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Optimization of Ferry Ship Design on the Bombana - Tanjung Pising - Baubau Route

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ABSTRACT

The objective of this research is to get the optimal ship dimension for the Bombana - Tanjung Pising - Baubau crossing route. This research uses a linear programming optimization method. By identifying problems and mismatches of ships operating with the main objective of ferry transportation, and determining the objective function of optimization. Then determine the aspects of ship design that are adjusted to the characteristics of the ferry based on optimization constraints, namely demand conditions, oceanography and infrastructure. The direction of optimization is more emphasized on increasing the speed and effectiveness of greater loading capacity on passenger and vehicle. The results have been obtained in the form of the optimal principal dimension of the ship for the Bombana - Tanjung Pising - Baubau crossing route with effective ship speed

Keywords: *Optimization, Ferry, Bombana - Tanjung Pising – Baubau Route*

1. INTRODUCTION

Indonesia is confined to relatively large and small islands so that transportation access to one another is difficult, as many islands are not isolated due to the availability of transportation infrastructure in the sea crossing transportation sector. To respond to this condition, it is necessary to develop a crossing transportation that has adequate facilities so that it can support smoothness, accessibility and facilities in the sea crossing transportation sector. [1] states that the island regions, strengthening connectivity system is required so that the relationship within and between islands running smoothly in supporting the economic development of a region. On the islands, the connectivity scenario is expected to open up isolated areas, so it is connected with economic centers, aims to reduce the disparity in price and service, increased competitiveness and acceleration of poverty reduction could ultimately improve the social and economic accessibility. Based on Ministerial Regulation 104 (2017), crossing transportation is transportation that functions as a bridge that connects the road network and / or railroad network separated by water to transport passengers and vehicles and their cargo. Implementation of long-distance transport crossing is crossing transport services on long-distance cross-traffic set by the government to serve the commercial trajectory has not been profitable.

The crossing route Bombana (Kasipute) - Tanjung Pising - Baubau are between districts and sub-districts in Southeast Sulawesi Province, which connects 2 (two) islands, namely Kabaena Island and Buton Island. Bombana Regency and Baubau City are one of the regencies/ cities in Southeast Sulawesi Province, while Tanjung Pising is one of the sub-districts in Bombana Regency which is located on Kabaena Island. Currently, the ferry that enters Bombana Regency uses a mooring dock as a berth for loading and unloading passengers and vehicles. With these conditions, making ferry operating is limited to a ship size under 500 GT. The ferry that is currently operating is a converted LCT (Landing Craft Tank) type of ferry, namely KMP. Madidihang, with a GT of 223 tonnes, makes the construction dimensions a small ship.

The type of LCT ship that is converted is a type of ship that is not suitable for serving passenger cargo, due to the limited load capacity due to the initial construction of the LCT only for carrying heavy vehicle loads such as tanks, excavators and the like. Besides, over a period of 8 years, KMP. Madidihang uses mooring berth to dock and carry out the loading and unloading process for passengers and vehicles. However, since the inauguration of the Bombana (Kasipute) and Tanjung Pising crossing ports on 26 October 2019, this ship has experienced difficulties when docking at the Movable Bridge at low tide so that the comfort and safety of passengers and goods cannot be guaranteed properly when the ship is about to perform loading and unloading process at the port. Therefore, a suitable ship planning is need to serve this route, taking into account several factors, ranging from route and operational distance, total number and capacity, port and dock infrastructure, to the concept of passenger comfort and ship safety.

2. RESEARCH METHOD

This research focuses on the area of Bombana Regency with the Kasipute and Tanjung Pising crossing. Kasipute Port is in Rumbia District on the island of Sulawesi and Tanjug Pising Ferry Port is in North Kabaena District on the Kabaena Islands. As shown in Figure 1, is a map of Southeast Sulawesi Province where you can see the length of the traversed line is depicted in red, this route has a length of 28 miles passing through several islands in the Masaloka Raya Islands and directly to the Ferry Port in North Kabaena. Until now, the ports used by the community from Kasipute to Kabaena are the Kasipute people's port and the Sikeli port, with a route of 45 miles. The ships serving the route are people's ships, pioneer ships and privately owned vessels.

Figure 1. Bombana - Tanjung Pising - Baubau Crossing Route

There are 6 Districts in the Kabaena Islands, namely Kabaena, North Kabaena, East Kabaena, South Kabaena, West Kabaena and Central Kabaena Districts and Buton Regency which depends on Tanjung Pising Port on the north of the island, Dongkala Port on the east of the island, Batuawu Port on the south of the island and Sikeli port west of Kabaena island. Adequate and smooth transportation traffic will increase the competitiveness of superior products in each sub-district, and equitable development will be carried out well.

