ECONOMIC EVALUATION AND GAS EMISSIONS FOR COAL TRANSPORTATION USING PUSHER BARGE SYSTEM AND EMPTY BARGES PLACEMENT AT PORT

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ABSTRACT

Coal as a natural resource that is utilized for the benefit and needs of human life. In this study, coal transportation utilizes sangkulirang river as a transportation lanes. The target of coal transportation is 7,000,000 tons per year and will be increased to 14,000,000 tons per year. The tidal river difference occurs twice in one day, with the lowest water depth of 3.4 m. The capacity of the conveyor for loading coal at the river terminal is 1,840 mt / hr and 1,042 mt / hours in the transhipment terminal. Under normal conditions, the location of tidal areas that can't be traversed by a barge of 500 m. The size of the barge used is 270 ft with a capacity of 5,260 Tons. Distance traveled as far as 61.10 km.
The results shows the use of pusher barge became the preferred mode of transportation and used of empty barge placement in Jetty and at transhipment point. Results of coal transportation obtained 6.611.820 ton per year and total trip 1.257 per year. The use of 270 ft barge with draft of 3,6 m is the most optimal choice with the effeciently of 15% compares to without placing an empty barge. Coal transportation by using pusher barge system is Rp 54.876 per ton. From the environmental point of view is the most environmental friendly.

Keywords: coal transportation, tow barges, empty barges, tidal, exhaust gas emissions

INTRODUCTION

Natural resources such as coal that can be exploited for the various interests and needs of human life, coal has an important role in Indonesia's economic development. With the production and export of coal, and not supported by adequate transportation, it will undoubtedly hinder the economic rate for coal export. In Kalimantan river has playing important roles for coal transportation. Determination of the type of transportation to be used is also one of the most important means. In this study two options for coal transportation are used, first option is used tow barge system and the second one is pusher barges system, the comparison between modes of transportation based of the amount of transport generated. With the placement of barges in the riverside terminal and transhipment at sea, it will make coal transportation more efficient and optimal. Therefore, it is necessary to collect the data such as, geographically, weather, and tidal water.
The initial coal transport capacity is 7,000,000 ton and will be increased to 14,000,000 ton per year by river utilization to transhipment at sea and then using large ship for export. So the selection of the right barge will increase the efficiency of the amount of coal to be transported. The barge size used as a reference is 180 ft, 230 ft, 250 ft, 270 ft and 300 ft. Differences of tidal rivers that occur as much as two times in a day with different times. The depth of the river is 3.4 m and there is a tidal landing location along the 1.7 km that can't be traversed by high water laden. The loading capacity at jetty in river side coaql terminal about 1,840 MT per hour and unloading capacity in Transhipment at open sea about 1,042 MT per hour.

The results shows the use of pusher barge became the preferred mode of transportation and used of empty barge placement in Jetty and at transhipment point. Results of coal transportation obtained 6.611.820 ton per year and total trip 1.257 per year. The use of 270 ft barge with draft of 3,6 m is the most optimal choice with the effeciently of 22,75% compares to without placing an empty barge. Coal transportation tariff is Rp 54.876 per ton. From the environmental point of view is the most environmental friendly.

TRANSPORTATION CONCEPT

Coal Transportation from the river side coal terminal to the transhipment point at the sea is determined by 5 stages as shown in figure 1.

Fig. 1 Distance and Stages of Coal transportation

The five stages in the transportation of coal while the stages are determined due to the shallowing or narrowing of the routes and coal ports, where details of the stages as follows:

1. Stage 1, the location of the jetty at the river, where the ship speed about 2 knot.
2. Stage 2, distances of about 5 km with the ship speed of 2 knots and in this stage there are critical areas that has a depth of 3 m with the distances about 500 m.
3. Stage 3, distances about 2.3 km and ship speed about 4 knot.
4. Stage 4, distances 53.8 km with the ship speed about 5 knot.
5. Stage 5, the location of transhipment point at the sea.

In this study, firstly perform a comparison of all types of vessels that can be used to transport coal from the jetty at the river toward transhipment point at open sea. There are two types of vessels that can be used in the transport of coal, such as towed barge system and pusher barge system. The selection of the two of ship can be used for coal transportation based on parameters, such as availability in the market, shipyard facility to perform maintenance of the ship, the optimization of transportation, the standard of the crew, the cost of investment, maneuvering ship, the draft of the ship, ship speed, and environmentally friendly.

