Model Design of Inter-Island Ships Base on Transport Demand and Port Facility

Syamsul Asri
Doctoral Student in Department of Civil Engineering
Engineering Faculty of Hasanuddin University
Indonesia

Muh. Saleh Pallu
Lecturer in Department of Civil Engineering
Engineering Faculty of Hasanuddin University
Indonesia

M. Arsyad Thaha
Lecturer in Department of Civil Engineering
Engineering Faculty of Hasanuddin University
Indonesia

Misliah
Lecturer in Department of Naval Architecture
Engineering Faculty of Hasanuddin University
Indonesia

Abstract— **Inter-island transportation plays an important role in order to strengthenen inter-island conectivity in Indonesia. The challenge in organizing the inter-island transportation in Indonesia is availability of ro-ro ferry corresponding to port class, traject distance and demand of transport service in each inter-island transportation network. The port class becomes constrain of ship tonage to able to operate in a route. This means that port class also become constrain for ship dimension and capacity. In orther hand, demand of transport capacity and ship speed are dependent of service transport demand and traject distance. This paper discusses regarding concept design model of ro-ro ferry. This model is formulated based on analysis results of technical specification consist of main dimension, tonnage, loading capacity and ship speed regarding operation pattern of inter-island transport. The ship length and breadth are estimated by uisng matrix approach to arrange vehicle in main deck. The ship height and draught are estimated through emprical approximation of ratio between ship length and ship height and ratio between ship breadtrh and ship draught. The ship tonnage is estimated by using emprical formula. The maximum speed of ship is determined from result of resistance analysis of sample ships. The technical spefication of ship is separated base on the port class. Following the obtained loading capacity and ship speed, operation pattern and transport capacity in a certain route is determined base on port class and traject distance. Finally, model design of ro-ro ferry consist of design requirement (loading capacity and ship speed) is obtained base on demand of service transport for each route considering port class and traject distance. The main dimension is estimated base on required loading capacity. The maximum speed is determined to be validated with required speed.**

Keywords— Inter-Island Transport, Ro-Ro Ferry, Model Design

I. INTRODUCTION

Intern-island transportation is play an important role in sea transportation in order to strengthenen the inter-island conectivity. The inter-island tranportation in Indonesia was organized as a part of land transportation. Service of the intern-island transportation was conducted by placement and operating ships continously and regularly in every route of inter-island network. The ship type required to be operated in a inter-island transportation traject is a ro-ro ferry.

The inter-island transportation network consist of port and route. Two ports is connected by one route. Base on port hierarchy of Indonesia, the port class is devided into three clases [7], port capacity for berthing service is determined based on ship tonage (GT). The first class is a port to be able to service ships with gross tonage (GT) more than 1000 GT, the second calss is that for ships between 500 GT and 1000 GT and the third class is that for ships with capacity less than 500 GT. These ports capacity was referred as variable of main facility of port at sea within this paper.

Following the regulation about mechanism of determination and formulation for calculating tariff of inter-island transportationa in Indonesia [8], the ship tonage was classified base on 8 group of traject distance range from ships tonage of about 300 GT for traject distance not more than 1 miles to ships tonage of about 1500 GT for traject distance larger than 120 miles. If the classification of traject distance is related to the port class corresponding to the ship tonnage, it can be concluded that the port class III was provided for route with taject distance less than 10 miles, the port class II for route with traject distance between 10 miles to 80 miles and the port class I was provided for the route with traject distance more than 80 miles. In practical point of view, the port capacity is more correlated to ship tonnage to be operated in a certain route corresponding to demand of transport service. This is based on evidence that ships with tonage more than 1000 GT was operated in traject distance less than 10 miles especially in the route with high demand of transport service [1]. Oppositely, ships with tonnage less than 500 GT or even more less than 300 GT may also be operated in a traject distance more than 80 miles.

As explained in the previous second paragraph, the ship tonnage to be operated in an inter-island route depends on the port class. The ship tonnage directly affect the ship dimension. As the ship loading consist of vehicle and passenger to be located in the deck area, the length and the breadth of ship depend on her loading capacity. In the other hand, the ideal of maximum ship speed is influenced by proportion of length and breadth of ship. The draught, height and freeboard of ship should exactly correspond to the proportion of length and breadth. The ratio between breadth and draught and the freeboard of ship is related to ship stability.

Based on traject distance, operation frequency per unit time of service depends on ship speed. In principle, maximum service frequency for each route should be the same. However, for a certain distance difference, number of operated ships is larger in longer traject distance. The loading capacity and service frequency become main variable in determination of transport capacity of inter-island transportation. Maximum transport capacity in a certain route of inter-island transportation depends on maximum loading capacity of a ship to be oprated correspoding to the port class. The maximum transport capacity was referred as standard or parameter of transport service demand.

This paper discusses regarding model design of ro-ro ferry operates in Indonesia base on service transport demand corresponding to port class and traject distance. Model of concept design is formulated base on relation between port hierarchy and traject distance with technical spesification of ship and its implication on transport capacity of route.

Tonnage, dimension, speed and loading capacity of ro-ro ferry will be grouped base on ship tonnage in accordance with port hierarchy. As the standard of maximum demand of transport service, the maximum of transport capacity of route was also grouped refer to the port classification. The maximum transport capacity was confined only for one traject in every route, in other word, there is only one quay for every port noose. The model design of ro-ro ferry to be formulated in this paper consist of estimation of loading capacity as function of demand of transport service in every class of port, determination of main dimension as funnction of loading capacity and estimation of maximum ship speed. Here, the loading capacity means the number of car to be accomodated in vehicle deck area.

II. RESEARCH METHODOLOGY

This research was conducted with four analysis steps consist of : formulation for estimating maximum speed of ro-ro ferry, classification of ro-ro ferry based on port hierarchy, estimation of loading capacity of inter-island transportation route according to the port hierarchy and hierarchy of model design for ro-ro ferry.