Based on the results of the previous discussion, the demographic and economic conditions of Bombana Regency, as well as the survey that was carried out on the Bombana - Tanjung Pising - Baubau crossing, there are several things that can be discussed, namely:

1) The Bombana - Tanjung Pising - Baubau crossing route has not yet been operated because the hinterland road conditions in the Tanjung Pising area are not sufficient for heavy vehicles to pass.
2) The people of Bombana have used traditional boats (wooden materials and speed boats) to cross to Kabaena Island. So it can be proposed that the tariff for the ferry that is operated will be cheaper or the rate is the same as the public ship operating at the Kasipute Public Port.
3) Based on the demographic conditions of Bombana Regency, most of the people live on the coast, so they need adequate transportation facilities. Judging from the population growth rate of Bombana Regency which is higher than Kendari City, it is necessary to increase the passenger capacity for ferry boats.
4) Based on the economic condition of Bombana Regency, it is proposed that the operating ferry boats be able to carry more Class IV to VIII vehicles.

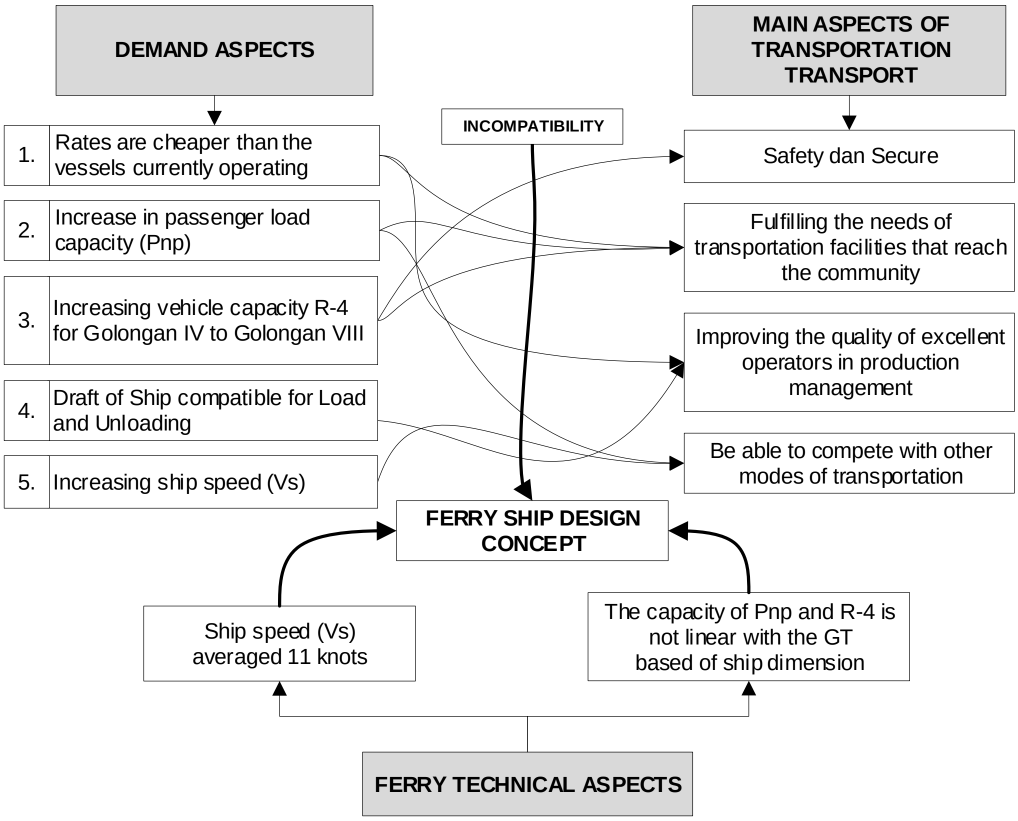

Figure 2. Identification Problem in the Route Area

The mismatch process between aspects of demand based on previous research with aspects of the main purpose of crossing freight, as well as technical aspects of ships to demand conditions can illustrates in Figure 2. So that these three things are measured in the ferry design concept on the Bombana - Pising - Baubau route.

Based on the identification of problems from the demand aspect, the technical aspects of the ferry and the main objective aspects of ferry transportation using the linear programming method, an objective function can be taken which is the main objective in the optimization process, namely obtaining and minimizing ship operating costs in the pre-ship design stage.

This type of research is quantitative using a research design based on work procedures of quantification to measure research variables through selection and data structure design. To facilitate and direct the process and steps for completing this research, a research stage is made in the form of an analytical framework that describes the sequence of work in the completion of the research report as shown in Figure 3.

