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Technical Approach for Improving Fuel Oil Distribution in Small Islands

Edwin Matatula[1], IGN Sumanta Buana[2], Achmad Zubaydi[3], Tri Achmadi[2].

[1.] *Students of the Marine Technology Postgraduate Program, Sepuluh Nopember Institute Technology – Surabaya (ITS)*

[2.] *Department of Marine Transportation Engineering, Sepuluh Nopember Institute Technology - Surabaya (ITS)*

Abstract

Small islands with very limited infrastructure and supported by small scale economic activity generally depend on fuel oil to meet its demand for energy. This source of energy is supplied from outside using unreliable traditional logistics system. In terms of technology aspects, the distribution requires affordable simple yet reliable system to overcome this problem. A combination of tug-boat and barge is proposed and will be applied in the Lease Archipelago (Central Maluku) – Indonesia. This paper will explains conceptual design and operational concept of the proposed system.

Keywords: Small islands, oil fuel distribution, tug-boat, barge

I. INTRODUCTION

In distributing fuel oil to small islands in archipelago region, many problem arise due to infrastructure capacity and availability, dealing with port and transportation mode either land or marine types. Most ports do not have adequate facility. The vessel as a carrier of fuel oil is generally small, not specifically designed to transport liquid cargo and has low level of safety. Geographically these islands are scattered and heavily influenced by weather condition. These circumstances hamper the distribution process and, in the worst case, create scarcity. This will eventually increase the price. In addition, the number of people living in these areas is small, making the demand for fuel oil as the source of energy is also low.

The above situation needs to be overcome by providing appropriate distribution system. One of them is tug-barge concept. This concept has been developed because of its low operating and capital costs compared to the other maritime transportation modes, such as, tanker vessel. Tug-barge operating scheme can be used to transport cargo to several places where demand and consumption rate is relatively low, by applying drop and swap operational procedure. Other benefit of this concept is that it can be used as an alternative to minimize land traffic congestion due to the use of trucks as well as to reduce the impact of air pollution . The concept of tug-barge was also developed in an effort to optimize the transportation service network in the context of intermodal services [1].

This study aims to offer a concept of distributing fuel oil in remote islands that have lack infrastructure and relatively small demand quantities. This study is conducted in the Lease Archipelago, Central Maluku, Indonesia, which consists of three islands, namely, Saparua Island, Haruku and Nusalaut Island. The existing supply chain will be evaluated and then be used to develop the tug-barge system.

II. LITERATURE REVIEWS

Energy consumption having become the main focus of the global economy, states that an important aspect in terms of meeting energy needs is the availability and its demand [2], [3]. Supply chain management is the coordination of production, inventory, location, and transportation among the elements in the chain to achieve a good, responsive and efficient interaction for the needs served [4]. Transportation has an important role for industry because producers have an interest so that the goods are transported to consumers in time, exactly to the place where they are determined, and in good condition. In other words, logistics activities have a function of time and place. This means it provides a place function by moving goods/commodities from the point of production to the place where demand exists. The value of time means that goods and services will be available when consumers need them [5].

The consequences of costs arising in the process of transportation and storage need to be studied further to obtain economic value while still ensuring the availability of commodity stocks at the consumer level. This problem is approached by minimizing shipping costs and inventory costs. The way to do this is to optimize shipping routes, ship size and frequency of delivery with the aim of minimizing shipping costs and inventory costs [6]. In addition, the proposed model not only provides operator flexibility in decision making, but also provides a tool to analyze the trade-off between shipping costs and inventory costs. [7] Developed a model for the problem of supply routes where sailing time and waiting time at ports are uncertain. Ship routing and scheduling are associated with weather uncertainty and unexpected waiting times at the port.

One of the cost efficiency efforts is the choice of transportation equipment that is in accordance with operating conditions. In this case, barge is one type of transportation that is feasible to consider. [8] conducted a study about the use of Integrated Tug Barge (ITB) in coastal shipping or short sea shipping. ITB as one of the alternative choices for transporting goods in the Northern Coast of Java, Indonesia. ITB is able to carry these goods with less transportation costs compared to the other modes. More advanced version of integrated tug-barge system is called articulated tug-barge (ATB), which has proven to be able to operate in open sea [9].