Formulation for estimating the maximum speed of ro-ro ferry was conducted through resistance analysis of 50 sample ships with 5 variation of ship breadth as shown in Table I. The length and the breadth of ships was estimated as function of loading capacity of vehicle [2] with the equations as follows:

$$LBP = (\Sigma(Cv_i\, Lv_i) + Dfa\,(Cv - 1)) / Lr \qquad (1)$$

$$B = \Sigma(Rv_i\, Bv_i) + Ds\,(Rv - 1)) + 2\,Dvp + 2\,Dps \qquad (2)$$

Here Cv_i, Lv_i, Dfa, C, and Lr are the number of coulom for each vehicles classification, length of each vehicles classification, distance between the vehicles in one coulom, number of coulom and ratio between the length of vehicle deck and the length between perpendicular of ship, respectively. Lr was determined to be 0.9. Rv_i, Bv_i, Ds, Rv, Dvp, and Dps indicate the number of row for each vehicles classification, breadth of every class of vehicles, distance between the vehicles in one row, the number row, the distance between the vehicles with the border of vehicles area and the distance between the border of vehivles area and the ship side, respectively . Following technical guidance of requirement for minimum service of river, lake and inter-island transportation in Indonesia [10], Dfa, Ds, dan Dvp are determined to be 0.3 meters, 0.6 meters and 0.6 meters, respectively. While Dps is determined to be 1.5 meters.

The ship length (*LBP*), height (*H*), and draught (*T*) for every variation of breadth (*B*) are determined within range of ratio of main dimension of ro-ro ferry operating in Indonesia [2]. The ship height and her draught are determined to be the same for every breadth variation.

TABLE I. MAIN DIMENSION AND LOADING CAPACITY

Length Series		Breadth Series					
		Code	*B2*	*B3*	*B4*	*B5*	*B6*
		B (m)	9.00	11.70	14.40	17,10	19.80
		H (m)	2.70	3.51	4.12	5,08	6.61
Code	*LBP (m)*	*T (m)*	1.80	2.34	2.68	3,37	4.63
		CB	0.55	0.55	0.55	0,55	0.55
			Load capacit,(Lc (Vu)				
L5	29.11		10				
L6	35.00		12	18			
L7	40.89		14	21			
L8	46.78		16	24	32		
L9	52.67		18	27	36	45	
L10	58.56		20	30	40	50	
L11	64.44		22	33	44	55	66
L12	70.33			36	48	60	72
L13	76.22			39	52	65	78
L14	82.11			42	56	70	84
L15	88.00				60	75	90
L16	93.89				64	80	96
L17	99.78				68	85	102
L18	105.67					90	108
L19	111.56					95	114
L20	117.44					100	120
L21	123.33						126
L22	129.22						132

Value of Bn and Ln indicate number of row and column of goup IV of vehicles loaded, respectively. The subscript n indicates variation of ship breadth and length. Vehicle dimension shown in Table 2.

All sample ships have the same characteristics of hull form. The stern has transom form with normal stem without bulbous bow. The hull form coefficient consist of the block coefficient is 0.55, the midship coefficient is 0.94, the waterline coefficient is 0.83 and the prismatic coefficient is 0.58. An example of hull form of sample ships in Table 1 is shown in Figure 1.

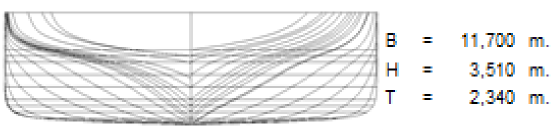


Fig. 1. An example of hull form of sample ships

The resistance of sample ships was estimated for speed variation until 22 knots with interval of 0.5 knots. The resistance of sample ships were estimated by using Holtrop Method [5]. According to the obtained resistance, estimation of the recommended maximum ship speed was formulated with the following step:

a. Estimation of ratio between resistance and cumulative loading capacity of all sample ships (*RLRc*) using the following equation:

$$RLRc = (\Sigma(Vmr_i\ RLR_i)) / \Sigma(Vmr_i) \quad (3)$$

Vmr_i is the maximum speed in knot of each sample ships with smaller resistance compared with the other sample ships within the same group of breadth and RLR_i indicates the ratio between resistance in maximum speed and loading capacity of each sample ships in Newton per vehicle unit (*N*/*Vu*).

b. Estimation of speed for each sample ships according to ratio between resistance and cumulative loading capacity (*RLRc*) referred to point a. *RLRc* between the calculated ship speed is determined by linear interpolation.

c. Formulation for estimating ship speed (*V*) as function of ship length (*LBP*) and breadth (*B*) using regresion appproach with ship speed as independent variable obtained in point b.

d. The formula for calculating ship speed in point c then compared with ship speed obtained as function of Froude number [4] shown in the equation (4).

$$V = Fn\ (g\ L)^{0,5} \quad (4)$$

V is the ship speed in m/s. *Fn* is Froude number. Here, the Froude number was determined to be 0.294 according to the block coefficient (*CB*) of sample ships of 0.55 [4]. The ship length is LBP in meter.

The second step is classification of ro-ro ferry corresponding to hierarchy of port. Determination of main dimension of sample ships and their grouping for classification purpose are conducted with the following steps:

a. Determination of vehicles area and loading capacity by using matrix simulation approach for car placement in car deck or main deck of ro-ro ferry. Length of the vehicle area (*Lva*), breadth of vehicle area (*Bva*) and loading capcity (*Lc*), respectively were determined by using the equations (5) – (7) as follows:

$$Lva = (\Sigma(Cv_i\ Lv_i) + Dfa\ (Cv\text{-}1)) \quad (5)$$

$$Bva = \Sigma(Rv_i\ Bv_i) + Ds\ (Rv\ \text{-}1)) + 2\ Dvp \quad (6)$$

$$Lc = \Sigma(Rv_i\ Cv_i\ \ Iv_i) \quad (7)$$

Iv_i indicates index convertion unit for each vehicle group as shown in Table II.