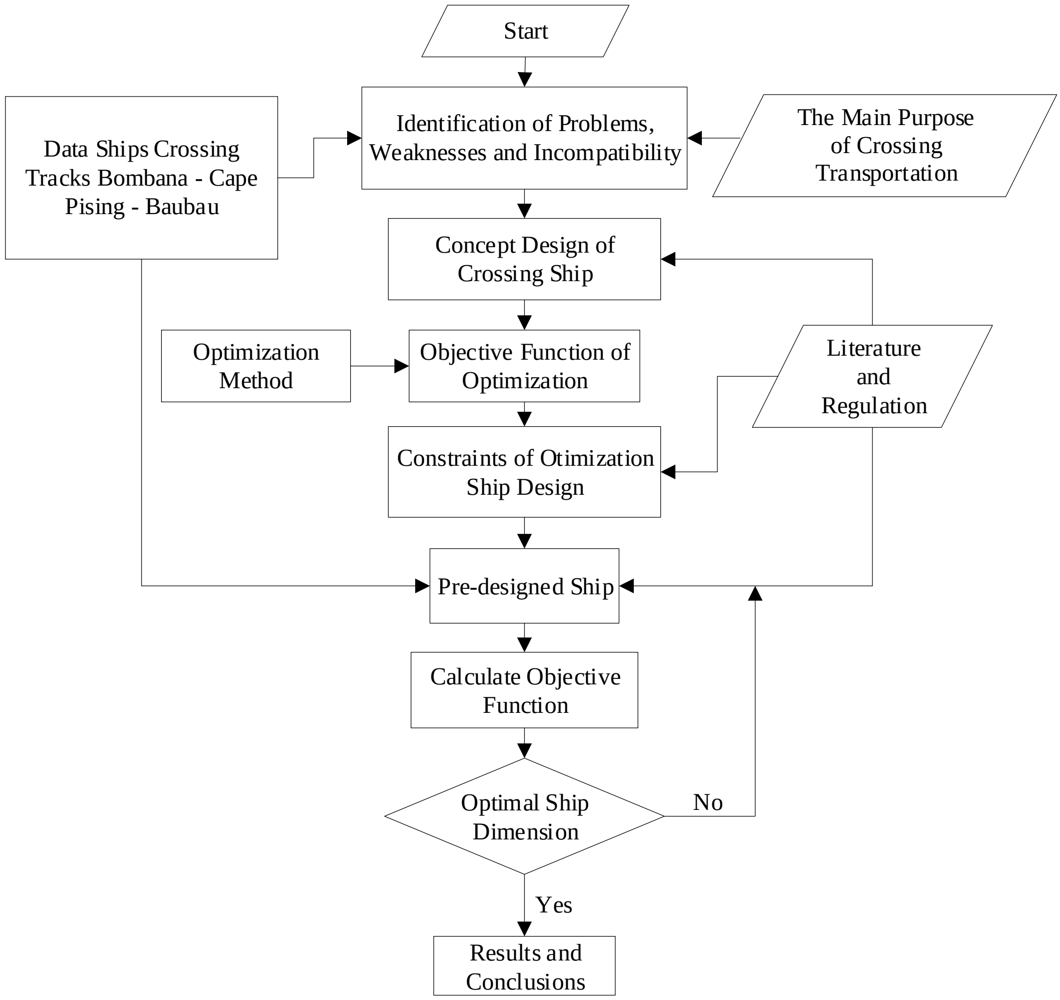

Figure 3. Research Framework

Based on the data obtained, a calculation analysis is carried out with the following steps:

1) Survey and analysis of the Kasipute - Tanjung Pissing - Baubau crossing area based on geographical, demographic and economic sector aspects;
2) Identifying problems and incompatibilities of ships operating with the main objective of ferry transportation;
3) Determine the aspects of ship design that are adjusted to the characteristics of the ferry as well as the conditions of demand, oceanography and infrastructure of the Kasipute - Tanjung Pissing crossing route;
4) Determine the optimization method to be used;
5) Determine the objective function of optimizing the design of the Kasipute - Tanjung Pissing crossing ship;

6) Formulating ship design constraints;
7) Creating a flowchart optimization of pre-designed ships;
8) Inputting data according to demand conditions, oceanography and infrastructure for the Kasipute - Tanjung Pissing crossing;
9) Obtaining the optimal ship size;
10) Draw conclusions from the research results.

Objective Functions

The dimensions of the ship greatly affect the capacity of the ship's cargo, ship tonnage (GT) and the price of the ship itself. The large size is able to provide a bigger load capacity but the ship price and the size of the ship tax are getting higher too. If it is not balanced with a good effectiveness value, the economic value of the ship will decrease. As seen in the problems in previous studies, large ships but low load factor values (demand conditions), the operator will bear the losses on operating costs of ships and service users due to the increase in tariffs. So that in this problem the ship is considered ineffective.

The efficiency value of the ship is measured based on the speed of the ship itself which is accompanied by an increase in the performance of the ship's engine power (Hp). Ships that have high speed will be able to provide satisfaction to service users so that the ship is efficient. Fuel consumption will be lower if the time required is shorter, so that this efficiency value can have a good effect on ship operators.

Connected between problem identification and the design concept of ferry ship, it is necessary to plan a new ferry fleet capable of meeting the main objective aspects of ferry transportation. The effective and efficient value of a ferry can be measured from the dimensions of the ship and the speed of the ship, where these two measurements are formulated in the ship's operational costs (BOK). The planning of the new crossing fleets is reviewed against the operational costs of the ship per trip, to measure the difference in the fleet that is temporarily operated with the new fleet concept. As in previous studies, ship operating costs and BOK per trip are formulated by the following equation (1).

Based on the results of problem identification from the demand aspect, the ferry's technical aspects and the main objective aspects of ferry transportation using the linear programming method, an objective function can be taken which is the main objective in the optimization process, namely obtaining and minimizing ship operational costs (BOK) in the pre-ship design stage.