Tug-barge system was implemented to transport compressed natural gas (CNG) in Sembakung-Nunukan, Indonesia [10]. The other studies related to the use of the system with other modes were conducted by [1], [11] to optimize the barge service network in intermodal services. Various indicators are used to test the performance of intermodal transportation systems, including the barge operational system in inter-port shipping lines. [12] conducted a study, which takes into account the uncertainty of transportation demand in the distribution network model. Increased container flows have caused problems related to carbon emissions, traffic congestion around the port area and port capacity. This situation requires the concept of effective and high capacity transportation. In this case, barge is considered able to answer this problem. [13] also optimized the use of barge for container services, by planning the ports to be visited and the number of containers to be sent between each port, thus maximizing the profit of the shipping company. A new approach was proposed where shipping companies can simultaneously optimize routes, final port choices, service cycle length and fleet size. [14] conducted a study of barge transportation system in the inland river paths. The study was carried out to investigate the tug-scheduling problem at the port located at the mouth of the river and connect the hinterland ports along the river with global sea transportation networks.

III. PROBLEM BACKGROUND

Fuel oil is mainly required as the source of energy. In Indonesia, fuel oil is distributed using combination of marine and land mode of transportation, such as, tanker vessel and truck. The distribution chain consists of several levels as shown in Fig.1. Starting from the refining center, the oil is distributed to a shelter terminal covering certain regions. From the shelter terminal, distribution to oil fuel depots is carried out to smaller areas. Furthermore, from the depot, fuel is shipped to agents, before going to the final consumers.

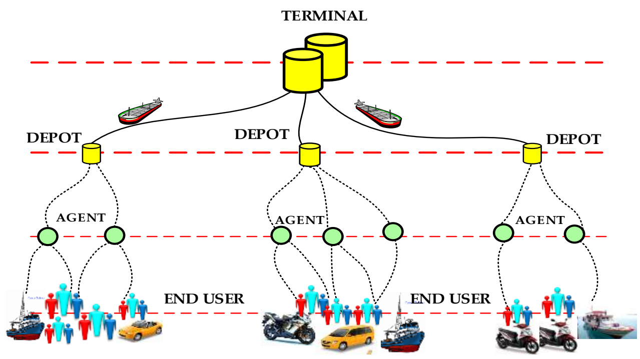

Fig. 1. Fuel Oil Distribution Network

A. Distribution of Fuel Oil to Lease Archipelago

One of the distribution areas is the Lease Archipelago, located close to Ambon Island as a distribution center. Despite its close location, there are problems in providing fuel oil mainly in terms of distribution chain. The long distribution chain with relatively heavy logistical work and minimal infrastructure support are the main reasons for the availability of fuel oil in this region. From Wayame-Oil Terminal in Ambon, fuel oil is transported about 30 kilometers to Tulehu, using tanker truck with capacity of 5000 liters. Travel time from Wayame to Tulehu is approximately 1 hour. Here, fuel oil is transferred to several small boats, by pumped or by gravity system drained into several drums on board of the boats. This process takes about 1 hour. Furthermore, fuel oil is shipped to each island (Saparua, Haruku and Nusalaut) within 1.5 – 4 hours. The supply network is shown in Fig. 2.

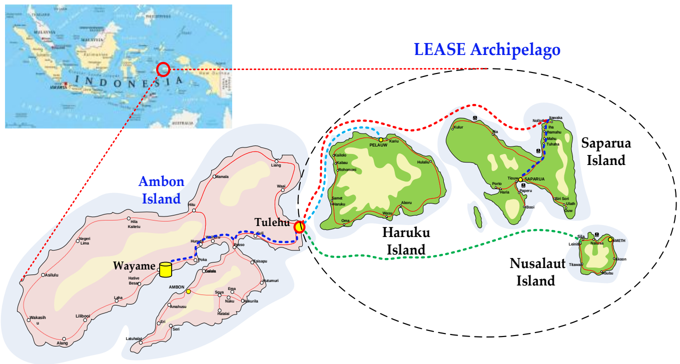

Fig. 2. The Fuel Oil Supply Network in Lease Archipelago

The loading and unloading process on the island is carried out by means of drums being plunged into the sea, then with human power pushed to land and lifted to the truck. This unloading process takes approximately 1 hour. The truck will bring these drums to the agent with a travel time of 45 minutes. Upon arrival at the agent, the fuel is transferred to the storage tank and the drums are then returned to the ship for subsequent distribution in the following days (see Fig. 3).