TABLE II. DIMENSION AND UNIT OF VEHICLE

Vehicle Groups	Vehicle dimensions		Product (*Lv+Dfa*) x (*Bv+Ds*)	Index of vehicle units (*Iv*)
	Length (Lv (m)	*Breadth (Bv (m)*		
IV	5	2.1	14.310	1.000
V	7	2.1	19.710	1.377
VI	10	2.1	27.810	1.943
VII	12	2.5	38.130	2.665
VIII	16	2.5	50.530	3.531
IX	20	2.5	62.930	4.398

b. The length between perpendiculars (*LBP*) as function of length of vehicle area (*Lva*) was estimated by using the equation (8) as follow.

$$LBP = Lva\ /\ Lr \quad (8)$$

Lr indicates the ratio between the length of vehicle area and the ship length (*Lva/LBP*). The value of *Lr* was determined to be 0.9.

c. The ship breadth (*B*), the ship height (*H*) and the ship draught (*T*) were estimated from ratio of main dimension by using the equation as follows [2].

$$LBP/B = 0,594\ LBP^{0,4832};\ \pm\ 0,512 \quad (9)$$

$$LBP/H = 5,2463\ (LBP/B)^{0,6792};\ \pm\ 1,592 \quad (10)$$

$$B/T = 1,1765\ (B/H)^{1,1617};\ \pm\ 0,569 \quad (11)$$

d. Estimation of maximum speed using equation obtained in the first step analysis.

e. The gross tonnage (*GT*) was calculated by using the equation (12) as follows [9].

$$GT = (0.2 + 0.02\ \log 10\ V_T)\ V_T \quad (12)$$

where V_T is volume of ship tonnage defined as volume of closed area of ship hull and volume of closed area of superstructures (*Vss*). The volume of ship hull and the volume of supersctructures of ro-ro ferry can be estimated by using the formulae proposed by Asri [3] as follows.

$$Vh = 1.04\ LBP\ B\ T\ CB\ (1.25\ H/T - 0.25) \quad (13)$$

$$Vss = LBP\ B\ (0.0036\ LBP\ B + 0.6677) \quad (14)$$

Here the block coefficient is mean of block coefficient. It was assumed to be 0.6.

e. Classification of dimension, speed and loading capacity base on tonnage of ro-ro ferry in accordance with port hierarchy.

The third step is estimation of transport capacity of inter-island transportation through the following steps.

a. Estimation of ship speed dan pattern of time operation in each trajects distance with the following equation.

$$St = c\ Pt \quad (15)$$

$$Vo = Rd\ /\ St \quad (16)$$

$$Ff = \text{int}\ [\ Ust\ /\ (Pt + St)\ ] \quad (17)$$

St and *Pt* indicate sail time and time of ship in port, respectively designated in hour/trip. *Pt* was determined to be 1 hour/trip [6]. c is integer with minimum value of 1 and its maximum value is determined until *Vo* the same as maximum speed (*Vmax*) obtained from the equation in the first step of analysis. c was also confined with operation frequency (*Ff*) atleast 2 trips for longest traject distance (*Rd*, (mile) per unit time service (*Ust*). In accordance with estimation of maximum load capacity, *Ust* was deterimined to be 24 hours/day.

b. Determination of number of ship departured (*Nsd*) successively in each noose port with the following equation.

$$Nsd = (Pt + St\ )\ /\ Pt \quad (18)$$

c. Determination of operation frequency (Ff_n) of each ship according to successive departure using the equation (19) as follow.

$$Ff_n = \text{int}\ [(Ust - (n - 1)\ Pt\ )\ /\ (Pt + St)] \quad (19)$$

n is departure order of each ship.

d. Estimation of total operation frquency (*Fft*) and total service frequency (*Fs*), respectively using the equations as follow.

$$Fft = 2\ (\Sigma Ff_n) \quad (20)$$

$$Fs = 2\ (\Sigma Ff_n + (Nsd - 1)) \quad (21)$$

The calculated operation frequency (Ff_n) is arrival of ship crossing to destination port in a unit time service. There is only one of several operated ships using equal operation time with the unit service time. The other ships are still able to depart in running time or service day but the arrival time is in the next service day. Therefore, the number of departured ships (*Nsd*) become addition factor in determination of total service frequency. As the ship departure from noose port, multiplier 2 was used in the equations (20) ans (21) in order to obtain the total frequency.

e. Determination of ship operated (*Nf*) by using the equation (22) as follow.

$$Nf = 2\ Nsd \quad (22)$$

f. Estimation of transport capacity of route (*Tc*) as function of total service frequency (*Fs*) and loading capacity (*Lc*) with the following equation (23).

$$Tc = Fs\ Lc \quad (23)$$

The last step is formulation of model design of ro-ro ferry namely concept design. Discussion in this step is continuation of the previous step, consist of:

a. Formulation for estimating loading capacity (*Lc*) as function of transport service demand (*Td*) using the equation (24) as follow.

$$Lc = c\ (Td/Td_{max}) \quad (24)$$

Here, c was determined by regression analysis of relation between *Lc* and ratio Td/Td_{max}. Maximum demand of transport service (Td_{max}) was used as constrain variable for service capacity corresponding to port hierarchy. Data of *Lc* and *Td* are calculated data obtained in second step of analysis. The value of *Td* was taken from transport capacity of crossing route (*Tc*) according to loading capacity (*Lc*) of operated ship. Td_{max} is taken as the largest value of loading capacity of crossing route (*Tc*) in each route group corresponding to port hierarchy.

b. Formulation for estimating main dimension of ro-ro ferry referring results of the second step. The main dimension consists of ship length (*LBP*) as function of loading capacity (*Lc*), ship breadth (B) as function of *LBP*, ship height (*H*) as function of *LBP* and *B*, and draught (*T*) as function of *B* and *H*. Formulation for estimating the draught is also conducted by considering effect of ratio between breadth and draught (*B*/*T*) and ratio between freeboard and breadth (*Fb*/*B*) for ship stability point of view. The vertical center of gravity significantly decreases when *B/T* is larger than 5.5 but righting arm tends to increase as ratio *B*/T increases [3]. Maximum righting arm tends also to increase as ratio *Fb*/*B* increases but the alteration of righting arm is not significant when this ratio is larger than 0.08.

c. Formulation for determining maximum speed. This part is to confirm analysis results obtained in part A (Formulation for determining maximum ship speed).