The components of ship operational costs (BOK) include ship price (PS), ship tonnage (GT), engine power (PB), speed (Vs), shipping distance (S) and frequency (Tn) as shown in Equations (1) and (2). It appears as if there is more than one objective to be achieved in the optimization of this research, but these components are described against one objective. The components of ship price, GT, engine power and ship speed are directly related to the main size of the ship, while the number of trips is related to shipping distance and ship operational speed. Optimization using one objective can be formulated by equation (3).

$$BOK = (c1.P_S) + (c2.GT) + (c3.P_B.{}^{S}\!/_{VS}.Trip) + 6\% \tag{1}$$

$$BOK / Trip = BOK / Tn \tag{2}$$

$$\text{Find } X = \{X1, X2, X3, \ldots, Xn\} \tag{3}$$

where X is a design vector or selection variable, by maximizing the objective function f (X) which is based on the constraints of geometrical conditions, demand, oceanography, infrastructure formulated in equations and inequalities in the optimization process as shown in equation (4).

Maximizing $\sum_{j=1}^{n} f_j X_j$, with constraints

$$\left.\begin{array}{l} \sum_{j=1}^{n} a_{ij} X_j \le b_i, i = 1 \ldots q \\ \text{dan} \\ X_j \ge 0, j = 1 \ldots p \end{array}\right\} \tag{4}$$

Or simply can be formulated as:

$$\left.\begin{array}{l} g_j(X) \le 0, j = 1, 2, \ldots\ldots\ldots\ldots\ldots, q \\ \text{dan} \\ h_j(X) \ge 0, j = q+1, q+2, \ldots\ldots, p \end{array}\right\} \tag{5}$$

The tonnage of the ship which is the result of measuring the volumes of the closed rooms. The ship is very important to know because the tonnage of the ship is closely related to the operation of the ship. From an economic point of view, the tonnage of the ship will affect the amount of expenditure by the ship owner and the amount of government tax revenue on the ship, namely when the ship will be docked or at the time of mooring at the port. For international calculations intended for ships with a length of 24 meters or more, the equation used is:

$$GT = K_1.V_{GT} \tag{6}$$

$$K_1 = 0{,}2 + 0{,}02(Log.V_{GT}) \tag{7}$$

$$V_{GT} = V_1 + V_2 \tag{8}$$

$$V_1 = Loa.B.H.f \tag{9}$$

$$V_2 = 18\%.V_1 \tag{10}$$

$$GT = 1{,}831.(K_1.V_{GT})^{0{,}956} + 2\% \tag{11}$$

3. RESULTS AND DISCUSSION

The design stage follows the ship design process which is generally carried out at the pre-design stage, with the addition of several design controls to support the determination of the optimization objective function. Before starting the design stage, it is necessary to know the conditions of demand, infrastructure conditions, oceanographic conditions, and operational conditions as design considerations. The spiral design stages with the optimization method of the linear programming method can be illustrated in Figure 4.

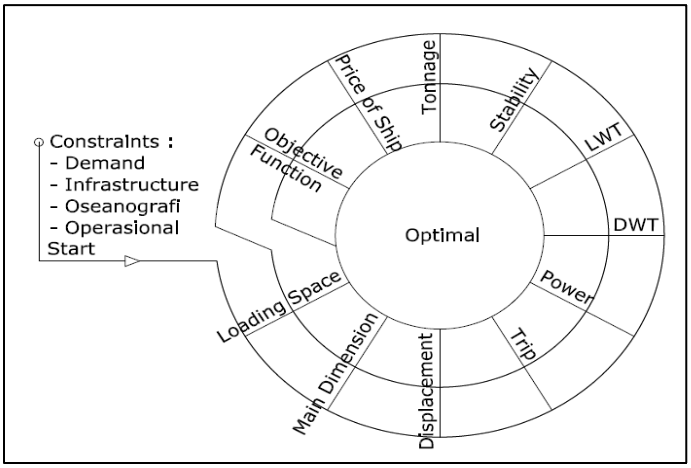

Figure 4. Spiral Diagram of Ship Design

The main dimension of the ship as a design variable is adjusted to the demand conditions for the amount of cargo, infrastructure constraints, oceanographic boundaries and geometric boundaries (main dimension ratio of Loa/H, Loa/ B, B/T, H/T, Froude number (Fn), and block coefficient (CB) as discussed in the previous section.

From total of 80 roro-type ferries serving crossings in the Eastern Indonesian Region were used as research objects. Based on the ship data, 15% of the vessels are with a capacity of 150-300 GT and 25% are vessels with a capacity of 300-500 GT. The largest number is 50% ships with a capacity of 500-1000 GT and only 10% ships with a capacity above 1000 GT. The shipping distance in Eastern Indonesia is around 47.4% of short-distance shipping and 52.6% of long-distance shipping with an average ship operating speed of around 11 knots which is classified as low speed.

