: Authors.

Ship stability simulations were conducted under three loading conditions: full load (100%), half load (50%), and empty load (0%). The longitudinal balance or trim of the ship for each loading condition is presented in Table 5.

The stability criteria of IMO A.749(18) Ch 3 – Design criteria applicable to all ships were applied, and the results were found to be in compliance with the criteria for all loading conditions.

Ship handling simulations were performed at wave heights corresponding to sea states 2, 3, and 4. The wave heights were selected based on the actual conditions of the pioneer ship's operating area. Ship speeds of 8 knots, 12 knots, and 14 knots were considered. At a speed of 8 knots, the ship exhibited good comfort levels under the sea state 2 and 3 conditions. Under the sea state 4 conditions, the ship experienced moderate discomfort levels at wind directions of 180, 150, and 120 degrees. The highest discomfort level was observed at a speed of 14 knots under the sea state 4 conditions with a wind direction of 180 degrees.

Table 5: Longitudinal balance (trim) of the vessel.

	Full Load 100%	**Half Load 50%**	**Empty Load 0%**
Trim by Stern (m)	0.026	0.045	0.73
Trim degree	0.037	0.064	1.04

Source: Authors.

3.4. Mini-Container Packaging System.

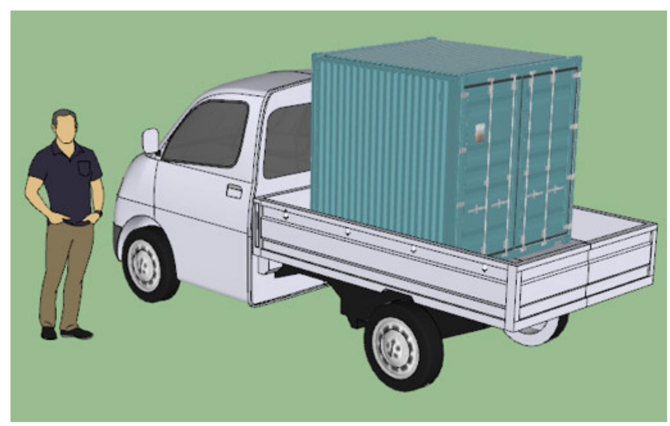
The selection of an appropriate mini-container packaging system for pioneer vessels hinges on several critical factors, including cargo capacity, loading and unloading capabilities, and cargo handling ease. Considering these factors, the design of mini-container packages in 6ft and 8ft sizes was undertaken. While these sizes are readily available in the market, their dimensions remain too large for efficient transportation using pickup trucks, a common cargo handling method. Consequently, calculations were performed to determine the optimal mini-container dimensions that align with effective cargo handling practices. To achieve this goal, a scaling procedure was employed, applying Formula 8 to adjust the dimensions of the 6ft mini-container to match the cargo dimensions of a pickup truck.

$$Scale\ factor = \frac{B_k - f_k}{B_c} \tag{8}$$

where:
B_k = pickup truck width (m)
f_k = safety factor
B_c = 6 ft container width (m)

Based on the calculation results, the dimensions of the mini-container packaging were determined to be 1.277 meters in length, 1.361 meters in width, and 1.344 meters in height. A visual representation of the mini-container is provided in Figure 7.

Figure 7: Visual representation of the mini-container packaging.