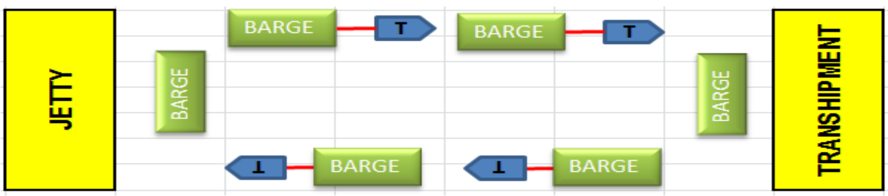

Fig. 2 Pusher Barges With Placement Empty Barges at the Port

In order more improvement for coal transportation capacity, pusher barge system has applied. The pusher barge system has advantages than tow barge system [Nakamura and Yamaguchi] especially for safety and ship speed. Figure 2 shows the concept of coal transportation for pusher barge with placing the empty barge at the jetty river and transhipment point.
Figure 3 shows the concept of coal transportation for towed barge with placing the empty barge at the jetty river and transhipment point. In this concept the tug boat has no waiting time in the

port. When the tug boat and barge arrive in the port, the tug boat directly pull the empty barge to return at the next port.

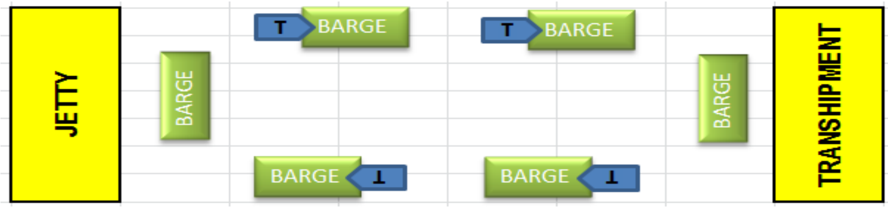

Fig. 3. Tow Barges With Placement Empty Barges at the Port

METHOD

A model has been developed to determine an appropriate coal shipment by using towed barge system and pusher barge system, from jetty at river to transhipment point at sea. In order to find the optimal transportation efficiency for towed barge system or pusher barge system, the sailing time between jetty at river to transhipment point must be greater or equal to the coal handling in the port.

The jetty at river is marked by *a* while node *b* indicates transhipment point at sea. Let d_{ab} be distance between port *a* and port *b*. V_k is the speed of ship type *k* from port *a* and port *b*, including sailing time in river, at sea and in the port, meanwhile α is the time for connecting and disconnecting between pusher and barge. Total time for all sub-route to transport coal per trip can be expressed as.

$$T = \sum_{1}^{n} \frac{d_{ab}}{V_k} + \alpha \quad \text{.......(1)}$$

When the pusher or tug has no waiting time in the port for cargo handling, in this case the sailing time of a towed barge or pusher barge for sailing distances d is bigger than the waiting time and the total number of trip per year is given by.

$$N_1 = \frac{T_o}{Tl} \; x \; np \quad \text{.......(2)}$$

Pusher or tug has waiting time in the port for cargo handling, in this case the sailing time of a pusher barge or towed barge for distance d is less than the waiting time and the total number of trip per year is given by

$$N_2 = \frac{T_o}{T+tl} \; x \; np \quad \text{.......(3)}$$

where T_o = 340 is operation days per year, np is the numbers of pusher or tug, *tl* is waiting time in the port for cargo handling and Wo is barge cargo capacity.

Then the annual transportation capacity per year for pusher barge system without pusher waiting time in the port is obtained as

$$W_1 = Wo \text{ x } N_1 \quad \text{.......(4)}$$

The annual transportation capacity per year for pusher barge system or towed barge system with pusher has waiting time in the port is obtained as

$$W_2 = Wo \text{ x } N_2 \quad \text{.......(5)}$$

.In order to calculate the economical of coal transportation, the required freight rate method is used and its obtained as

$$RFR = \frac{AAC}{C} \qquad (6)$$

$$AAC = Y + (CRF \times P) \qquad (7)$$

.

where AAC = average cost of ship per year; Y = operational cost of ship per year, CRF = coefecient factor = 0,11017; P = revenue per year and C= total capacity per year.

