Conceptual Design and Operation Plan of Floating Medical Wastes Treatment Facility for Archipelagic Area: A Case Study of Maluku and Papua

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Abstract. Indonesia has been facing considerable challenges in medical wastes management. In 2020, the medical wastes reached 294.66 tons/day, but the total capacity of the aggregate wastes treatment facilities nationally was only 224.23 tons/day. Maluku and Papua are Indonesia's largest archipelagic region consisting of four provinces, which are included in the region with the lowest index of medical wastes management as well as the minimum number of medical wastes treatment facilities. The existing wastes treatment in Maluku and Papua does not meet the standards, it is carried out by open-air burning and open dumping. Therefore, the objective of this study is to create the conceptual design and operation plan of floating medical wastes treatment for archipelagic area. By using a multi-port relay operating pattern for each province, the medical wastes transport started from the hub point which was determined by using the centre of gravity method. Considering the number of medical wastes in each province so that the nonlinear programming method was used to determine the most optimum main dimensions of floating facility. The result obtained that the number of floating facilities required was four SPCB-type with costs overall by 63.14 billion IDR/year.

Keywords: Medical wastes treatment, floating facility, conceptual design, ship optimization

1. Introduction

Maluku and Papua are Indonesia's largest archipelagic regions, which consists of four provinces, namely Maluku, North Maluku, Papua, and West Papua, cover approximately 26.1% or more than a quarter of Indonesia's territory. These regions own 111 general hospitals, three specialty hospitals, and 218 floating public health centres. In 2020, The Directorate of Environmental Health of the Ministry of Health stated that aggregately, of 1,055 healthcare facilities in these regions were only 14 facilities or 1.33% that met the medical wastes treatment standards. Provincially, the highest percentage among these regions was reached by Maluku around 4.12%. [1]

The existing medical wastes treatment in Maluku and Papua is conducted by each healthcare facility, carried out by manual shredding process for the sharp wastes (used syringes and other needles), followed by open-air burning and open dumping (Figure 1).

Table 1. Number of healthcare facilities that meet the medical wastes treatment standards.

Items	Registered Healthcare Facilities	Healthcare Facilities that Meet the Medical Wastes Treatment Standards	Percentage (%)
Aggregate	1,055	14	1.33
Maluku Province	243	10	4.12
North Maluku Province	160	1	0.63
West Papua Province	181	2	1.10
Papua Province	471	1	0.21

Those processes have not met the standard for medical wastes treatment and potentially harm human health. The open-air burning process produces some toxic compounds, for instance it usually forms carbon monoxide (CO), which can bind to form carboxy haemoglobin so that the blood can no longer supply sufficient oxygen to body tissues. Hence, burning the infectious medical wastes will be more dangerous. [2] Meanwhile, the World Health Organization (WHO) states that open dumping can harm humans and other living things through the food chain. [3]

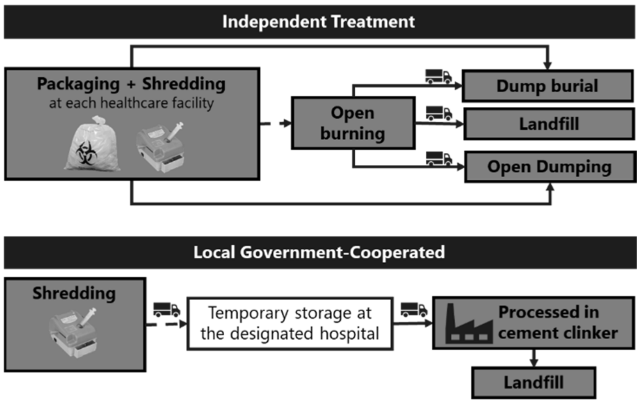

Figure 1. Existing medical wastes management flow in Maluku and Papua

According to the Directorate of Environmental Health in 2020, the total capacity of medical wastes treatment facilities in Indonesia reached 224.23 tons/day (hospital-based wastes treatment capacity was 53.12 tons/day, and the third party-based capacity reached 171.11 tons/day). However, this number does not describe the actual capacity and condition. The medical wastes treatment facility mentioned above is centralized in Java, with a total of 29.44 tons/day of hospital-based capacity and 133.308 tons/day of third party-based capacity (aggregately 72.56% of the national capacity). Ironically, there is no medical wastes treatment facility in Maluku and Papua. The medical wastes treatment facilities in some public hospitals in Maluku and Papua no longer operate, and there is no third-party provider in charge to build those facilities.