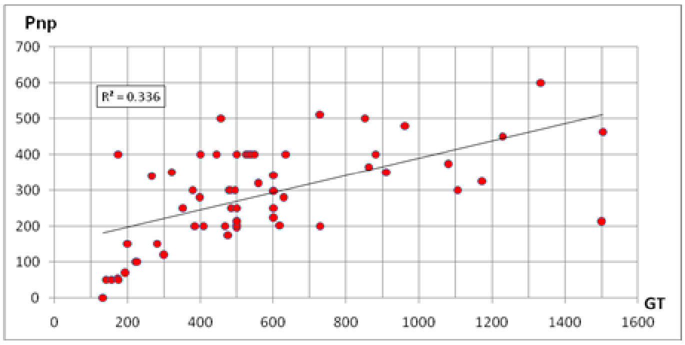

Figure 5. Relationship between ship's GRT and passenger load capacity (Pnp) of the roro ferry in the Eastern Indonesian Region

The relationship between the ship's GRT and the passenger cargo capacity (Pnp) of the roro ferry in KTI can be seen in Figure 5. Ships with a passenger load capacity of less than 100 people are 7.5% and 33.75% ships with a passenger load capacity of 100-300 people. The largest number is 40% of ships with a passenger load capacity of 300-600 people. It can be seen from the data and graphs that the relationship between the ship's GT and passenger load capacity (Pnp) is not linear with the ship's data, with a coefficient of determination of 0.332.

The relationship between the ship's GRT and the vehicle load capacity (R-4) of the roro ferry in Eastern Indonesia can be seen in Figure 6. Ships with a vehicle load (R-4) below 10 are 17.7% and 24.2% ships with a cargo capacity vehicle (R-4) 21-30. The largest number of ships with 54.8% vehicle load capacity (R-4) 11-20 units and a capacity above 31 units R-4 is only 3.2%.

It can be seen from the data and graphs that the relationship between the ship's GT and vehicle load capacity (R-4) is not linear with the ship's data, with a determination coefficient value of 0.338. These two things (Pnp and R-4) do not mean that they have to be linear, they can predictably be adjusted to demand conditions, oceanography and track infrastructure.

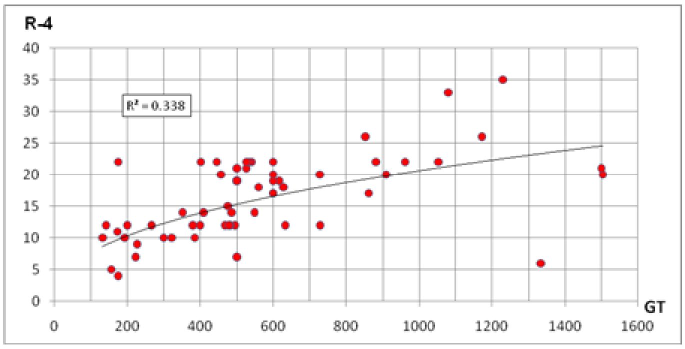

Figure 6. Relationship of ship's GRT with vehicle load capacity (R-4) of the roro ferry in Eastern Indonesia

The control of the cargo space make use of the load ratio to systematize the load capacity. The ratio of cargo ratio is a value that describes the ratio of the load ratio of the R-4 vehicle with the passenger cargo that can be carried by a ferry. In the minimum requirements for ship construction for passenger services, the ratio of seating or passenger beds is approximately 60% of the deck area. The remaining 40% of the deck area is assumed to the space used for the sanitary room, galley, cafeteria or kitchen, and lounge or prayer room. The area of other rooms such as the place for placing lifeboats and other equipment is a projection of the area of the crew room on the deck of the vehicle's cargo. The minimum room size for crew ship is 2.35 m^2 for 2 people.

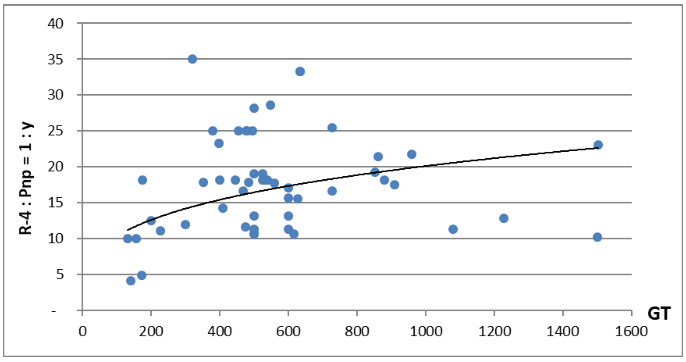

Figure 7. The ratio of R-4 cargo to Pnp cargo to the GT size of ships in Eastern Area of Indonesia

Figure 7 provides a relationship between the ratio of R-4 cargo capacity to the passenger cargo capacity of Pnp with the GT size of ships operating in Eastern Indonesia. The larger the GT size of the ship, the greater the cargo ratio R-4: Pnp of the ship with a ratio range of 4 to 35, with a ratio of R-4 / Pnp ranging from 0.026 to 0.25. This concept is used at the design stage in relation to the population growth rate and the vehicle density index. The greater the population growth rate, the smaller the ratio of R4 / Pnp.