After the operation mode is known, fuel consumption is calculated by considering the fraction of maximum fuel consumption of each mode of operation of the ship. It is necessary to cconsider the actual fuel consumption during different phases of ship operations carried out in the port area. The modelling for estimation pollutant emission from ship activities are calculated included main engine types, fuel types, operation types, navigation times and ship speed, other data include emissions factors, and specification parameters such as ship fuel consumption, engine type and ship operation mode at the port. Calculation of total emissions of a pollutant from the main engine is shown in the following equation Trozzi:

$$E_i = \Sigma_{jklm} E_{ijklm} \qquad (8)$$

$$E_{ijklm} = S_{jkm}(GT)\, t_{jklm}\, F_{ijklm} \qquad (9)$$

where i = pollutant; j = type of fuel; k =ship type; l = engine type; m = vessel operating mode; Ei = total emissions pollutans i; E_{ijklm} = Total emissions of pollutant i, type of fuel is j, type of ship is k and l is type of engine and m is vessel operating mode. F_{ijklm} = average emission factor of fuel pollutant i, and type of fuel is j, types of vessel is k and engine type is m. S_{jkm} (GT) = Daily fuel consumption by type of fuel j, type of ship is k, with the vessel operating mode m by using the function GT. t_{jklm} = navigation of the ship type k with the type of engine is l, the type of fuel is j and ship operation mode is m. While to estimate the fuel consumption of auxiliary engines obtained from the following equation Ishida.

$$f = 0{,}2 \times O \times L \qquad (10)$$

where: f = fuel consumption (kg/ship/h), O = rated output (PS/engine), L = load factor (crusing: 30%, hotelling (tanker): 60%, hotelling (other ship): 40% and 50% maneuvering.

RIVER CONDITIONS

Table 1 shows the tidal at Sangkulirang river in Province East Kalimantan on February, this month is the driest month or the lowest river water depth.

Table 1 Tidal on February (The Driest Month)