III. RESULTS AND DISCUSSION

A. Formulation for Determining Maximum Speed

According to calculation results of resistance for sample ships, the ships with larger length in the same breadth group have smaller gradient of resistance increasing due to increase the ship speed. Therefore, the ship with larger length have smaller resistance compared with the ships with smaller length in a certain range of ship speed as shown in Figure 2. Every group of breadth has simliar trend of resistance alteration.

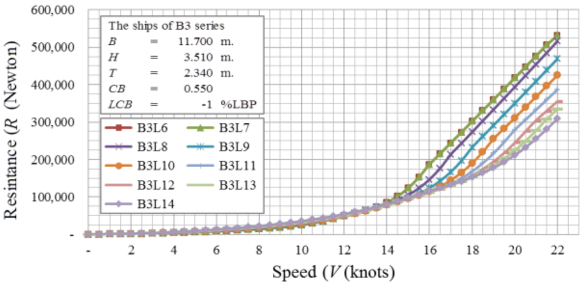


Fig. 2. Resistance of sample ship as function of ship speed

Ships with larger dimension in length have larger resistance compared with others sample ships on their maximum relative speed in the same breadth group. As gradient of difference in resistance become more larger when the ship length increases, ratio between resistance and loading capacity (*R*/*Lc*) become larger for ships with larger dimension in length.

For ships in the same group of length between perpendicular, the ratio between resistance and loading capacity (*R/Lc*) for ships with larger breadth is larger than the smaller ones except for ships in the breadth series 6 (the sample ships with largest breadth) which are have smaller ratio *R/Lc* compared with the others group of breadth.

The smallest ratio of *R/Lc* is 1685.543 Newton per unit dimension of vehicle (*N/Vu*). This is for sample ship of B6L11 series. The largest ratio of *R/Lc* is 4293.871 *N/Vu* for sample ship of B5L20 series. Using the equation (3), the cummulative ratio of *R/Lc* for all sample ships is 3414.015 *N/Vu*. According to this cummulative ratio of *R/Lc*, the ship speed can be estimated as shown in the following Table III.

TABLE III. ROCOMMENDED MAXIMUM SPEED OF SAMPLE SHIPS

Length Series		Breadth Series					
		Code	*B2*	*B3*	*B4*	*B5*	*B6*
		B (m)	9.00	11.70	14.40	17.10	19.80
		H (m)	2.70	3.51	4.12	5.08	6.61
Code	*LBP (m)*	*T (m)*	1.80	2.34	2.68	3.37	4.63
		CB	0.55	0.55	0.55	0.55	0.55
			Speed (knots)*				
L5	29.11		11.30				
L6	35.00		12.06	12.40			
L7	40.89		12.89	12.84			
L8	46.78		13.66	13.46	13.86		
L9	52.67		14.37	14.18	14.28	14.45	
L10	58,56		14.99	14.85	14.87	14.77	
L11	64,44		15.57	15.47	15.45	15.19	14.88
L12	70,33			16.05	16.00	15.66	15.23
L13	76,22			16.54	16.52	16.17	15.64
L14	82,11			17.05	16.97	16.65	16.09
L15	88,00				17.45	17.11	16.52
L16	93,89				17.89	17.50	16.90
L17	99,78				18.29	17.93	17.32
L18	105,67					18.33	17.72
L19	111,56					18.71	18.10
L20	117,44					19.07	18.47
L21	123,33						18.83
L22	129,22						19.17

** Ship pseed with ratio (R/Lc) =3414,015 N/Vu*

Figure 3 shows ship speed according to the ship speed shown in Table III as function of ship length and breadth.

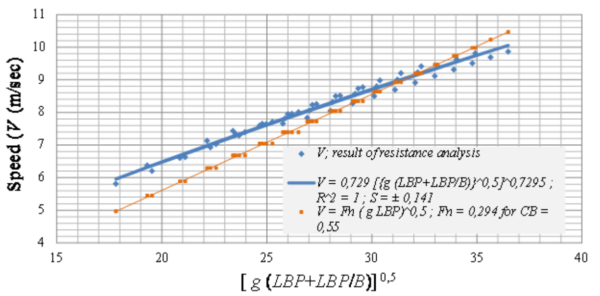


Fig. 3. Recommended maximum speed of sample ships

The ship speed has high linear correlation with the length between perpendicular (*LBP*). However, the ratio between ship length and ship breadth (*LBP/B*) needs to be included as variable in order to consider effect of ship breadth on the ship speed. The unit for speed variable (*LBP* + *LBP/B*) is meter and unit for the ship speed is meter per second (*m/s*). Therefore, the axis value used here is root square of product between gravity acceleration and the number of speed variable shown as axis in Figure 3. Base on results of regression analysis as shown in Figure 3, the maximum speed (*Vmax*) of ro-ro ferry may be estimated by using the equation (25) as follow.

$$Vmax = 0{,}729\ [\{g\ (LBP + LBP/B)\}^{0{,}5}]^{\ 0{,}7295} \qquad (25)$$

If the ship speed is calculated by using the equation (25), the obtained result is different with the ship speed used to develope the regression equation (see Table IV). The difference between the obtained speed and the data is 0.239 percent.