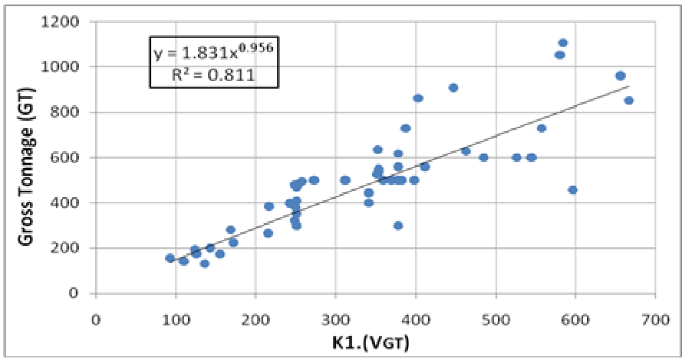

Figure 8. Gross tonnage (GT) of ro-ro ferries operating in Eastern Area of Indonesia

Figure 8 provides an illustration of the actual GRT relationship of ships operating in KTI with the ship's GRT estimation equation with a correlation coefficient R2 of 0.811. By connecting the actual GT data to the approximate equation, equation 11 is created. The value of 1.831 and the power of 0.956 is the value of the curve function on the graph which is formed from the relationship between the approximation equation and the actual ship GT value. The trend curve is formed from the value of the highest price and the value of the lowest price at each point and is outlined into a curve from the midpoint of the two values. Addition of 2% to the GT from the difference in the average approach equation to the ship's actual GT.

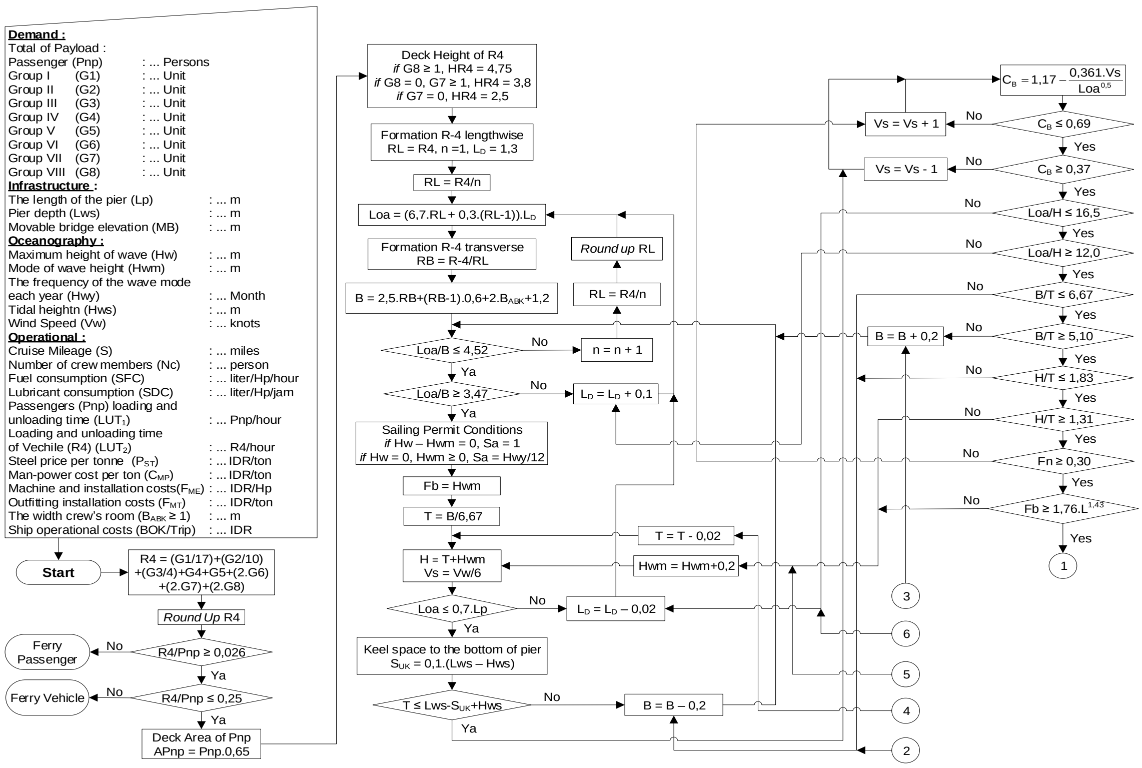

Figure 9. Flowchart of ship design optimization

Figure 9 depicts the process of optimizing the design of a ferry in Eastern Indonesia, inputting demand condition data based on cargo groups as regulated in the Decree of the Minister of Transportation No. KM. 58 of 2003. The input of ferry port infrastructure data is the length of the pier (Lp), the depth of the pier pool (Lws), the tidal height (Hws), and the maximum elevation of the

MB (movable bridge). If the port does not have a rim or still uses a concrete pier, then the distance from the end of the pier to the surface of the water is defined as the maximum elevation of the rim.

Operational data input is data that is not used in determining the minimum and maximum size of the vessel. This data is used in the process of optimizing the main size after the measurement of the ship's geometric boundary. The planning of the main size of the roro ferry is determined based on the approach to the number of cargo R-4 vehicles. Therefore the planning is carried out with the concept of the space equivalent of R-4 for the variation of the load based on the Group. Space equivalence provides a comparison of the equivalent space for each class except passenger load. The statistical data of transportation provides the number of R-4 cargo and passengers (Pnp) for each ship operating in the Eastern Indonesia Region, where R-4 is a Class IV car cargo and a Group V medium-sized car load. So that in space equivalent, the cargo in each class will equivalent to a charge of R-4. One R-4 charge is equivalent to 17 Group I charges 10 Group II charges and 4 Group III charges. Two charges of R-4 are equivalent to each of one charge for groups VI, VII and VIII. After all groups are defined into the charge R-4, they are added together to get the total charge R-4.