J / T	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	4.1	4.3	4.6	4.9	5.1	5.2	5.1	4.8	4.4	4.1	3.9	3.8	4.0	4.3	4.8	5.2	5.6	5.8	5.7	5.4	5.0	4.6	4.2	4.0
2	4.0	4.1	4.5	4.8	5.2	5.3	5.3	5.0	4.7	4.3	3.9	3.7	3.8	4.1	4.5	5.0	5.4	5.7	5.8	5.6	5.2	4.8	4.3	4.0
3	3.9	4.0	4.3	4.7	5.1	5.4	5.4	5.3	4.9	4.5	4.1	3.8	3.7	3.9	4.2	4.7	5.2	5.6	5.7	5.7	5.4	4.9	4.5	4.1
4	3.9	3.9	4.2	4.6	5.0	5.3	5.5	5.5	5.2	4.8	4.3	3.9	3.7	3.8	4.0	4.4	4.9	5.4	5.6	5.6	5.4	5.1	4.6	4.2
5	3.9	3.9	4.0	4.4	4.8	5.2	5.5	5.6	5.4	5.1	4.6	4.2	3.9	3.8	3.9	4.2	4.7	5.1	5.4	5.5	5.4	5.2	4.8	4.3
6	4.0	3.9	4.0	4.2	4.6	5.0	5.4	5.5	5.5	5.3	4.9	4.5	4.2	4.0	4.0	4.2	4.5	4.9	5.2	5.4	5.4	5.2	4.9	4.5
7	4.2	4.0	3.9	4.1	4.4	4.8	5.2	5.4	5.5	5.4	5.1	4.8	4.4	4.2	4.1	4.2	4.4	4.7	4.9	5.1	5.2	5.1	4.9	4.6
8	4.3	4.1	4.0	4.1	4.3	4.6	4.9	5.2	5.4	5.4	5.2	5.0	4.7	4.5	4.3	4.3	4.4	4.6	4.8	4.9	5.0	5.0	4.9	4.7
9	4.4	4.2	4.1	4.1	4.2	4.5	4.7	5.0	5.1	5.2	5.2	5.1	5.0	4.8	4.6	4.5	4.5	4.6	4.7	4.8	4.8	4.8	4.8	4.7
10	4.5	4.4	4.3	4.2	4.3	4.4	4.5	4.7	4.9	5.0	5.1	5.1	5.1	5.0	4.9	4.8	4.7	4.7	4.7	4.7	4.7	4.7	4.6	4.6
11	4.6	4.5	4.5	4.4	4.4	4.4	4.4	4.5	4.6	4.7	4.9	5.0	5.1	5.1	5.1	5.1	5.0	4.9	4.7	4.6	4.5	4.5	4.5	4.5
12	4.5	4.6	4.6	4.6	4.6	4.5	4.4	4.4	4.4	4.5	4.6	4.8	5.0	5.1	5.3	5.3	5.3	5.1	4.9	4.7	4.4	4.4	4.3	4.4
13	4.5	4.6	4.7	4.8	4.8	4.7	4.5	4.4	4.3	4.2	4.3	4.5	4.7	5.0	5.3	5.4	5.5	5.4	5.1	4.8	4.3	4.3	4.2	4.2
14	4.3	4.5	4.8	4.9	5.0	4.9	4.7	4.5	4.2	4.1	4.1	4.2	4.5	4.8	5.2	5.5	5.6	5.6	5.4	5.0	4.3	4.3	4.1	4.1
15	4.2	4.4	4.7	5.0	5.1	5.1	5.0	4.7	4.3	4.1	3.9	3.9	4.2	4.5	5.0	5.3	5.6	5.7	5.5	5.2	4.4	4.4	4.1	4.0
16	4.0	4.3	4.6	5.0	5.3	5.3	5.2	4.9	4.5	4.2	3.9	3.8	3.9	4.2	4.7	5.2	5.5	5.7	5.7	5.4	4.5	4.5	4.1	3.9
17	3.9	4.1	4.5	4.9	5.3	5.5	5.4	5.2	4.8	4.4	4.0	3.7	3.7	4.0	4.4	4.9	5.3	5.6	5.7	5.5	4.7	4.7	4.2	3.9
18	3.8	4.0	4.3	4.8	5.2	5.5	5.6	5.4	5.1	4.6	4.2	3.8	3.7	3.8	4.2	4.6	5.1	5.5	5.6	5.6	4.8	4.8	4.4	4.0
19	3.8	3.9	4.2	4.6	5.0	5.4	5.6	5.6	5.3	4.9	4.4	4.0	3.8	3.8	4.0	4.4	4.8	5.3	5.5	5.5	5.0	5.0	4.5	4.1
20	3.9	3.8	4.0	4.4	4.8	5.3	5.6	5.7	5.5	5.0	4.7	4.3	4.0	3.9	4.0	4.2	4.6	5.0	5.4	5.4	5.0	5.0	4.7	4.3
21	4.0	3.9	3.9	4.2	4.6	5.1	5.4	5.6	5.6	5.4	5.0	4.6	4.3	4.0	4.0	4.2	4.5	4.8	5.2	5.2	5.1	5.1	4.8	4.4
22	4.1	3.9	3.9	4.1	4.4	4.8	5.2	5.4	5.5	5.4	5.2	4.9	4.6	4.3	4.2	4.2	4.4	4.6	5.0	5.0	5.0	5.0	4.8	4.5
23	4.3	4.1	4.0	4.1	4.3	4.6	4.9	5.2	5.4	5.4	5.3	5.1	4.8	4.6	4.5	4.4	4.5	4.6	4.9	4.9	4.9	4.9	4.8	4.6
24	4.4	4.2	4.2	4.2	4.3	4.5	4.7	4.9	5.1	5.2	5.2	5.1	5.0	4.9	4.7	4.6	4.6	4.6	4.7	4.7	4.7	4.7	4.7	4.6
25	4.5	4.4	4.3	4.3	4.3	4.4	4.5	4.7	4.8	4.9	5.0	5.1	5.1	5.1	5.0	4.9	4.8	4.7	4.6	4.6	4.6	4.6	4.6	4.6
26	4.6	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.2	5.1	4.9	4.6	4.6	4.4	4.4	4.4	4.4
27	4.5	4.6	4.7	4.7	4.7	4.6	4.5	4.4	4.4	4.4	4.5	4.7	4.9	5.1	5.3	5.3	5.3	5.2	4.7	4.7	4.3	4.3	4.3	4.3
28	4.5	4.6	4.8	4.9	4.9	4.8	4.6	4.4	4.3	4.2	4.2	4.4	4.6	4.9	5.2	5.4	5.5	5.4	4.8	4.8	4.3	4.3	4.1	4.2

Table 2 Tidal on May (The wettest Month)

