The Conceptual Design of Ferry ro-ro Based on Operation Pattern

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Abstract

Ro-ro ferry crossing routes in several Indonesian locations frequently face the constraint of prolonged vehicle queues during specific periods, such as long holidays and major religious festivals. The short Bengkalis-Sungai Pakning crossing route is one of the ferry ports that very often encounters this problem. The conceptual design takes into the some of the Short Sea Shipping (SSS) factors. A viable medium-term solution is to construct a new ro-ro ferry with a capacity tailored to operational demands, which can be determined by analyzing current operational patterns. Operational pattern data are derived from queue duration, vehicle waiting time, and existing vessel data. In this study, the main ship characteristics were obtained by analyzing these operational patterns, yielding a vessel payload of payload 79 tons, overall length 30 m, width 8 meters, height 3.5, draft 2.2, service speed 10 knots for a voyage duration of 1 hour.

Keywords : Ferry; Ro-ro; Vessel; Design

1. INTRODUCTION

The primary mode of transportation for vehicles entering and exiting Bengkalis Island is the Ro-Ro ferry operating on the round-trip Bengkalis-Sungai Pakning route, which is classified as a short voyage covering approximately 10.3 nautical miles. According to data from the Dinas Perhubungan, vehicle crossings are restricted to at least 300 four-wheeled units during long holidays. The problem arises when the number of crossing vehicles increases significantly, but the number of operating vessels does not, resulting in prolonged vehicle queues and congestion that can last for several hours, potentially exceeding 10 hours. The Bengkalis Regional Government has implemented several measures to minimize these long queues, including adding more vessels to the fleet, enforcing a 24-hour crossing schedule, and controlling traffic using odd-even license plate restrictions and queue-limit quotas. While these efforts are deemed highly effective in shortening waiting times during long holidays, they pose a constraint during normal days because the limited vehicle volume carried leads to financial losses. Therefore, one viable solution to this issue is the design and construction of a new Ro-Ro ferry tailored to operational demands. Before determining the main dimensions and cargo capacity of such a vessel, a detailed study is necessary. A survey must be conducted to determine the vehicle volume corresponding to the tolerable queuing time. The ultimate goal is to establish the required vehicle throughput to accurately calculate the cargo capacity, layout, and main dimensions of the ship

In Indonesia, Ro-Ro ferry vessels typically transport passengers and vehicles over short distance routes (Ardi, 2021). Determining the vessel's main dimensions including length, breadth, height, draft, and speed based on operational patterns, considering both queuing and vessel sailing efficiency is expected to yield more optimal results. Furthermore, the payload capacity, particularly for all types of four wheeled vehicles, is determined based on a maximum assumed queuing time of 30 minutes, which aims to improve efficiency in waiting duration. The Bengkalis-Sungai Pakning crossing has a sailing distance of approximately 3 to 5 nautical miles, classifying it as a short-distance route.

2. REVIEW OF LITERATURE

2.1 The design of the monohull ship's hull form utilizes NAPA® software to achieve optimal results. Design considerations encompass the ship's propulsion power, cargo capacity, and economic feasibility. The planned Ro-Ro passenger ferry is characterized as a high-speed vessel (Skoupas *et al*.,2019).

2.2 The optimization of the hull form aims to conserve fuel consumption by analyzing the ship's speed, draft, and maneuverability. Minimizing ship resistance renders the hull form more effective, leading to a more efficient operational use (Adam *et al*.,2024)

2.3 This study employs the fuzzy method to determine the ship's principal dimensions; however, its application is limited to bulk carriers and does not include a comparison with alternative decision-making methods. (Jianping *et al*.,2016)

2.4 This research is fundamentally focused on the creation of a structured flow diagram model to guide the optimization process for ferry design. The primary objective is to enhance the vessel's configuration by systematically accounting for three critical external factors like prevailing demand conditions, existing port infrastructure, and specific oceanographic data. As a quantitative investigation, the study employs a rigorous optimization methodology, utilizing linear programming as its core computational technique. Within this model, a defined objective function is established with the explicit goal of minimizing the ferry's operational expenditures (Noegraha *et al*, 2013)

2.5 The research methodology for this study was structured around two primary components. Initially, a field study was conducted to meticulously observe and establish the vessel's operational patterns. Subsequently, technical data was gathered from a comparable waterbus already servicing the Kangean Islands to serve as a benchmark. For the core naval architectural phase, the principal dimensions of the new waterbus were determined through the application of the linear regression method, a statistical technique used to model relationships between key ship parameters (Awwalin *et al*.,2022)

3. METHOD

This study aims to solve the problem of constantly fluctuating cargo loads on ferry roro at specific times. The Bengkalis-Sungai Pakning ferry crossing serves as the case study for this issue. Planning for a new vessel, which is proposed as a solution, is performed by considering operational data from both the port and the existing fleet. The operational data, including vehicle queue patterns, vessel load data, ship speed data, and others were analyzed to determine the optimal payload that accommodates the vehicle volume queuing every 30 minutes. This 30 minute interval was derived from respondent data obtained from a distributed questionnaire, which 354 responses by this link https://forms.gle/huVQHerCEdHHVeMc8.