The calculated speed for ships with larger ratio of *LBP/B* become larger than that for smaller ratio for sample ships with the same length between perpendicular. This is because of addition of *LBP* and *LBP/B* in the equation (25). Using the Froude number formula in the equation (4), the same speed will be obtained for ships with the same length between perpendicular even the breadth of ships is different. As shown in Figure 3, generally the ship speed obtained from the equation (25) is larger than that obtained by Froude number approach. The difference is ranged from 1.92 knots up to -0.80 knots or 19.93% to -3.95% with mean of 0.62 knot or 5.01%.

B. Classification of Ro-Ro Ferry Base on Port Hierarchy

There are 884 variation of column arrangement of vehicles was performed in order to estimate the main dimension of sample ships. Variation for single arrangement for vehicles class of IV, V, and VI consist of 19, 14, and 10 arrangement. Variation for combination arrangement between class vehicles of IV and V, class vehicles of IV and VI and class vehicles of V and VI with arrangement of 158, 109 and 77, respectively. Variation for three combination between the class vehicles of IV, V and VI with 497 arrangement.

Using the equation (5), range of length of vehicle area (*Lva*) for the 884 variation of column arrangement of vehicles is obtained between 19.6 meters to 117.1 meters. Within this range, there are only 553 variation of length of vehicle area.

The breadth of vehicles class IV, V, and VI is the same, namely 2.1 meters. By using the equation (6), alternative for breadth of vehicle area is obtained to be 6.0 meters for arrangement of 2 row vehicles, 8.7 meters when the vehicles are arrange to be 3 row, 11.4 meters for 4 row of vehivles, 14.1 meters in cases of 5 row and 16.8 meters when the number of row become 6 vehicles.

As explained in the previous two paragraphs, there are 553 alternative for length of vehicle area (*Lva*) and 5 alternative of breadth of vehicle area (*Bva*). However, only 886 variation of vehicle area (*Lva* x *Bva*) was choosen through analysis of combination between *Lva* and *Bva*. As variable for length and breadth of ship, combination between the length and the breadth of vehicle area was determined following proportion of length between perpendicular and ship breadth as implicated in the equation (9).

The length of vehicle area (*Lva*) is function of number of column for each group vehicle (C_i). The breadth of vehicle area (*Bva*) is function of number of row for each group vehicle (R_i). Loading capacity (*Lc*) for every combination of *Lva* and *Bva* is calculated by using the equation (7). Range of loading capacity is obtained from 7.509 vehicles in combination of *Lva* = 19.6 meters and *Bva* = 6.0 meters to 132.906 vehicles in combination of *Lva* = 117.1 meters and *Bva* = 16.8 meters. Range of the loading capacity and length of vehicle area for each group of ship breadth is shown in Figure 4.

Figure 4 shows the length of vehicle area as a function of loading capacity. The length between perpendicular of ship as function of length of vehicle area was calculated by using the equation (8) for each variation of vehicle area (*Lva* x *Bva*). The obtained range of length between perpendicular is 21.778 meters for loading capacity of 7.51 vehicles (*Vu*) in the combination of *Lva* = 19.60 meters and *Bva* = 6.00 meters to 130.111 meters for loading capacity of 132.91 vehicles (*Vu*) in the combination of *Lva* = 117.10 meters and *Bva* = 16.80 meters.

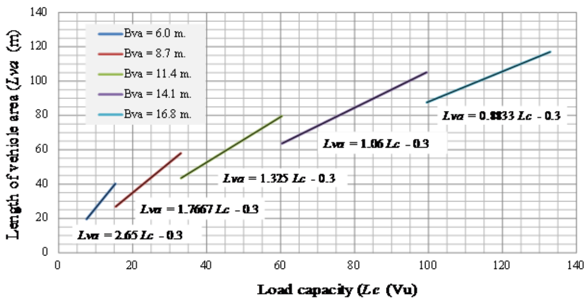
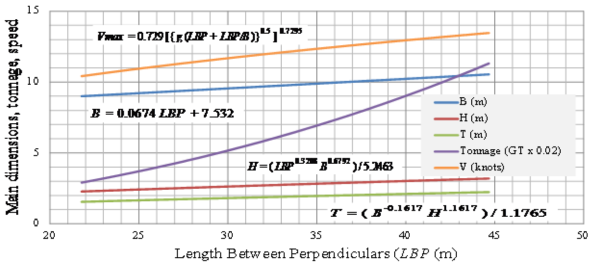
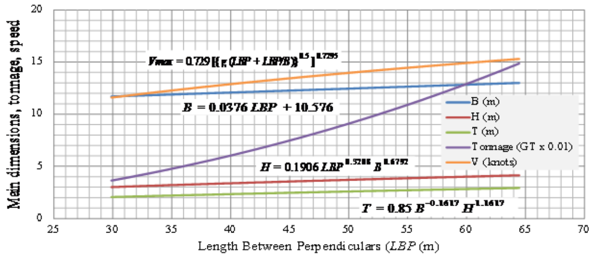


Figure 4. Length of vehicle area as function of loading

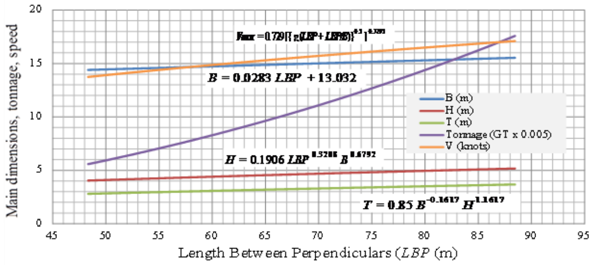
As the ship breadth is proportional with the ship length, the obtained ship breadth for ship with larger length becomes larger. However, this results valid only for ships with the same breadth of vehicle area. The ship breadth as function of ship length for each group of breadth of vehicle area (*Bva*) is shown in Figure 5.a – 5.c. These breadth are calculated by using the equation (9). The distance between the separate border of vehicle area and the ship side (*Dps*) was used as constraint in order to determine the ship breadth. This value was ranged from 1.5 meters to 2.27 meters.