J / T	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	4.1	4.6	5.0	5.5	5.7	5.8	5.4	5.3	4.8	4.4	4.1	3.9	4.0	4.2	4.5	4.9	5.1	5.2	5.1	4.8	4.5	4.1	3.8	3.8
2	3.9	4.3	4.8	5.3	5.7	5.9	5.8	5.6	5.1	4.7	4.2	4.0	3.9	4.1	4.4	4.7	5.0	5.2	5.2	5.0	4.6	4.2	3.9	3.8
3	3.8	4.1	4.5	5.0	5.5	5.8	5.9	5.8	5.4	5.0	4.5	4.1	4.0	4.0	4.2	4.5	4.9	5.1	5.2	5.0	4.8	4.4	4.0	3.8
4	3.8	3.9	4.3	4.8	5.2	5.6	5.8	5.8	5.6	5.2	4.8	4.4	4.1	4.0	4.1	4.4	4.7	4.9	5.1	5.1	4.9	4.6	4.2	3.9
5	3.8	3.9	4.1	4.5	5.0	5.4	5.7	5.8	5.7	5.4	5.0	4.6	4.3	4.1	4.1	4.3	4.5	4.8	5.0	5.0	4.9	4.7	4.4	4.1
6	3.9	3.9	4.0	4.3	4.7	5.1	5.4	5.6	5.6	5.5	5.2	4.9	4.6	4.3	4.2	4.3	4.4	4.6	4.8	4.9	4.9	4.8	4.6	4.4
7	4.2	4.0	4.1	4.2	4.5	4.8	5.1	5.4	5.5	5.4	5.3	5.0	4.8	4.5	4.4	4.3	4.4	4.5	4.7	4.8	4.9	4.8	4.7	4.6
8	4.4	4.3	4.2	4.2	4.4	4.6	4.8	5.1	5.2	5.3	5.3	5.1	4.9	4.8	4.6	4.5	4.4	4.5	4.5	4.6	4.7	4.8	4.8	4.7
9	4.6	4.5	4.4	4.4	4.4	4.5	4.6	4.8	4.9	5.1	5.1	5.1	5.0	4.9	4.8	4.6	4.5	4.5	4.5	4.5	4.6	4.7	4.7	4.8
10	4.8	4.8	4.7	4.6	4.5	4.5	4.5	4.6	4.7	4.8	4.9	5.0	5.0	5.0	4.9	4.8	4.7	4.5	4.4	4.4	4.4	4.5	4.6	4.8
11	4.9	5.0	5.0	4.9	4.8	4.6	4.5	4.4	4.4	4.5	4.6	4.8	4.9	5.0	5.0	5.0	4.8	4.6	4.4	4.3	4.3	4.3	4.5	4.7
12	4.9	5.1	5.2	5.2	5.1	4.9	4.7	4.5	4.3	4.3	4.4	4.5	4.7	4.9	5.0	5.1	5.0	4.8	4.5	4.3	4.2	4.2	4.3	4.5
13	4.8	5.1	5.3	5.4	5.4	5.2	4.9	4.6	4.3	4.2	4.2	4.3	4.5	4.8	5.0	5.1	5.1	4.9	4.7	4.4	4.1	4.0	4.1	4.3
14	4.6	5.0	5.3	5.5	5.6	5.5	5.2	4.8	4.5	4.2	4.1	4.1	4.3	4.6	4.8	5.1	5.1	5.0	4.8	4.5	4.2	4.0	3.9	4.1
15	4.4	4.8	5.2	5.5	5.7	5.7	5.5	5.1	4.7	4.3	4.1	4.0	4.1	4.4	4.7	5.0	5.1	5.1	4.9	4.6	4.3	4.0	3.8	3.9
16	4.1	4.5	5.0	5.4	5.7	5.8	5.7	5.4	5.0	4.5	4.2	4.0	4.0	4.2	4.5	4.8	5.0	5.1	5.0	4.8	4.4	4.1	3.8	3.8
17	3.9	4.3	4.7	5.2	5.6	5.9	5.9	5.6	5.3	4.8	4.4	4.1	4.0	4.1	4.3	4.6	4.9	5.1	5.1	4.9	4.6	4.3	3.9	3.8
18	3.8	4.0	4.5	5.0	5.4	5.8	5.9	5.8	5.5	5.1	4.6	4.2	4.0	4.0	4.2	4.5	4.8	5.0	5.1	5.0	4.8	4.4	4.1	3.9
19	3.8	3.9	4.2	4.7	5.1	5.5	5.8	5.8	5.6	5.3	4.9	4.5	4.2	4.1	4.1	4.3	4.6	4.9	5.0	5.1	4.9	4.6	4.3	4.0
20	3.9	3.9	4.1	4.4	4.8	5.3	5.6	5.7	5.7	5.4	5.1	4.7	4.4	4.2	4.2	4.3	4.5	4.7	4.9	5.0	5.0	4.8	4.5	4.2
21	4.0	3.9	4.0	4.2	4.6	5.0	5.3	5.5	5.6	5.5	5.2	4.9	4.6	4.4	4.2	4.3	4.4	4.6	4.8	4.9	5.0	4.9	4.7	4.5
22	4.3	4.1	4.1	4.2	4.4	4.7	5.0	5.3	5.4	5.4	5.3	5.1	4.8	4.6	4.4	4.3	4.3	4.5	4.6	4.8	4.9	4.9	4.8	4.7
23	4.5	4.4	4.3	4.3	4.4	4.5	4.7	5.0	5.1	5.2	5.2	5.1	4.9	4.7	4.6	4.4	4.4	4.4	4.5	4.6	4.7	4.8	4.9	4.8
24	4.8	4.6	4.5	4.4	4.4	4.5	4.6	4.7	4.9	5.0	5.1	5.1	5.0	4.9	4.7	4.6	4.5	4.4	4.4	4.5	4.6	4.7	4.8	4.9
25	4.9	4.9	4.8	4.7	4.6	4.5	4.5	4.5	4.6	4.7	4.8	4.9	5.0	4.9	4.9	4.7	4.6	4.5	4.4	4.3	4.4	4.5	4.7	4.8
26	5.0	5.1	5.1	5.0	4.9	4.7	4.6	4.5	4.4	4.5	4.6	4.7	4.8	4.9	4.9	4.9	4.7	4.6	4.4	4.3	4.2	4.3	4.5	4.7
27	4.9	5.1	5.3	5.3	5.2	5.0	4.7	4.5	4.4	4.3	4.3	4.5	4.7	4.8	4.9	5.0	4.9	4.7	4.5	4.3	4.2	4.1	4.3	4.5
28	4.8	5.1	5.4	5.5	5.4	5.3	5.0	4.7	4.4	4.2	4.2	4.3	4.4	4.7	4.9	5.0	5.0	4.8	4.6	4.3	4.1	4.0	4.1	4.3
29	4.6	5.0	5.3	5.6	5.6	5.6	5.3	4.9	4.6	4.3	4.1	4.1	4.2	4.5	4.7	5.0	5.0	5.0	4.8	4.5	4.2	4.0	3.9	4.0
30	4.3	4.7	5.2	5.5	5.7	5.8	5.6	5.2	4.8	4.4	4.1	4.0	4.1	4.3	4.6	4.9	5.0	5.1	4.9	4.6	4.3	4.0	3.8	3.9
31	4.1	4.5	4.9	5.4	5.7	5.9	5.8	5.5	5.1	4.7	4.3	4.0	4.0	4.1	4.4	4.7	5.0	5.1	5.0	4.8	4.5	4.1	3.9	3.8