4. RESULT & DISCUSSION

Operation Pattern Data

The operational pattern data in this study consist of the number of vehicle queues recorded every 30 minutes at both the Bengkalis and Sungai Pakning ports, and were collected as primary data directly from the field. Queue samples were taken over a 7-day period within the vessel's operational hours, specifically from 06:00 AM to 11:30 PM Western Indonesian Time (WIB) daily. The survey results, presented in Table 1 and Table 2, were then used to calculate the average number of vehicles queuing per day and per 30-minute interval. Vehicle queue data will be calculated on average based on time per 30 minutes and the average number of vehicle queues per day using the following general equation.

$$\bar{x} = \frac{\sum x}{n} \quad \text{.........................(1)}$$

The description:
$\bar{x}$: Average number of vehicles per day
$\sum x$: Number of vehicles per day
n : Number of samples

Table 1. Average number of queues at the Ro-ro port of Air Putih Bengkalis

No	Day	Number of sample per 30 minutes (06.00 WIB s.d 23.30 WIB)	Number of Vehicle Per day	Average of Vehicle Per 30 minute
1	Tuesday	36	233	6
2	Wednesday	36	242	7
3	Thursday	36	239	7
4	Friday	36	220	6
5	Saturday	36	195	5
6	Sunday	36	219	6
7	Monday	36	159	4
			Overall Average	**6**

Table 2. Average number of queues at the Ro-ro port of Sungai Selari Pakning

No	Day	Number of sample per 30 minutes (06.00 WIB s.d 23.30 WIB)	Number of Vehicle Per day	Average of Vehicle Per 30 minute
1	Tuesday	36	440	12
2	Wednesday	36	525	15
3	Thursday	36	373	10
4	Friday	36	530	15
5	Saturday	36	901	25
6	Sunday	36	218	6
7	Monday	36	512	14
			Overall Average	**14**

Based on the data in Table 1 and Table 2, it can be seen that the average number of vehicles queuing every 30 minutes every day is 6 (six) vehicles at Air Putih Bengkalis Port. Meanwhile, the number of vehicles queuing every 30 minutes every day at Sei Selari Sungai Pakning Port is 14 units. Here, the difference in the number of queues on both sides of the port is clearly 3:7. The number of two wheeled vehicles is made in a balanced ratio with four wheeled minicars is 1:1 when based on survey data, the average number of two wheeled vehicles queuing every 30 minutes is 10 units. The capacity of Ro-Ro (Roll-on/Roll-off) ferries in Indonesia is adjusted to the capacity standards of the ports they serve. (Fachrudin et al.,2022)

Table 3. Payload Analysis

No.	**Vehicle Type**	**Full Load (Ton)**		**Vehicle Length**	**Quantity**	**Total Weight**
		Range	**Used**	**(m)**	**(Unit)**	**(Ton)**
1	Motorcycles <500cc and Handcarts	0.15−0.20	0.2	2	14	2.8
2	Passenger Vehicles (Jeep, minicars, minibus) up to 5 meters in length	1.8−2.0	2	≤ 5	10	20
3	Motorcycles >500cc and Three-wheeled vehicles	0.35−0.45	0.45	2 − 3	1	0.45
4	Passenger Vehicles (Bus) 5 to 7 meters in length (25-30 seats)	8.0−10.0	10	5 − 7	1	10
5	Heavy Cargo Vehicles (Tronton, Trailer, Heavy Equipment 12−16 m)	30−45	45	12 − 16	1	45
6	No vehicle / Passengers only	The quantity could not be detected because so many passengers were included with their accompanying vehicles				-
7					**Total**	**78.25**

Design of the Ship

The initial principal dimension for the ship was obtained based on its payload, which was 78.25 tons. A ship model was then created using this initial data, taking into account various aspects, one of which was ship stability. Ship stability refers to the IMO criteria for passenger ships A.749(18) Ch3 - These are the fundamental design standards and principles that must be followed during the construction of every type of sea-going vessel. The principal dimension and hull were obtained using a hull analysis method that addresses ship stability. If the ship's stability meets these criteria, the principal dimension can be used as a baseline for hull shape and layout design. The layout of the vehicles, passenger room, and other ship components is planned on the general arrangement. After obtaining this layout, the hull of the ship is drawn on the lines plan. The hull is based on the hull of a typical roll-on-roll-off (RO-RO) ferry, particularly the shape of the vessels currently operating on the Bengkalis-Pakning River crossing. The basic design consists of the concept phase and the preliminary design. (Cepowski etc.,2021). Ensuring the comfort of both crew and passengers is a fundamental and primary design objective that is critically integrated into the development of ferry vessels (Suastika et.al, 2018)