The gap between the number of medical wastes and its treatment capacity and the unevenly distributed capacity results in a large pile of unprocessed medical wastes. Moreover, as the impact of the Covid-19 pandemic, the number of medical wastes continuously rises. Responding those problems, along with several private companies, Indonesia's government through the Ministry of Environment and Forestry has been planning to establish some medical wastes treatment facilities in several regions. Unfortunately, this establishment plan has been delaying due to no private companies/ third-party wastes treatment providers who plan to build the facilities in Maluku and Papua. Therefore, an appropriate medical wastes treatment facility is required to accommodate the medical wastes in Maluku and Papua.

2. Determining medical wastes

Due to lack of historical data to predict the number of medical wastes that could be generated in Maluku and Papua, the following step is required to identify the number of wastes in those areas. The first step is to estimate the number of patients in the hospital per day. It is assumed to be 1.23% of the population in the area covered by each hospital [4]. Furthermore, based on the equation obtained from the previous research [5], the number of medical wastes for each hospital is determined as follows:

$$GW = -15.76 + 1.21(PAT) + 0.714(BED) + 10.74(TYPE) \quad (1)$$

Where:

GW = The number of medical wastes (Kg/day)
PAT = Estimated number of patients (people/day)
BED = Number of hospital beds (units)
TYPE = dummy variable; 0 for private hospitals, 1 for government hospitals

Therefore, the number of medical wastes in each pick-up point (the nearest port of the health facilities on each island) can be seen in Table 2 as below:

Table 2. The number of medical wastes at each pick-up point

Port Name	Port Code	Medical Wastes (Kg/day)	Port Name	Port Code	Medical Wastes (Kg/day)
Namlea	NAM	93.52	Sofifi	SFI	34.90
Bula	BLA	64.68	Nabire	NBX	99.95
Gorom/Gorong	GMR	21.91	Serui	ZRI	65.94
Banda Naira	NDA	30.92	Biak	BIK	145.79
Amahai	AHI	152.87	Korido	IKU	28.87
Haria/Saparua	RUH	43.90	Sarmi	ZRM	12.51
Ambon	AMQ	1,173.82	Jayapura	DJJ	870.08
Tual	TUA	171.92	Amamapare	AMA	211.40
Dobo	DOB	38.21	Agats	AGS	47.89
Saumlaki	SXK	66.00	Moor	MMR	44.26
Moa	KWU	12.09	Boven Digoel	BDL	93.74
Bobong	BOG	14.91	Merauke	MKQ	236.42
Sanana	SQN	33.14	Kaimana	KNG	30.09
Laiwui	LWI	15.19	FakFak	FKQ	59.17
Babang/Labuha	BBG	67.56	Bintuni	NTI	23.86
Weda	WED	24.62	Teminabuan	NAB	34.25
Buli	BLI	81.46	Sorong	SOQ	337.76
Tobelo	TBO	95.38	Waisai	WSA	49.15
Daruba (Morotai)	DRA	36.11	Manokwari	MKW	283.00
Jailolo	JIO	61.91	Wasior	WSR	52.30
Ternate	TEI	311.38			
Trikora (Soasio)	SIO	74.87			

3. Operation plan

3.1. Packaging and ship type
According to the Regulation of Ministry of Environment and Forestry Number P.56/Menlhk-Setjen/2015 regarding Procedures and Technical Requirements for the Management of Hazardous and Toxic Wastes from Healthcare Facilities, medical wastes can be stored in an enclosed space for maximum of 90 days in low temperature (below 0^0C). [6]

Utilizing the sea modes, where the medical wastes were transported by ship, the most appropriate storage is a reefer container – using cold storage system. A container vessel is needed to transport that wastes by using reefer container. Considering the vessel compatibility with the operational area, the floating medical wastes treatment facility should have shallow draft that allows the vessel to operate in a shallow water. Therefore, a self-propelled container barge is the most suitable vessels to deal with this operation.