From the table, river tidal occurred two times a day with varying heights during limited hours. The lowest water level is at a water depth of 3.7 m and the highest water level reaches a height of 5.8 m. because of that the lowest level water depth ships cannot pass through the shipping routes at the critical areas. Meanwhile Table 2 shows the tidal river on May, this month is the wettest month. The water depth is better than other months in a year, so the ships have a chance to pass through the ship routes more compare to the driest month.

TUG AND BARGE DIMENSIONS

From the data of river tidal, the use of barges size should be taken into account and adapted to the geographical conditions and tides that occur in the river, due to geographical conditions there are some point that cannot be passed by barge with a high draft. It needs a careful analysis to accommodate the size and capacity of the barge against the geography conditions, especially in the critical area. Based on safety consideration for maximum draft of barge with the following conditions is taking into account.

- *Trim by stern* = 0.4 m
- *Clearance with seabed* = 0.5 m

Table 3 shows the maximum of barge draft for several size of barge are commonly used for coal transportation in Indonesia with considering geografical conditions and shipping safety [Indonesian Classification Bureau].

Table 3. Maximum draft of barge

No	Barge Dimensions (Feet)	Barge Draft (m)	Trim by Stern (m)	Seabed Clearence (m)	Total (m)
1	180	2.31	0.4	0.5	3.21
2	230	2.77	0.4	0.5	3.67
3	250	3.27	0.4	0.5	4.17
4	270	3.80	0.4	0.5	4.70
5	300	4.26	0.4	0.5	5.16

Figure 4 shows the comparison between river water depth and several barge which are commonly use in Indonesia, such as barge type 300 feet, 270 feet, 250 feet, 230 feet and barge type 180 feet. While the river water depth data shows from january to may or five month.

Barge with a size of 300 feet can only sail with the highest tidal conditions and only at certain hours, therefore coal capacity transport per year can’t meet export demand. While for barge with size of 270 feet can pass safely to transport the coal with water at high tide conditions that often occur. At the same time the barge with size of 250 feet, 230 feet and 180 feet can also be passed by the tidal conditions, but with barge cargo capacity like that, it will be inefficient because it must use a barge with a high number to achieve the coal capacity transport per year in order to meet the export demand.

Therefore, barge with size of 270 feet will be used for coal transportation, however barge with size of 270 feet still has problems when barge draft reached of 4.7 m due to the river water depth especially ini critical area and will affect the transport capacity of coal per year.