The ratio R-4 / Pnp is used to measure the effective value of the room, if R-4 / Pnp is less than 0.026, the ship suitable for demand conditions is a special passenger ferry. If the R-4 / Pnp ratio is greater than 0.25, the suitable vessel for the demand condition is a special vehicle ferry. The ratio is obtained from statistical data processing and tested by conducting simulations based on regulations. The height of the vehicle deck is the minimum height based on regulations. If there is Group VIII then HR-4 is 4.75, if there is only Group VII then HR-4 is 3.8, and if there is only Group V or below then HR-4 is 2.5. Longitudinal and transverse R-4 vehicle formations are measured by the Loa / B ratio. The process of reducing longitudinal formation and transverse addition of R-4 will continue until the Loa and B. Determination of minimum Freeboard (Fb) and minimum velocity (Vs) is based on oceanographic data. The minimum speed must be greater than Vw / 6 because a wind speed of 30 knots will reduce the ship's speed by 5 knots in the condition that the ship's heading is opposite the wind. The height of the raised hull is defined as the same as the wave height, this is done with the assumption that the height of Fb will reduce the possibility of water entering the deck of the ship (green seas). By following the design rules of the ferry port, the maximum length of the ship (Loa) cannot be more than 70% of the length of the pier. This is assumed so that the dock is still able to moor the ship when loading and unloading or resting in bad weather. If it is more than required, the length of the ship will be reduced. Draft (T) must not be more than the depth of the pier (Lws) with the space of the ship's bottom to the dock (SUK) by the tides of the port (Australian Maritime Safety Authority, 2007). If it exceeds, a reduction will be made to the width of the ship (B). Changes in width will change the minimum load of the ship. Ship speed is related to Cb.

The block coefficient (Cb) which is less than the ratio limit causes a reduction in velocity (Vs). The block coefficient (Cb) is more than the ratio limit, the increase in ship speed (Vs) results in additional engine power (Pb) needed. Variations were made on the speed and not on the length of the ship (Loa) because the effect of the length of the ship was significant on the increase in ship building costs (CS). To get a high efficiency value at ship speed, the requirement for Fn must be increased ≥ 0.3. If the value of Froude is less than the limit, an increase in ship speed (Vs) results in an increase in the ship's engine power (Pb) required. Minimum hull size must comply with ILLC regulations, where the ship length parameter is a variable of Fb. The longer the ship, the higher the minimum Fb size.