5.a. Load capacity between 7.509 *Vu* and 15.283 *Vu*



5.b. Load capacity between 15.396 *Vu* and 31.000 *Vu*



5.c. Load capacity between 33.057 *Vu* and 60.302 *Vu*

Fig. 5. Variation of of dimension, tonnage, and speed of ro-ro ferry in loading capacity group

The height and draught of ship for every dimension of length and breadth are also shown in Figure 5. These dimension were calculated by using the equation (10) and the equation (11), respectively. The ship speed for every variation of main dimension was estimated by using the equation (25) as well as shown in Figure 5.

There are 886 variation of main dimension of ship sample through analysis as explained the previous three paragraphs. The gross tonnage for all sample ships was calculated by using the equation (12) – (14). The sample ships with length (*LBP*) larger than 59.889 meters with breadth (*B*) larger than 14.642 meters have gross tonnage larger than 1.500. The main dimension and the ship speed shown in Figure 5 are only for sample ships with gross tonnage less than 1.500 GT.

Regarding the port hierarchy, operational classification of ro-ro ferries was determined as shown in Table IV.

TABLE IV. CLASSIFICATION OF RO-RO FERRIES BASE ON PORT

Tonnage Groups	Ship's Tonnage	Main Dimensions				Vmax	Lc
		LBP	*B*	*H*	*T*		
<500	244	29.11	9.49	2.59	1.79	11.56	10.00
	347	35.00	9.89	2.83	1.96	12.35	12.00
	394	31.33	11.75	3.07	2.10	11.80	16.13
	472	40.89	10.29	3.05	2.13	13.05	14.00
	477	35.00	11.89	3.21	2.20	12.28	18.00
	496	35.78	11.92	3.23	2.23	12.37	18.84
500 up to 1000	523	36.89	11.96	3.27	2.26	12.51	18.96
	545	43.89	10.49	3.16	2.22	13.38	15.02
	628	40.89	12.11	3.44	2.36	12.99	21.00
	803	46.78	12.34	3.61	2.51	13.63	24.00
	992	52.33	12.54	3.78	2.65	14.20	26.83
>1000	1004	52.67	12.56	3.79	2.66	14.23	27.00
	1117	48.33	14.40	4.08	2.80	13.74	33.06
	1231	58.56	12.78	3.97	2.79	14.78	30.00
	1304	52.67	14.52	4.18	2.91	14.18	36.00
	1486	64.45	13.00	4.14	2.93	15.30	33.00
	1496	56.78	14.64	4.31	3.01	14.57	38.79

** Group of ship tonage according to national port hierarchy [7]*

C. Transport Capacity of Crossing Route

Specification of sample ships used to estimate capacity of inter-island transportation were shown in Table V. Alternative ship to be able to operate in a certain route has different maximum speed and loading capacity. Using the equation (15) – (17), the obtained operational speed are the same for several different traject distance. Figure 6 shows alteration trend of operational speed as a function of traject distance for the first sample ship with gross tonnage of 244, maximum speed of 11.56 knots and the loading capacity of 10 *Vu*.

Sail time of ship (*St*) will be longer for longer traject distance. Therefore the number of ships to be able to depart from the departure port (*Nsd*) is higher for traject with longer distance, for example 2 ships for traject distance between 0.5 miles to 11 miles, 12 ships for the traject distance between 116 miles to 127 miles. Here, *Nsd* is calculated by using the equation (18).

Operation frequency (*Ff*) to be able to reach depends on departure order. The first departure ship will reach higher operation frequency. For example, operation frequency for ship to be departed at the first time for the traject distance of 0.5 miles and 11 miles is 12 trips/day. The second departed ship will reach only 11 trips/day.

The operation frequency can be calculated by using the equation (20). Caculation results show that the operation frequency for shorter traject distance is higher than that for longer traject distance. Maximum trip of 48 per day can be reach for traject distance of 0.5 miles and 11 miles. The maximum trip for one day is only 26 trips for traject distance of 116 miles and 127 miles. These frequency includes the last depart even the ship will arrive at destination port in next day. Service frequency can be estimated by using the equation (21). Base on this equation, the service frequency is the same for all traject distance. That is 48 trips per day as shown in Figure 6.

In order to reach service frequency of 48 trips per day, the number ships to be operated depend on traject distance as shown in Figure 6. 4 ships are necessary for traject distance of 0.5 miles and 11 miles. For traject distance of 116 miles and 127 miles, 24 ships are necessary in order to reach 48 trips per day. This ship demand is calculated using the equation (22).

With service frequency of 48 trips per day and the loading capacity of 10 *Vu* then the route capacity is determined to be 480 *Vu* per day. This transport capacity is the same in all traject distance. This transport capacity was calculated by using the equation (23).

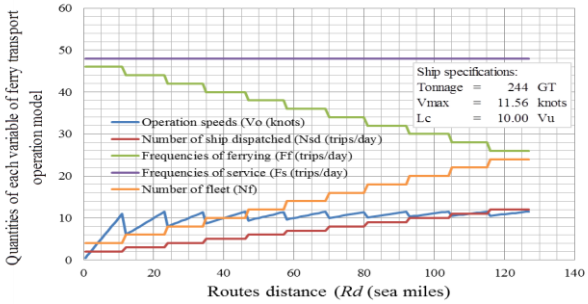


Fig. 6. Operation pattern of inter-island transportation

Figure 6 show an example of operation pattern of inter-island transportation with ship spesification of 244 GT, *Vmax* = 11.57 knots and *Lc* = 10 *Vu*. If speed of operated ship is higher and larger loading capacity, the traject distance will be longer and the total transport capacity becomes larger. According to alternative ships to be operated, the total transport capacity base on port class is shown in Table V.