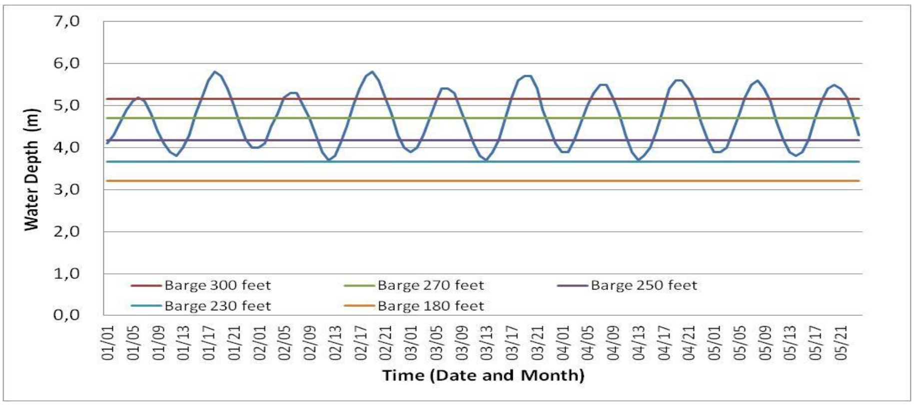

Fig. 4. Comparison between river water depth and barge draft

The tug boat is used to tow or push the barge for coal transportation [4] with the following dimensions:

- Ship Type = *Tug Boat*
- Dimensions :
  - Length Over All (LOA) = 21.50 m
  - Length Between Perpendicullar (LBP) = 19.68 m
  - Breadth (B) = 6.80 m
  - Height (H) = 3.34 m
  - Draft (T) = 2.60 m
- Main Engine (M/E) = 829 HP YANMAR 6AYM (2 Unit)
  RPM = 1900 rpm
- Auxilliary Engine (A/E) = 30 kW/ 37.5 KVA 4CHL Series
- Ship Speed = Max : 11 Knots, Normal : 9 Knots, Economic : 8 Knots
- Fuel Type = HSD/ Solar

Data of loading capacity the jetty at river and unloading capacity transhipment point at sea with operational hours of 24 hours as follows.

a. Jetty at River
   - River Water Depth = 9 - 12 m
   - Conveyor Capacity = 2,400 t/hour
b. Transhipment at sea
   - Sea Water Depth = ± 25 m
   - Unloader Capacity = 25,000 t/day = 1,042 t/hour
   - Coal Carrier Ship = 65,000 ton

RESULT AND DISCUSSION

In order to obtain more optimal result, the barge draft will reduction with the reduction of the barge capacity, where the ton per centimeter (TPC) of barge is 12 ton. The maximum draft barge is the sum of normal barge draft and added with the seabed clearance and trim by stern with total at least of 0.90 m. The simulation shows that the barge size of 270 feet with a maximum draft of 3.60 m provides the best results for the cargo capacity per year with a total of 510,220 ton per year and total the trip are the 97 trips. Table 5 shows the result of cargo capacity at the driest month.

The use barge of 270 feet with normal draft of 3.60 m has a total minimal waiting time both in port and shipping routes compared with the other draft. This comparison is done in February with the assumption that this month is the month with fewest number of days and driest conditions compared to other months, therefore it is expected the other months barge would be better in the number of trips because of the height river water depth more deeper.

Table 4 Results of cargo capacity of comparison various barge draft 270 feet at the driest month

No.	Draft Barge (m)	TPC (t)	Draft Max. Barge (m)	Min. Height Tidal (m)	Capacity (t)	Trip per year	Capacity per year (t)
1	3.80	0	4.70	1.30	5,500	91	500,500
2	3.70	120	4.60	1.20	5,380	93	500,340
3	3.60	240	4.50	1.10	5,260	97	510,220
4	3.50	360	4.40	1.00	5,140	98	503,720
5	3.40	480	4.30	0.90	5,020	101	507,020

Further analysis of the coal transportation trip is done by using the towed barge system without empty barge in the port, towed barge system with empty barge in the port and a pusher barge system with empty barge in the port. For towed barge system with and without barge system in the port have same characteristics such as ship speed in all stages, connection and connection between tugboat and barge, meanwhile the pusher barge system has more speed compare to the towed system due to good manouvering and seakeeping at the sea.