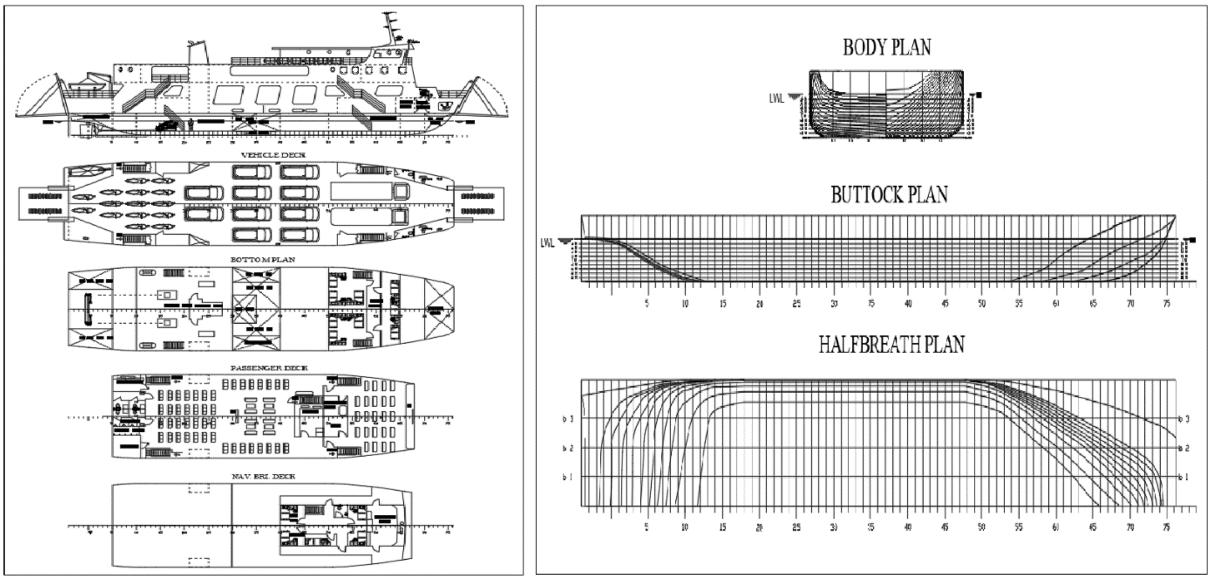

Figure 1. Design of General Arrangement and Lines Plan

Figure 1 These are general arrangement and line plans that meet standard stability criteria. As a first step in further analysis, these two drawings can be used for maneuver analysis, principal dimension optimization, maneuver analysis, and other. Technical analysis starts from determining the ship's load to designing a 3D model by determining the Ro-Ro ship's load in the form of the number of passengers, vehicles and luggage. (Wibawa, 2017).

The stability of ship can be seen with several condition:

a. Loadcase 1 : 100% Fuel oil, 100% payload, 0% water ballast
b. Loadcase 2 : 50% Fuel oil, 100% payload, 0% water ballast
c. Loadcase 3 : 10% Fuel oil, 100% payload, 0% water ballast
d. Loadcase 4 : All 0% condition

Table 4a. The status of stability of the loadcase

Criteria	Value	Units	Loadcase-1		Loadcase-2		Status
			Actual	Margin %	Actual	Margin %	
3.1.2.1: Area 0 to 30	0,0550	m.rad	0,5590	+916,36	0,5934	+978,94	Pass
3.1.2.1: Area 0 to 40	0,0900	m.rad	0,7996	+788,46	0,8532	+848,00	Pass
3.1.2.1: Area 30 to 40	0,0300	m.rad	0,2406	+702,02	0,2598	+765,90	Pass
3.1.2.2: Max GZ at 30 or greater	0,200	m	1,477	+638,50	1,590	+695,00	Pass
3.1.2.3: Angle of maximum GZ	25,0	deg	24,5	+1,82	24,5	+1,82	Pass
3.1.2.4: Initial GMt	0,150	m	5,116	+3310,67	5,313	+3442,00	Pass
3.1.2.5: Passenger crowding: angle of equilibrium	10,0	deg	0,0	+100,00	0,0	+100,00	Pass
3.1.2.6: Turn: angle of equilibrium	10,0	deg	0,0	+100,00	0,0	+100,00	Pass