TABLE V. TRANSPORT CAPACITY OF CROSSING ROUTE

Ferry ports[a]		Ships specifications[b]			Rd[c]	Nf	Fs	Tc
Claas	*Capaciy*	*GT*	*Vmax*	*Lc*				
III	< 500 GT	244	11.56	10.00	127	24	48	480
		347	12.35	12.00	135	24	48	576
		394	11.80	16.13	129	24	48	774
		472	13.05	14.00	143	24	48	672
		477	12.28	18.00	135	24	48	864
		496	12.37	18.40	135	24	48	883
II	500 GT up to 1000 GT	523	12.51	18.96	137	24	48	910
		545	13.38	15.02	147	24	48	721
		628	12.99	21.00	142	24	48	1008
		803	13.63	24.00	149	24	48	1152
		992	14.20	26.83	156	24	48	1288
I	>1000 GT	1004	14.23	27.00	156	24	48	1296
		1117	13.74	33.06	151	24	48	1587
		1231	14.78	30.00	162	24	48	1440
		1304	14.38	36.00	155	24	48	1728
		1486	15.30	33.00	168	24	48	1584
		1496	14.57	38.79	160	24	48	1862

[a] According to national port order [7], [b] Main dimension as shown in Table V, [c] The longest traject distance where the ship can be operated.

D. Model Design of Ro-Ro Ferry

1) Determination of Loading Capacity: Corresponding to the loading capacity (*Lc*) of operated ship, transport capacity of route (*Tc*) as shown in Table VI. Within this analysis, the transport capacity was assumed as transport demand (*Td*). Maximum transport demand (Td_{max}) to be serviced in a route with port class of III, port class II, and port class I is 883 *Vu*, 1288 *Vu*, and 1862 *Vu*, respectively. The equation (24) shows that loading capacity (*Lc*) is estimated as function of ratio of transport demand and maximum transport demand (Td/Td_{max}) as shown in Figure 7.

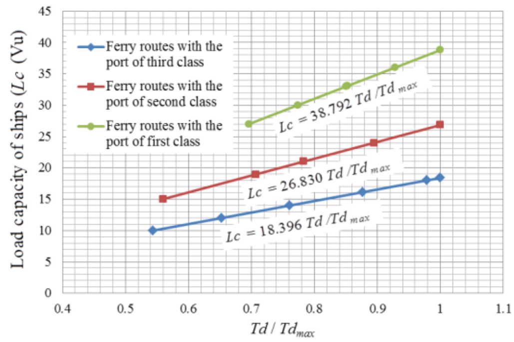


Fig. 7. Loading capacity as function of service transport

The equation for estimating loading capacity of ship is obtained by linear regression of data shown in Figure 7. The loading capacity obtained from this equation is transport service with frequency of 48 trips per day and loading factor of 100%. This service frequency is assumed to be the maximum frequency (Fs_{max}) to be able to reach for one day service. The loading capacity of ship can be increased if service frequency (*Fs*) is smaller than Fs_{max} and loading factor is smaller than 100%. Therefore, estimation of loading capacity (*Lc*) as function of transport service demand (*Td*) can be formulated as follows:

$$Lc = 18.396\ (Td/883)\ (48/Fs)\ /\ Lf \quad (26)$$

$$Lc = 26.830\ (Td/1288)\ (48/Fs)\ /\ Lf \quad (27)$$

$$Lc = 38.792\ (Td/1862)\ (48/Fs)\ /\ Lf \quad (28)$$

The equations (26) – (28) are equations to estimate the loading capacity for each route of inter-island transportation with port class of III, II, and I. These three equations valid only for demand of transport service (*Td*) of car group IV, V, ans VI (see Table II). *Td* is amount of vehicle after multipled by their convertion index, respectively (see Table II). The value of Td/Td_{max} should be smaller than one. This means that *Td* should be smaller than Td_{max}. The service frequency (*Fs*) should not be exceeded 48 trips per day. Considering the main dimension of ship and port class, *Fs* and *Lf* are estimated with loading capacity (*Lc*) is not larger than the value of coefficients in the equations (26) – (28).

2) Determination of Main Dimension: Estimation of loading capacity as function of length and breadth of vehicle area has been discussed in point B. The length of vehicle area was estimated using polynomial regression as function of loading capacity. The equation for estimating the length of vehicle area is different in five aternative breadth of vehicle area as shown in Figure 4.

The lenght between perpendicular (LBP) is estimated by using the equation (8) as function of length of vehicle area. The ship breadth is estimated by using the equation (9) as function of LBP. This estimation of ship breadth is also conducted under consideration that the ship breadth is also function of breadth of vehicle area as shown in the equation (6). The equation for estimating ship breadth as function of LBP is shown in Figures 5.a – 5.c.