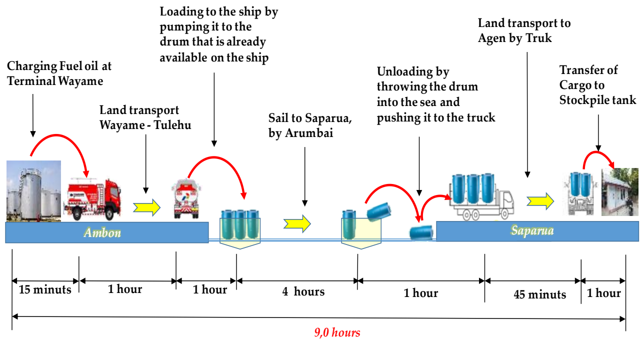

Fig. 3. Fuel Oil Supply Chain from Wayame-Ambon to Saparua Island

B. Distribution Problems

The boats return to Tulehu carrying empty drums within 3.5 hours. When arriving at Tulehu, the loading process can be immediately carried out, provided that, truck tanker from Terminal Wayame has arrived. The loading time is 1 hour. If the tanker truck has not arrived at Tulehu, then it takes time to wait for the next truck. The boat waiting time in Tulehu is sometimes long because only one tanker truck serves the process of transporting fuel oil from Wayame to Tulehu. If two boats will transport the oil and depart at same time, the tanker truck will load the first boat and after that has to return to Wayame for the second boat. This causes the boat's waiting time relatively long, approximately 2.5 - 4 hours.

*Existing Fleet***:** Boat used to supply fuel oil to the Lease Archipelago, is of traditional type, called *Arumbai* (see Fig. 4). This boat is made of wood with length between 9-10 meters, width of 2.5 - 3 meters, and height about 1.5 meters. The boat does not have deck house and its propulsion system is an outboard engine mounted on the stern. The speed is 6 -7 knots. This type of boat has an average capacity of 5-7 tons, does not have a special space for liquid cargo. Fuel oil is stored in several plastic drums that is put on the hull sometimes with other cargoes. The boat safety is poor, because, besides its small size, it is not equipped with adequate safety equipment. When wave is high and wind blows very strong, the boats cannot operate.

Fig. 4. Arumbai Boat Transporting Fuel in Drums from Ambon to Saparua Island

Fleet Supply Capacity: Fuel oil is transported from Tulehu in Ambon island, almost. Saparua Island has the largest number of demands, namely 404 KL per month. This volume can be further into three according to oil types, that is, 227 KL gasoline, 132 KL kerosene and 44 KL diesel oil. The oil is transported every day using three unit of boat.

Haruku Island has a number of demands per month is 300 KL, for gasoline and kerosene only. Details of each type are; gasoline 187 KL and kerosene 113 KL. There are two unit boats to supply in Haruku with a total supply 300 KL per month. With the installed capacity of the fleet and its performance, the distribution process in Haruku are carried out almost every day.

While, Nusalaut Island has a total demand per month of 41 KL with details of 36 KL gasoline and 5 KL kerosene. Fleet capacity available at Nusalaut is quite feasible to supply fuel during consumption.

Infrastructure Availability: Unavailability of port facilities, loading and unloading equipment on ships and on land, tank storage. The loading and unloading at the destination is carried out by human labor where drums are plunged into the sea and then loaded to small truck, which carries them to shelter/agent.

C. Identification of Problems.

Problems regarding oil distribution usually occur at the agent level to the final consumer. Some problems in the distribution process at this level are:

- Consumers are on islands that are geographically dispersed with extreme weather challenges at certain times,
- Quantity of demand is relatively small, because of the small population with slow economic activity, and
- Lack of infrastructure, both ships and supporting facilities for operations on land.

In order to overcome these circumstances, a concept of sea transportation needs to be developed.

IV. METHODS

The methods presented in this paper include the following four main steps, with detailed explanations below.