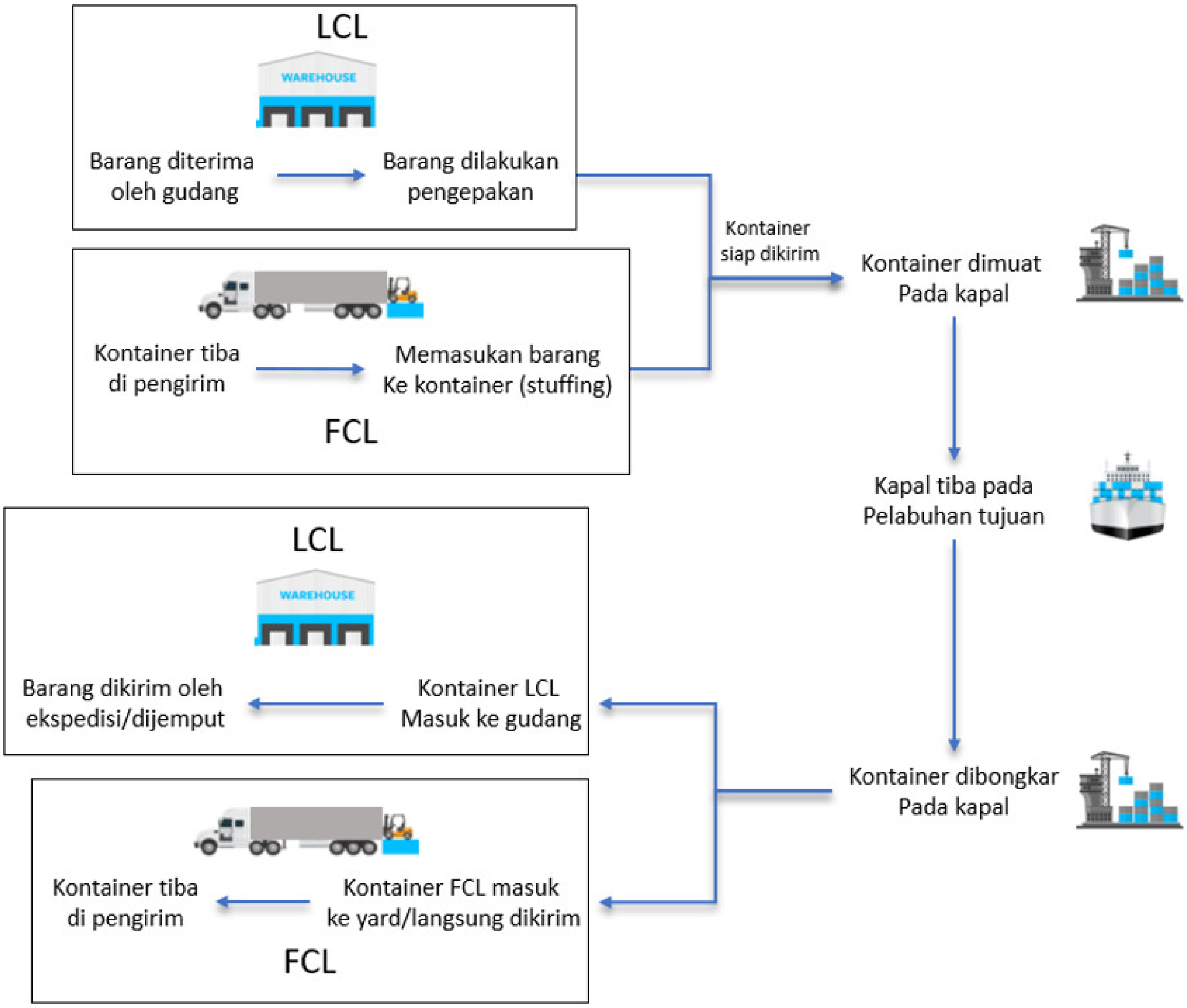
Source: Authors.

The proposed mini-container design is capable of being transported on a specially designed vessel with a maximum capacity of up to 36 mini containers, arranged in a 3-row, 4-bay, and 3-tier configuration. The mini-container loading and unloading system utilizes a crane mounted on the vessel, facilitating movement between the ship and the dock. Upon reaching the dock, mini-containers can be transferred to either forklifts or pickup trucks for further transportation. The logistics process for mini-containers can employ either the Full Container Load (FCL) or Less Container Load (LCL) systems, as illustrated in Figure 8.

Conclusions.

Current pioneer vessels on route R-36 have a capacity of up to 466 passengers and a maximum cargo load of 100 tons. However, based on calculations of transport realization at Bitung Port, the optimal capacity for pioneer vessels is 160 passengers with a cargo capacity of up to 170 tons. This value was obtained from estimates for the next five years. Additionally, the

Figure 8: FCL and LCL mini-container loading and unloading process flow.



Source: Authors.

appropriate ship dimensions were determined to be LOA = 41.1 m, B = 10.7 m, T = 2.5 m, and H = 5.6 m. These dimensions were derived from calculations of existing comparable vessels. Furthermore, the main dimensions of the designed vessel were adjusted to accommodate the shipping route's wave heights of up to sea state 4.

For the use of mini-containers on pioneer vessels, the designed vessel can carry up to 36 mini-containers arranged in 3 rows, 4 bays, and 3 tiers. The dimensions of each mini-container are 1.277 m for length, 1.361 m for width, and 1.344 m for height. These dimensions were determined based on the ease of handling mini-containers.

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