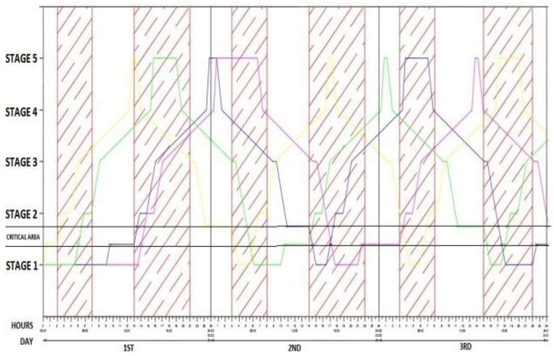

Fig. 5 Cycles of towed barge system with empty barge in driest month (February)

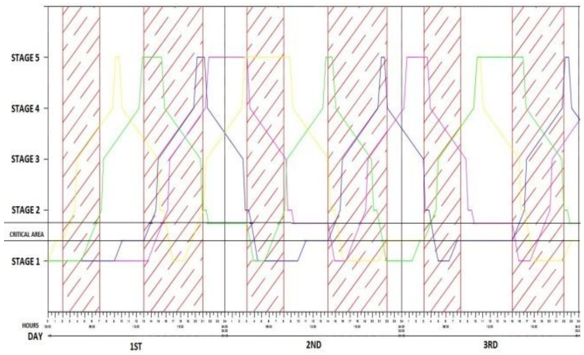

Fig. 6 Cycles of pusher barge system with empty barge in driest month (February)

Figure 5 shows the transportation cycles of towed barge system with empty barge in driest month. In this case, the cyles rise or more than towed barge system without empty barge in the port, it is because minimizing of the waiting time of tug boat and barge primarily at the port for loading and unloading by placing the empty barge at the port therefore increasing cycles or trips of towed barge system thus increasing the total transport capacity of coal per year.

Figure 6 shows the transportation cycles of pusher barge system with empty barge in driest. In this case the cyles or trips of pusher barge system more increase, therefore increases the amount of coal transportation capacity per year. Use empty barge in the port can eliminate waiting time for loading and unloading, thereby increasing the total transport capacity, or in other words, can increase the efficiency of coal transportation. The total capacity increase by using pusher barge system due to the good maneuvering and seakeeping, therefore the pusher barge can accelerate more ship speed in some sub route that will increase the total capacity per year.

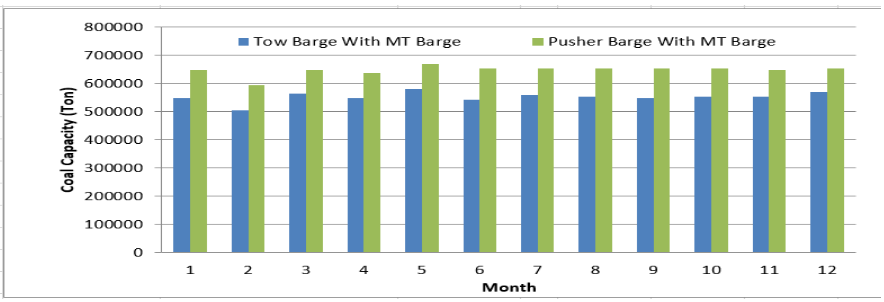

Fig. 7 Comparison annual transport capacity among three modes of coal transportation

Figure 7 shows the comparison of two transportation modes for coal transportation capacity in every month at Sangkulirang River in Province of East Kalimantan. The difference between the use of towed barge system and pusher barge system has increasing efficiency by 15% with using pusher barge system for the annual transport capacity. Meanwhile the annual transportation capacity, trip per year and required freight rate of each tansportation modes as shown in table 5. The results shows the RFR of pusher barge system lower than towed barge system about 14%.

Table 5. Annual Transportation Capacity, Trip per Year and RFR

No	Transportation Modes	Capacity (Ton)	Trip	Total (Ton)	RFR (Rp/ton)
1	Tow Boat With Barge	5,260	1,257	6,611,820	54.876
2	Pusher Barge With Barge	5,260	1,474	7,753,240	46.762

Table 6 shows the gas exhaust emissions of transportation modes of coal transportation, the results shows using pusher barge system more environmental friendly compared to towed barge system.

Table 6. Gas Exhaust Emissions of Transportation Modes

No	Transportation Mode	No2 (Ton)	CO (Ton)	CO2 (Ton)	VOC (Ton)	PM (Ton)	S02 (Ton)
1	Tow Barge With Barge	299,983	38,569	13713,528	12,856	6,428	85,710
2	Pusher Barge With Barge	351,771	45,228	16080,939	15,076	7,538	100,506

Using pusher barge system for coal transportation from jetty at riverside coal terminal to transhipment point at sea has advantages from coal capacity transportation, cost of transportation is the most economical transportation mode and from the environmental point of view is the most environmental friendly.

CONCLUSION

The coal transportation results shows that the most optimal coal transportation by using a pusher barge system due to the system having good maneuvering and seakeeping therefore it will increase the speed and finally will increase annual transport capacity. The result shows the efficiency increase of annual coal transportation capacity of 15%. Meanwhile for coal transportation cost of RFR by using pusher barge system lower than towed barge system about 14%. From the environmental point of view, the pusher barge system has advantages compared to towed barge system

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