- Identification of the amount of fuel oil demand on each island, as an important input to determine fleet load capacity.
- Determination of vessel operation patterns to service oil fuel demand on each island, by taking into account the size of the needs and operating conditions
- Determination of ship load capacity and dimensions of the ship by referring to the volume and weight of the fuel oil to be transported to the island.

V. SUPPLY AND DEMAND ANALYSIS

Fig. 5 shows schematically the problem solving process to get a balance between demand quantity and service capacity.

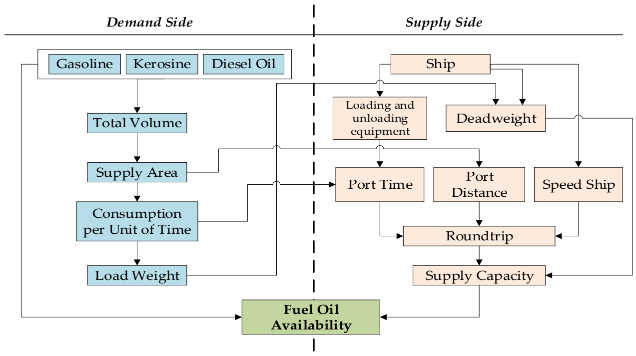

Fig. 5. Supply – Demand Analysis

A. Demand of Fuel Oil Quantity

Fuel oil for the Lease archipelago consists of gasoline, kerosene and diesel oil. The total demand of fuel oil per month for these three islands is 744 kilo liters (KLs) : 450 KL gasoline, 250 KL kerosene, and 44 KL diesel oil. Details of demand according to type of fuel oil at the each island, as shown in Table 1.

Table 1. The Total Demand of Fuel Oil per Month for Lease Archipelago

Type of Fuel Oil	Total Demand per Islands (kiloliters)			
	Saparua	Haruku	Nusalaut	Total
Gasoline	227	188	35	450
Kerosene	133	112	5	250
Diesel Oil	44	0	0	44
Total	**404**	**300**	**40**	**744**

B. Service Pattern Planning

The proposed the pusher-barge system for transporting oil fuel will be operated directly from the fuel oil terminal in Wayame-

Ambon to each island. The system dimension including tug power and barge capacity is calculated by paying attention on the type and the amount of fuel oil in each island. Total fuel oil demand in Nusalaut is smaller, so it is combined with the Haruku, so that the transportation system consists of one tug-boat and two barges.

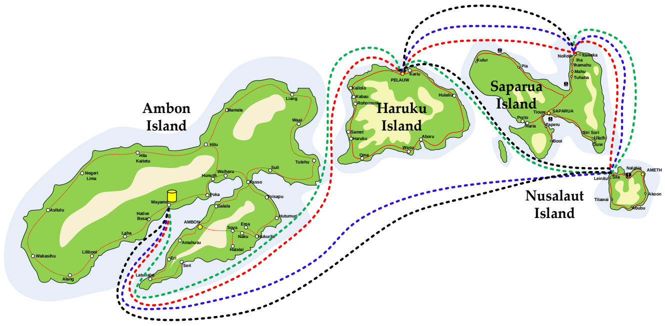

Fig. 6. Alternative Pattern of Barge Operation

There could be are 4 (four) alternative operating routes as shown in Fig. 6, that is, Ambon-Haruku-Nusalaut-Saparua (green line), Ambon-Haruku-Saparua-Nusalaut (red line), Ambon-Nusalaut-Haruku-Saparua (black line), and Ambon-Nusalaut-Saparua-Haruku (blue line). The lengths of these routes are almost the same. To select the appropriate route, it is important to evaluate the sequence of ship visits from the operational technical aspects by considering the amount of cargo demand from each island. Visiting the Saparua Island early was very impractical because it made the route very long. If the system visited Nusalaut Island is the last, then system will return to Ambon through the open sea in an empty barges. The operating system offered is drop & swap, the Nusalaut Island must be visited first because on the other two islands barges will be swapped. Thus, the selected route is *Ambon-Nusalaut-Saparua-Haruku-Ambon.*

C. Determining the Barge Capacity

Barge capacity is determined by knowing the total demand for fuel oil of each island in a certain period of time.