3.2. Hub point and Operating Pattern
Hub point is determined as a port near the toxic and hazardous wastes landfill sites planned for each province. The floating facility in this hub point is anchored after picking up the medical wastes from each pick-up point to the processed point. Since there are more than two pick-up points in each province, a multi-port relay operating pattern is used under this operation. Hereby, the process used to compute the hub point of each province:

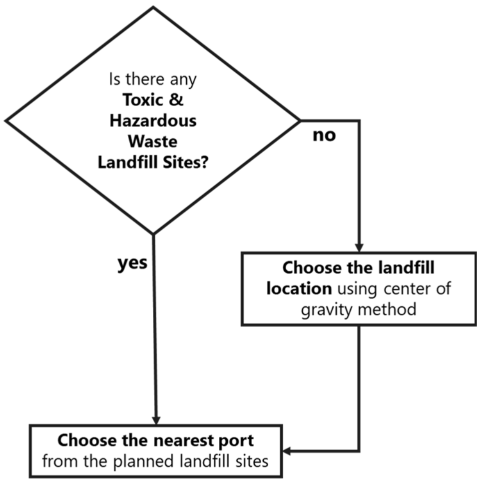

Figure 2. Determining the hub point

Centre of gravity method is applied to determine the hub point for each province by using the following formulation [7]:

$$\boldsymbol{C_x} = \frac{\sum Dl_x W_l}{\sum W_l} \quad (2)$$

$$\boldsymbol{C_y} = \frac{\sum Dl_y W_l}{\sum W_l} \quad (3)$$

Where:
Cx = Longitude of the landfill sites
Cy = Latitude of the landfill sites
Dlx = Longitude of the pick-up point
Dly = Latitude of the pick-up point

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Wl = The number of medical wastes at pick-up point (Kg)

The following figures are the results of centre of gravity method to find out the hub point as well as to create the operating routes of the floating medical wastes treatment facilities.

3.2.1 Maluku Province

According to integrated maps of toxic and hazardous wastes in Indonesia, Maluku Province has one landfill site located in Buru (Figure 3). Hence, the hub point location is in the port of Buru Island, which is Namlea Port.

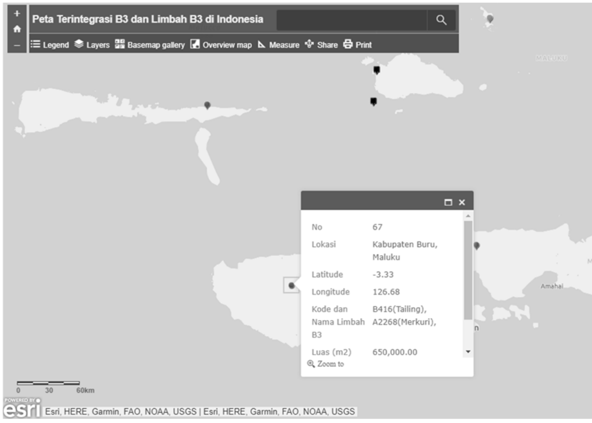

Figure 3. Toxic and hazardous landfill sites in Maluku Province

Namlea Port would be port of origin as well as port of the last destination for ship that assigned to load all medical wastes around Maluku Province. The route is started from Namlea-Bula-Gorom-Tual-Dobo-Saumlaki-Moa-Banda Naira-Haria-Amahai-Ambon-Namlea. The following Figure 4 depicts the operating route of ship assigned in this province:

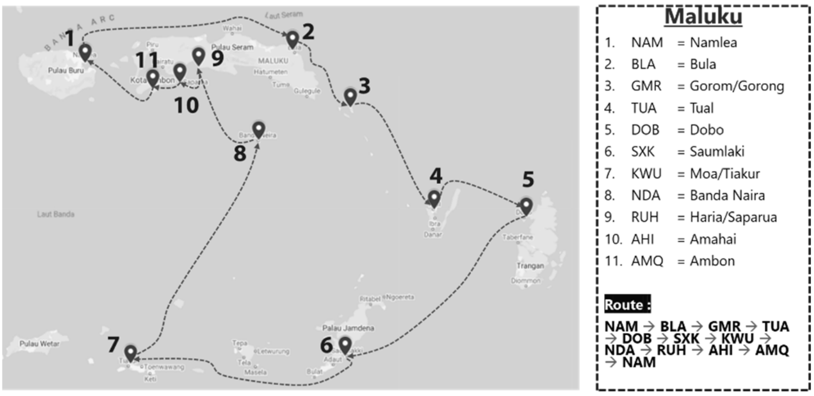

Figure 4. The operating route in Maluku Province

3.2.2 North Maluku Province

According to the Integrated maps of the toxic and hazardous wastes in Indonesia, there are no landfill sites in North Maluku. Thus, the hub point would be determined by using centre of gravity method as shown in Figure 5. As a result, the weighted centre of gravity that would be selected as a hub point for North Maluku Province is in Ternate.

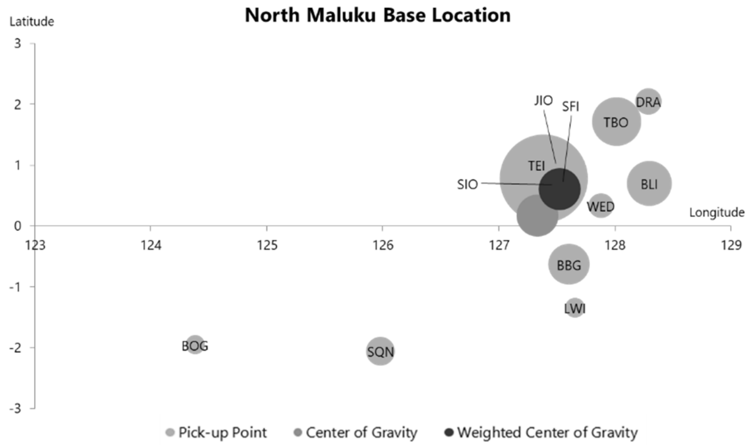

Figure 5. Centre of gravity diagram for hub point in North Maluku Province

In Ternate Port, the number of ships assigned would have an operational pattern as shown in Figure 6, where they pick-up all medical wastes around North Maluku and send them back to Ternate. The route is started from Ternate-Bobong-Sanana-Laiwui-Babang-Weda-Buli-Daruba-Tobelo-Jailolo-Sofifi-Soasio-Ternate. Afterwards, the ship will be anchored, and the medical wastes will be processed.