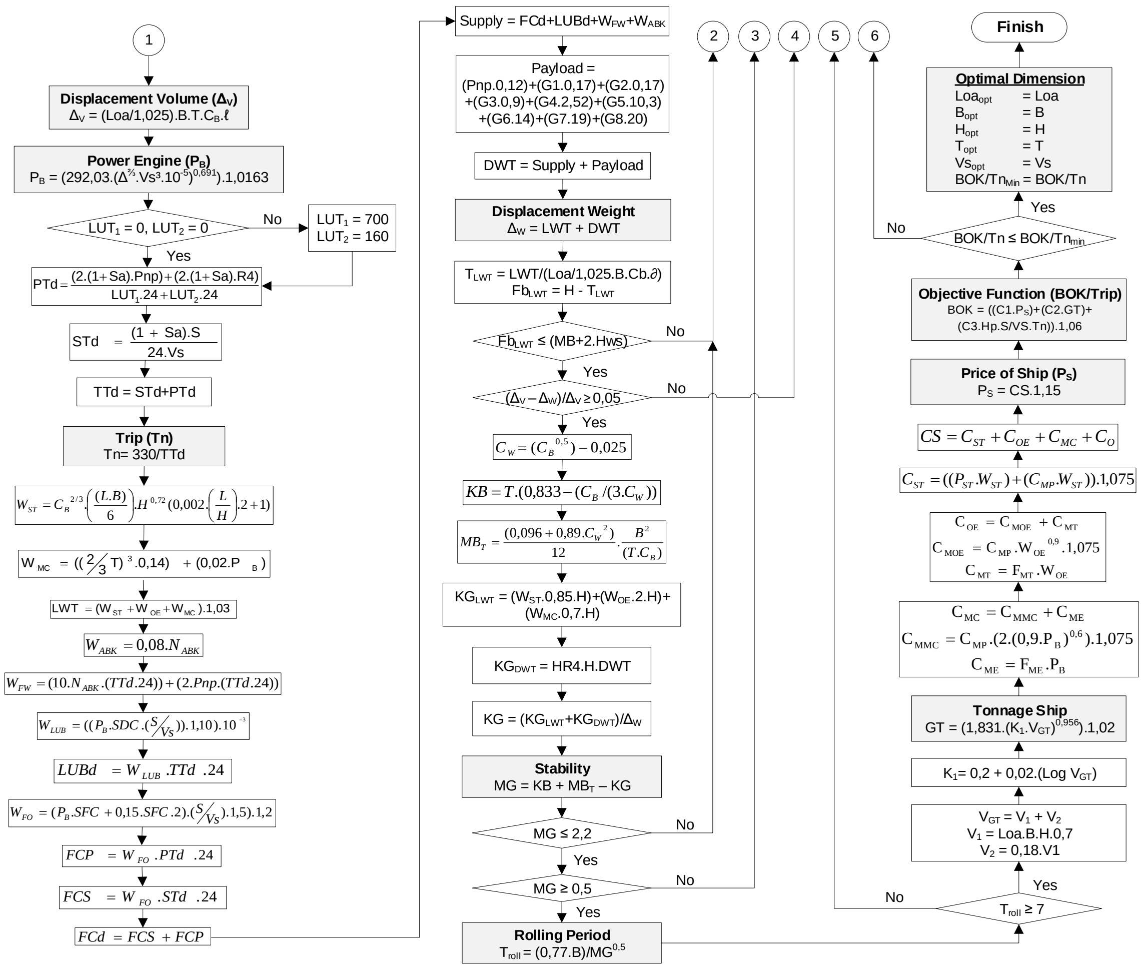

Figure 10. Flowchart of ship design optimization (continue)

Figure 10 depicts the process of optimizing the design of a ferry in Eastern Indonesia, volume displacement value of the ship is used to get the engine power value (PB). Determination of the engine power of the ship using an approximation equation, this is done to adjust to the optimization method and remain within the design variable parameters. To get the value of ship trips per year (frequency) requires data on the condition of the shipping permit (Sa), the loading and unloading time of the passenger cargo (LUT1) and the loading and unloading time of the R-4 vehicle (LUT2). The next process is calculating the ship weight displacement which consists of the Light Weight Tonnage (LWT) and Dead Weight Tonnage (DWT).

By using the linear programming method, the weight limit of the ship is used as a limitation for the equation. To maintain variations and changes in load weight, a weight tolerance of 5% is given from the difference in displacement volume with the weight of the ship. If it is too large than the tolerance, a reduction is made to draft of vessel (T). The next process is the calculation of the stability of the ship with the parameter of the transverse metacentra value (MG). If the MG value is less than the limit, the width of the ship (B) is added and the MG value is more than the limit, then the width of the ship is reduced (B). The rolling period parameter should not be less than 7 seconds for the roro ferry. If it is less than the stipulated condition, the height of the vessel (H) will be added which will cause a significant increase in the shaking period. The calculation of the gross tonnage of the ship (GT) is done using the approximate equation. The objective function of optimization is to obtain and minimize the operational costs of the ship per trip (BOK / Tn). If the BOK / Tn condition is greater than the minimum BOK / Tn (reference) then changes are made to the length of the ship (Loa) to get a significant change in the price of the ship (PS).

By using a ship design flowchart, the optimal size of the ferry can be found at each sample track based on oceanographic conditions, infrastructure and demand. The simulation is carried out by using the maximum size limit on the condition of the port infrastructure, so that the size of the demand for loading capacity is limited by the capacity of the port facilities. The maximum ship size is the optimal size obtained based on the limiting conditions. To run the simulation process, the following operational conditions are assumed Fuel consumption (SFC) is 0.130 Liter/Hp/hour; Lubricant consumption (SDC) 0.0033 Liter/Hp/hour; Steel plate price per ton (PST) is 750 US $/tonne; passenger (Pnp) loading and unloading time (LUT1) is 700 people/hour; Loading and unloading time of vehicle R-4 (LUT2) is 160 R4/hour; Manpower cost per ton (CMP) is 2,000,000 IDR/tonne; and machinery costs (FME): 1,200,000 IDR/Hp; and Outfitting costs (FMT) is 1,500,000 IDR/ton.

Table 1. Comparison of the results

Parameter	Symbol	Current Ship Operated	Optimal Design Ship	Unit
Length Over All	Loa	33,50	45,11	m
Breadth	B	9,00	11,90	m
Height	H	2,70	3,00	m
Draft	T	1,40	1,78	m
Velocity	Vs	10,00	13,00	Knots
Power	PB	900,00	1.582	HP
Stability	MG	(0,93)	1,16	m
Rolling Period	Troll	-	8,52	Second
Trip/Year	Tn	274	339	Trip
Gross Tonnage	GT	223	504	
BOK/Trip	BOK/Tn	3.085.580	4.983.366	IDR
Passengers	Pnp	100	450	People
Vehicle	R-4	7	15	Unit

The comparison of ships operating with ships optimized for ships on the Bombana – Tanjung Pising - Baubau trajectory can be seen in Table 1. Maximum ship size is used based on infrastructure and regulatory limitations. For optimal ship size, the optimization direction is more emphasized on increasing the speed and effectiveness of the loading capacity (Pnp and R-4). Despite the increase in the required engine power and an increase in the size of the ship's GT. The analysis on the number of trips is carried out without considering the ship rest time to get the lowest ship operating costs.

CONCLUSION

The results have been obtained in the optimal main dimension using the optimization method of linear programming where the objective function of optimization is to minimize the operating costs (BOK) of the ship for the Bombana - Tanjung Pising - Baubau crossing route. Optimum ship size is used based on constraints of demand, infrastructure, oceanography and regulation, where the direction of optimization is more emphasized on increasing the speed and effectiveness of the load capacity passenger (Pnp) and vehicle (R-4). The efficiency direction of ship design optimization can be seen by an increase in ship speed by 13 knots.

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