C.1. Demand Side

The fuel oil consumed by the people in Lease Archipelago is of gasoline, kerosene and diesel oil types. Total demand in Nusalaut, Saparua and in Haruku can be written as D_2, D_3, and D_4 respectively. Volume of oil based on its types can be denoted as shown in Table 2.

Table 2. Type of Fuel Oil Notation

	Nusalaut	**Saparua**	**Haruku**
Gasoline	D_{21}	D_{31}	D_{41}
Kerosene	D_{22}	D_{32}	D_{42}
Diesel Oil	D_{23}	D_{33}	D_{43}
Total	$\mathbf{D_2}$	$\mathbf{D_3}$	$\mathbf{D_4}$

C.2. Fleet Planning and Operating Patterns (Supply Side)

The general model of supply is intended to find the total transport capacity of the proposed system. Supply modeling is a function of the number of fleets, fleet capacity and frequency of visits.

- Barge Capacity

Total supply from Terminal Wayame, Ambon, $\boldsymbol{S_1}$, will be used to determine barge capacity. The corresponding barge capacity will be calculated based on the amount of fuel oil demanded in each island (*Nusalaut, Saparua, Haruku*). Total supply model is denoted as follows:

$$S_1 = D_2 + D_3 + D_4 \qquad (1)$$

where,

$$D_2 = D_{21} + D_{22} + D_{23} \qquad (2)$$
$$D_3 = D_{31} + D_{32} + D_{33} \qquad (3)$$
$$D_4 = D_{41} + D_{42} + D_{43} \qquad (4)$$

- Port Times (*Tport*)

Port time, *Tport*, is the total time required by a particular vessel in a port to carry out loading/unloading, bunkering and others. $Tp1$, Tp_2, Tp_3, Tp_4 are time spent in Ambon, Nusalaut, Saparua, Haruku respectively. Thus, total port time can be written as:

$$T_{port} = Tp_1 + Tp_2 + Tp_3 + Tp_4 \qquad (5)$$

$$T_{P1} = \left(\frac{S_{A1}}{C_{pump}}\right); \; T_{P2} = \left(\frac{S_{A2}}{C_{pump}}\right) \qquad (6)$$

where C_{pump} is pump capacity (m^3/hour). S_{A1} is the total quantity of fuel oil loading at Wayame terminal. S_{A2}, is the quantity of fuel oil discharging in Nusalaut.

- Sailing Time (*Tsea*)

Sailing time, *Tsea*, is the time for the system to sail from the origin port to the destination port. Sailing time is determined by the speed and distance of the voyage. Thus, the total sailing time can be calculated as follows:

$$T_{sea} = T_{S1} + T_{S2} + T_{S3} + T_{S4} \qquad (7)$$

$$T_{S1} = \left(\frac{d_1}{Vs}\right) ; \; T_{S2} = \left(\frac{d_2}{Vs}\right) ; \; T_{S3} = \left(\frac{d_3}{Vs}\right) ; \; T_{S4} = \left(\frac{d_4}{Vs}\right) \; (8)$$

where *Vs* is speed of the system (knot). T_{S1}, T_{S2}, T_{S3}, and T_{S4} are sailing time at Ambon-Nusalaut, Nusalaut-Saparua, Saparua-Haruku, Haruku-Ambon legs respectively. d_1 , d_2 , d_3, and d_4 are distance (nautical-miles) of Ambon-Nusalaut, Nusalaut-Saparua, Saparua-Haruku, Haruku-Ambon correspondingly.

- Frequency of Ship Visit (*Rtrip*)

The number of ship visits, *Rtrip*, can be determined by the amount of time available or the effective time (in years) divided by the time of the ship (T_{ship}), which is the total of sailing time, T_{sea}, and port time, T_{port}. [15]

$$Rtrip = \frac{365-z}{T_{Ship}} \quad (9)$$

$$T_{Ship} = T_{Sea} + T_{port} \quad (10)$$

where z is idle time of ship (days).

D. Principal Dimensions

From the total volume of fuel oil load, the ship capacity deadweight (*DWT*) is calculated. By knowing DWT, by referring to the existing fleet data, a regression is carried out to determine the principal dimensions of the ship, in this case Length (*L*), Breadth (*B*), draft (*T*) and Height (*H*).