Table 4b. The status of stability of the loadcase

Criteria	Value	Units	Loadcase-3		Loadcase-4		Status
			Actual	Margin %	Actual	Margin %	
3.1.2.1: Area 0 to 30	0,0550	m.rad	0,6152	+1018,45	0,7329	+1232,49	Pass
3.1.2.1: Area 0 to 40	0,0900	m.rad	0,8855	+883,92	10,735	+1092,78	Pass
3.1.2.1: Area 30 to 40	0,0300	m.rad	0,2704	+801,21	0,3406	+1035,38	Pass
3.1.2.2: Max GZ at 30 or greater	0,200	m	1,656	+728,00	2,044	+922,00	Pass
3.1.2.3: Angle of maximum GZ	25,0	deg	24,5	+1,82	25,5	+1,82	Pass
3.1.2.4: Initial GMt	0,150	m	5,451	+3534,00	6,333	+4122,00	Pass
3.1.2.5: Passenger crowding: angle of equilibrium	10,0	deg	0,0	+100,00	0,0	+100,00	Pass
3.1.2.6: Turn: angle of equilibrium	10,0	deg	0,0	+100,00	0,0	+100,00	Pass

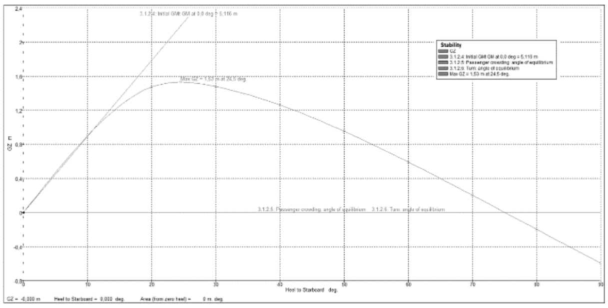

Fig 1. Loadcase 1

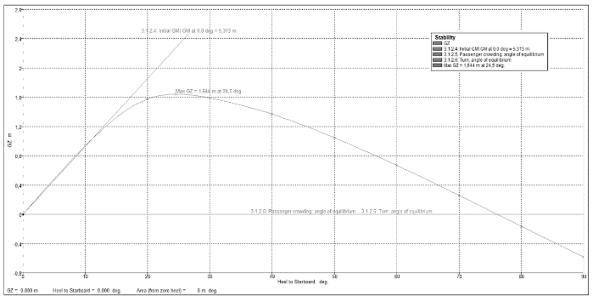

Fig 2. Loadcase 2

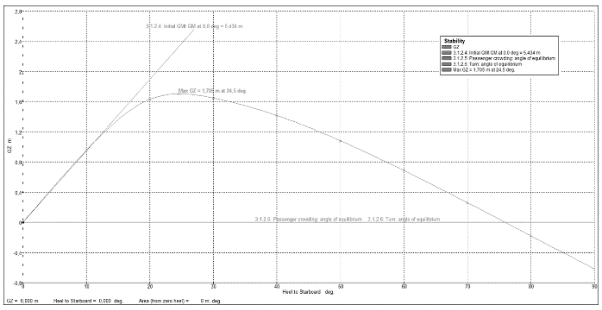

Fig 3. Loadcase 3

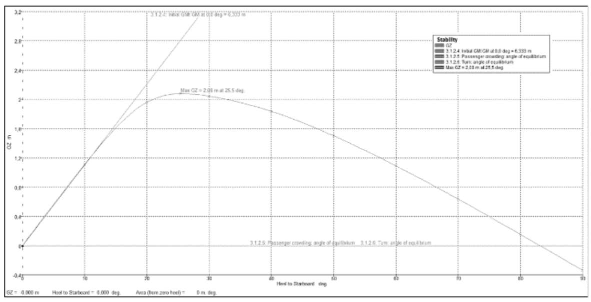

Fig 4. Loadcase 4

Based on layout planning, line plans and stability analysis, the following data information was obtained for the ro-ro ferry:

a. LoA	: 30	m
b. Lpp	: 27	m
c. Breadth (B)	: 8	m
d. Height (H)	: 3,5	m
e. Draft (T)	: 2,2	m
f. Payload	: 79	ton
g. Service Speed	: 10	knot
h. Block coefficient (Cb)	: 0,735	

The ship's service speed is based on existing ship data. Ship performance is closely related to the shipping route, not just the shape of the hull and superstructure. (Perera, 2018).

5. CONCLUSION

Based on the data on the operational pattern of vehicle queues on the Bengkalis-Sungai Pakning roro ferry crossing which has been calculated for payload, general plan, lines plan and stability analysis, the ship data obtained are: payload 79 tons, overall length 30 m, width 8 meters, height 3.5, draft 2.2, service speed 10 knots for a voyage duration of 1 hour.

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