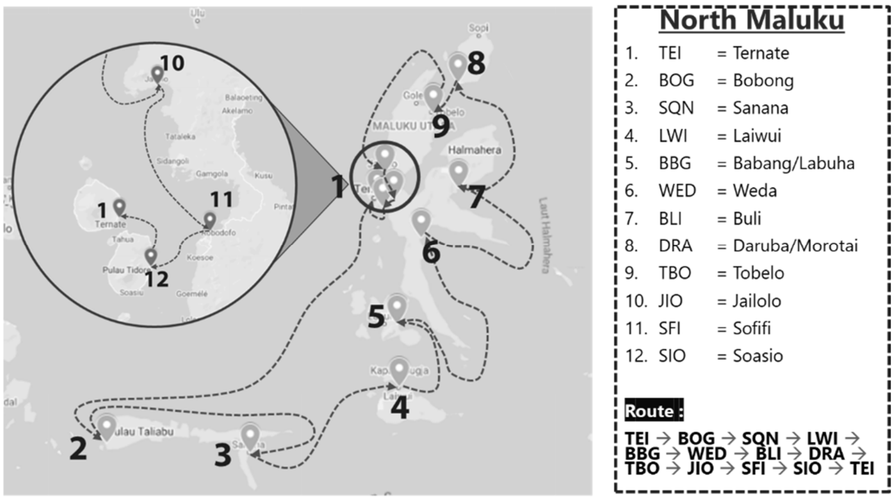

Figure 6. The operating route in North Maluku Province

3.2.3 Papua Province

The condition in Papua Province is the same as North Maluku, which is unavailability of landfill sites. Therefore, centre of gravity method was applied to find out the hub point for Papua Province. According to Figure 7, Jayapura was selected to be hub point for collecting the medical wastes around Papua Province.

As a hub point, Jayapura Port will handle the number of ships assigned to compile the medical wastes from each pick-up point around Papua Province to be returned to Jayapura for processing the wastes. The route is started from Jayapura-Sarmi-Serui-Nabire-Biak-Korido-Amamapare-Agats-Moor-Boven Digoel-Merauke-Jayapura. The detail for ship operation route in Papua Province can be seen in Figure 8.