VI. RESULTS AND DISCUSSION

There are two barge dimensions, i.e., one is for Saparua Island and the other is for Haruku and Nusalaut Island. The first barge is larger than the second one. The first barge has length of 28.07 meters, breadth of 7.59 meters, draft of 1.50 meters and deck height of 1.90 meters, while the second one has length of 26.56 meters, breadth of 7.59 meters, draft of 1.50 meters and deck height of 2.02 meters. The complete dimension and corresponding capacity of the two barges are shown in Table 3.

Table 3. Barge Dimensions

No	Barge	DWT *(tons)*	Principal Dimensions *(meters)*			
			Length *(L)*	**Breadth *(B)***	**Draft *(d)***	**Deck Heigth *(H)***
1	Saparua	183,5	28,07	7,59	1,50	1,90
2	Haruku & Nusalaut	151,76	26,56	7,59	1,50	2,02

Furthermore, by considering operational and technical aspects as well as by anticipating demand growth, the dimension of the barges will be the same. In other words, the larger one will be used for the system.

The system speed is set at 5 knots and the pump capacity to unload fuel oil is 150 m^3/hour. The process of supply of fuel oil according to the duration of consumption time is shown in Table 4.

Table 4. Roundtrip Time

Segment Roundtrip	Unit	Supply Duration (days)					
		30	25	21	14	10	7
Quantity Supply							
- *Gasoline*	tons	450.166	375.138	315.116	210.070	150.055	75.028
- *Diesel Oil*	tons	44.000	36.667	30.800	20.534	14.667	7.333
- *Kerosene*	tons	249.710	208.092	174.797	116.531	83.237	41.618
Loading (*Tp1*) Ambon	hours	3,00	2,50	2,10	1,40	1,00	0,50
Sailing (*Ts1*) Amb - Nusalaut	hours	12,20	12,20	12,20	12,20	12,20	12,20
Unloading (*Tp2*) Nusalaut	hours	0,23	0,19	0,16	0,11	0,08	0,05
Sailing (*Ts2*) Nusalaut - Saparua	hours	2,80	2,80	2,80	2,40	2,80	2,80
Barge Exchanger (*Tp3*) Saparua	hours	1,50	1,50	1,25	1,25	1,00	1,00
Sailing (*Ts3*) Spra - Haruku	hours	2,57	2,57	2,57	2,59	2,57	2,57
Barge Exchanger (*Tp4*) Haruku	hours	1,50	1,50	1,25	1,25	1,00	1,00
Sailing (*Ts4*) Haruku - Ambon	hours	7,14	7,14	7,14	7,14	7,14	7,14
Total Time	**hours**	**30,95**	**30,41**	**29,48**	**28,34**	**27,79**	**27,27**
	Days	**1,29**	**1,27**	**1,23**	**1,18**	**1,16**	**1,14**

The proposed tug-barge concept, will provide fuel oil supply services for the Lease Archipelago as a system consists of one tug-boat and four barges. The configuration is shown in Fig. 7.

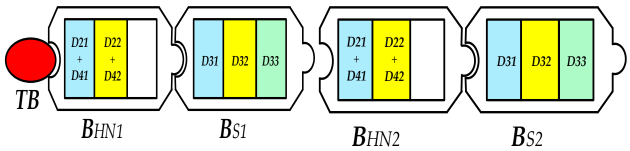

Fig. 7. Tug-barge Set for Supplying Fuel Oil to Lease Archipelago

Details of the system capacity and operating patterns can be explained as follows:

- The supply process starts from Wayame Terminal - Ambon Island. The system departs by carrying 2 (two) barges: barge for Saparua Island *(B_{S1})* and barge for Nusalaut and Haruku Island *(B_{HN1})*. *B_{S1}* carries 106 kiloliters gasoline *(D_{31})*, 62 kiloliters kerosene *(D_{32})* and 21 kiloliters diesel oil *(D_{33})*, while (B_{HN1}) transports with 104 liters gasoline *(D_{21}+D_{41})* and kerosene *(D_{22}+D_{42})* 55 kiloliters.
- The configuration of system is as shown in Fig. 8. Barge for Saparua Island is placed in front to facilitate the process of barge release because the system will stop at Saparua island after unloading some oil in Nusalaut.