Base on analysis explained in the provious two paragraphs, LBP and B of ro-ro ferry can be estimated as function of loading capacity (Lc). The equation is devided base on loading capacity group as follows:

a. Loading capacity (*Lc*) between 7.509 *Vu* and 15.283 *Vu*

$$LBP = (2.65\ Lc - 0.3)/0.9 \quad (29)$$

$$B = 0.0674\ LBP + 7.532 \quad (30)$$

b. Loading capacity (*Lc*) between 15.396 *Vu* and 33.000 *Vu*

$$LBP = (1.7667\ Lc - 0.3)/0.9 \quad (31)$$

$$B = 0.0376\ LBP + 10{,}576 \quad (32)$$

c. Loading capacity (*Lc*) between 33.057 *Vu* and 60.302 *Vu*

$$LBP = (1.325\ Lc - 0.3)/0.9 \quad (33)$$

$$B = 0.0283\ LBP + 13.032 \quad (34)$$

There are 886 variation of length and breadth of ships can be obtained from series analysis in Part B (Classification of Ro-Ro Ferry According to Port Hierarchy). The height and draught of ship correspoding to these length between perpendicular and breadthof ship can be estimated from the equation (10) and the equation (11), respectively. Following the equations (10) – (11), the ship height is calculated as function of length between perpendicular and ship breadth. The ship draught is formulated as finction of ship breadth and ship draught. The formula to estimate the ship height and the ship breadth are shown in the equations (35) – (36).

$$H = (\ LBP^{0.3208}\ \mathrm{B}^{0.6792}\ )\ /\ 5.2463 \quad (35)$$

$$T = (\ B^{-0.1617}\ H^{1.1617}\ )\ /\ 1{,}1765 \quad (36)$$

The obtained main dimension of ro-ro ferry by using these equations for sample ships shown in Table IV, the ratio between breadth and draught (*B/T*) is ranged from 4.220 up to 5.805 and the ratio between freeboard and breadth (*Fb/B*) is ranged between 0.081 and 0.096. The range of these two ratio is simliar with result of previous research [3]. However, stability analysis shoul be conducted in advance especially for ships with ratio of length between perpendicular and breadth (*LBP/B*) smaller than 2.275. A ship with ratio of length between perpendicular and breadth (*LBP/B*) less than 2.275, the ratio between breadth and draught (*B/T*) becomes larger than 5.5. As result, the critical of vertical center of gravity significantly decreases [3].

3) Determination of Ship Speed: The equation for estimating maximum speed was shown in the equation (25). This equation is used to determined the speed of sample ships using in this research. The maximum speed is used as variable to restrict maximum distance of route to be serviced by ro-ro ferry as shown in Table V. The effective service speed for each route can be estimated by using the equation (16) associated with the equations (15) – (17). Estimation of effective service speed shown in Figure 6 is example of using these equations.

IV. CONCLUSSION

The calculation results and analysis regarding effect of port class, traject distance and technical spesification on model design of ro-ro ferry, some conclusion can be remarked as follows:

1. The transport sevice demand for car to be serviced in a certain route is different of each port class. Those are 883 units per day for port class III, 1288 units per day for port class II and 1862 unit per day for port class I.
2. The maximum traject distance corresponding to the maximum ship speed, is also different depending on the port class with minimum frequency of 2 for one ship operated in a day. The traject distance of 135 miles is maximum traject distance for port class III, 156 miles for port class II and 168 miles for port class I, respectively.
3. The loading capacity of ro-ro ferry was estimated based on service transport demand. The maximum load capacity for ship tonage less than 500 GT or port class III is 18.40 vehicle units. For ships with tonage larger than 500 GT

and smaller than 1000 GT or port class II is 26.83 vehicle units. For ship with tonage large than 1000 GT and smaller than 1500 GT or port class I is 38.79 vehicle units.

4. The main dimension and service speed of ro-ro ferry are estimated based on the loading capacity considering the loading capacity corresponding to the three group of ship tonage and port class.

REFERENCES

[1] Syamsul Asri, Muh. Saleh Pallu, M. Arsyad Thaha, dan Misliah, “Study on Availabity of Ships for Inter-Island Transportation in Indonesia” (in Indonesia), Proceeding of the 9th National Seminar on Maritime, pp. A2 14-23, April 2014.

[2] Syamsul Asri, Muh. Saleh Pallu, M. Arsyad Thaha, dan Misliah, “Clustering of Dimension and Tonage of Ro-Ro Ferry Based on Classification of Inter-Island Trasportation” (in Indonesia), Scientific Publication of Research Results, Doctoral Program of Civil Engineering Hasanuddin University, Vol. XXIV, pp. 1-11, Oktober 2015.

[3] Syamsul Asri, Muh. Saleh Pallu, M. Arsyad Thaha, dan Misliah, “Intact Stability Criteria and Its Impact on Design of Indonesian Ro-Ro Ferries ”, International Journal of Engineering Research and Technology, Vol. 3 No. 3, pp. 1774-1779, March 2014.

[4] Taggart, R., 1980, Ship Design and Construction, The Society of Naval Architects and Marine Engineers (SNAME), New York.

[5] Molland, A., 2008. The Maritime Engineering Reference Book, A Guide to Ship Design, Construction, and Operation. Charon Tec Ltd., A Macmillan (www.macmillansolutions.com). Hungary.

[6] Suwarto, A. 2010. Final Report of Inter-Island Transportation in Merak – Bakauheni Route Until 2050, Research Collaboration between National Research Council of Research and Technolgy Ministry of Indonesia with Agency of Transportation Research and Development of Transportation Ministry of Indonesia, (Online), http://km.ristek.go.id/assets/files/Perhubungan/ 500n/500.pdf, aaccessed on 1 April 2013 (in Indonesia).

[7] Transportation Ministry of Indonesia, 2002. Prescription of Transportation Ministry of Indonesia Number KM 53 Regarding National Port Order (in Indonesia).

[8] Transportation Ministry of Indonesia, 2003. Prescription of Transportation Ministry of Indonesia Number 58 Regarding Mechanism of Determination and Formulation of Inter-Island Transportation Fare (in Indonesia).

[9] Transportation Ministry of Indonesia, 2013. Regulation of Transportation Ministry of Indonesia Number PM 8 regarding Ship Measurement (in Indonesia).

[10] Transportation Ministry of Indonesia, 1994. Prescription of Directorate General Land Transportation, Department of Transportation of Indonesia Number 005/3/13/DRPD/94 Regarding Technical Guidance for Requirement of Minimum Service for River, Lake and Inter-Island Transportation (in Indonesia).