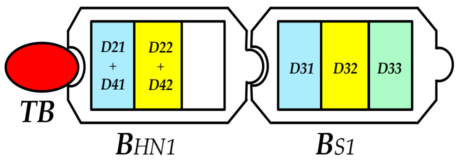

Fig. 8. Barge Configuration for The First Operation

- As the smallest island having the lowest demand, Nusalaut has to be visited first. This is important in order to reduce effect of free surface in the cargo space of barge.
- After that, the system goes to Saparua. Here, initially, the barge B_{S1} is detached and left.
- Finally, the system will call at Haruku and leave the second barge B_{HN1}, before returning to Wayame-Ambon. Complete route at the first operation pattern is as shown in Fig. 9

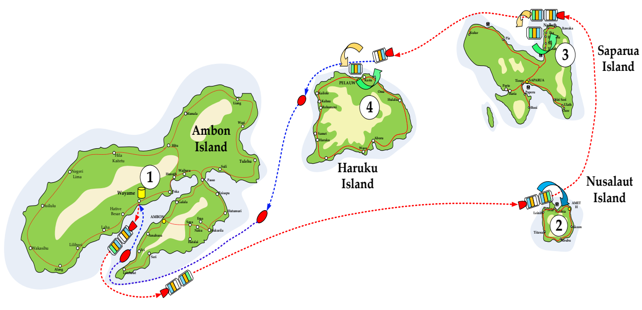

Fig. 9. First Operation Pattern

- The system will leave for the islands from Wayame with fully loaded barges (B_{S2} and B_{HN2}) when the initial barges almost empty. The configuration of system is as shown in Fig.8.
- As in the first voyage, the system goes first to Nusalaut. When arrive in Saparua, the fully barge B_{S2} will be swapped with the empty barge B_{S1}. The same procedure will be applied in Haruku, the fully barge B_{HN2} will be swapped with the empty barge B_{HN1}
- Finally, the system goes back to Wayame with empty barge. Complete route at the second operation pattern is as shown in Fig. 10

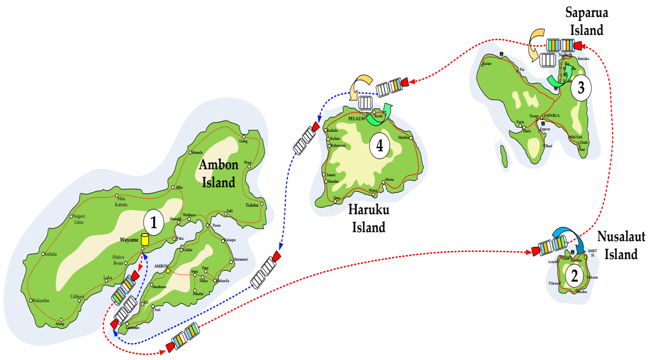

Fig. 10. The Second Operation Pattern

The system dimension is designed to transport fuel oil to the island for a consumption time of 14 days. The roundtrip time of ship is 28.34 hours or 1,18 days. Thus there are 12.8 days when the ship is not operating. The system will not operate for 12.8 days. In other words, the system is not productive, i.e., tug boat will be idle. In order to keep the system active, tug boat has to be used for other works, such as, tug operation in Wayame oil terminal or the same operation to transport oil to the other nearby places. The other option is to increase the frequency of ship visit, however, this this will reduce the amount of oil to be transported and as a consequence, will reduce barge dimension. This means that the barge dimensions will be smaller according to the rate of consumption on the islands. Smaller dimensions will lower the construction cost of the barge, but the operating cost will increase as the visit frequency increases.

VII. CONCLUSION

In this paper, we recommend the operation of the pusher-barge service type to supply fuel oil for small islands with a barge exchange mechanism, called drop and swap operation. This barge can also be used as a floating storage until the oil is empty, for a certain period of consumption time, i.e., for 14 days. This system can guarantee oil fuel stocks for that consumption time, while the traditional boat cannot because of its technical limitation. The proposed system will be safer than the traditional one because it is designed and operated in accordance with regulations. In addition, the barge can be deployed to other regions when necessary, such as, during natural disasters.

Because this system uses more than one barge which is secured using inter-barge connection, there should be a further study regarding this matter in order to obtain thorough safety. This is important because the proposed system will operate on harsh environment.

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