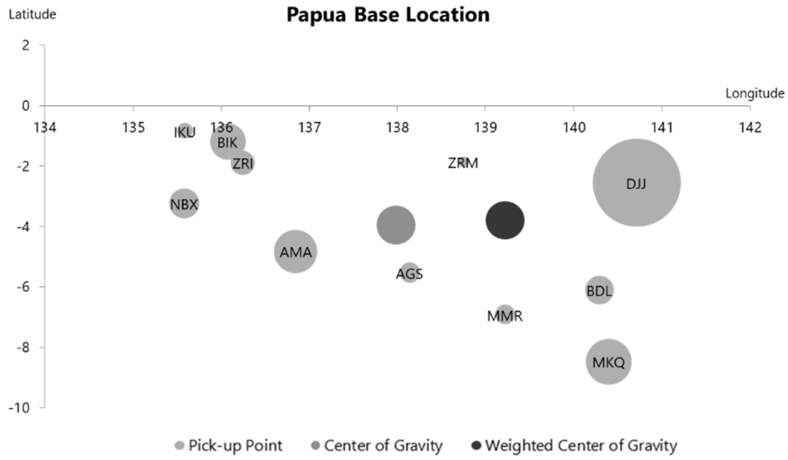

Figure 7. Centre of gravity diagram for hub point in Papua Province

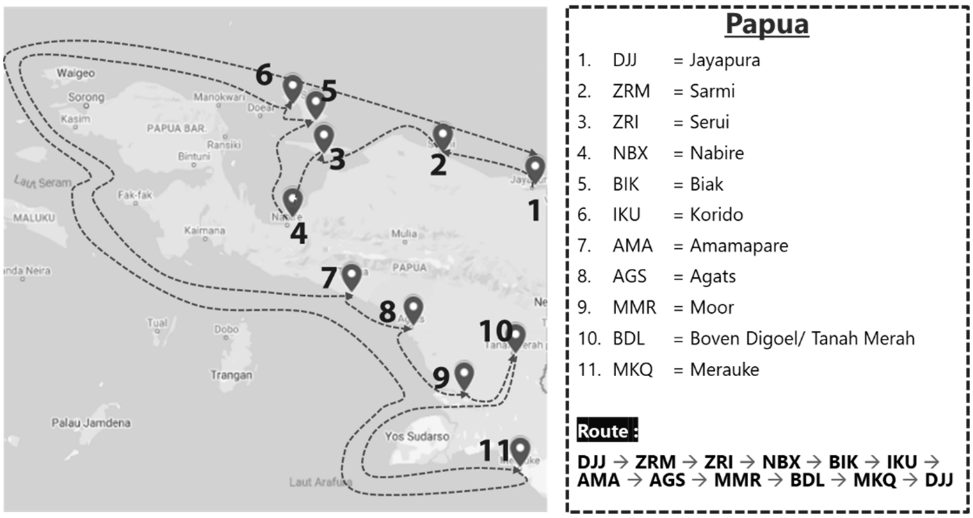

Figure 8. The operating route in Papua Province

3.2.4 West Papua Province

Similar to the previous province, West Papua Province does not have landfill sites as well. Therefore, centre of gravity method was applied to find out the hub point for this Province. According to Figure 9, Fak-fak was selected to be hub point for collecting the medical wastes around West Papua Province.

In Fak-fak Port, the number of ships assigned would have an operational pattern as follows: Fakfak-Kaimana-Wasior-Manokwari-Waisai-Sorong-Teminabuan-Bintuni-Fakfak. They pick-up all medical wastes around West Papua Province and send them back to Fak-fak. Afterwards, the ship will be anchored, and the medical wastes will be processed. The detail pattern for ship operation route in West Papua Province can be seen in Figure 10.

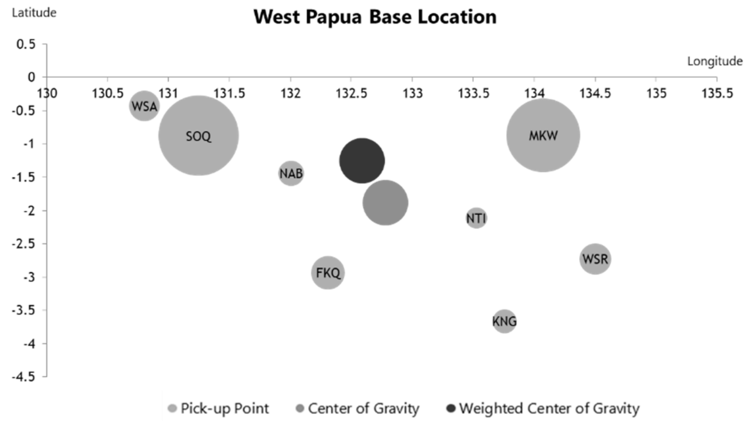

Figure 9. Centre of gravity diagram for hub point in West Papua Province

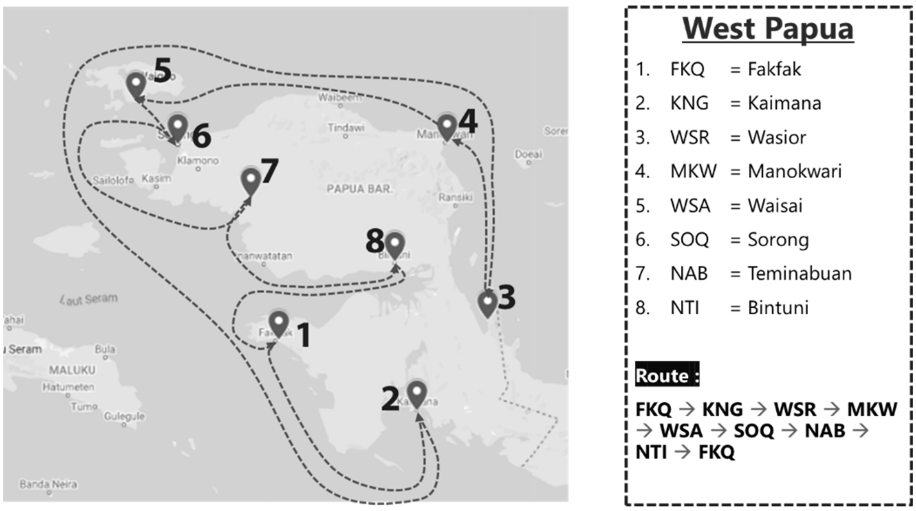

Figure 10. The operating route in West Papua Province

4. Fleet optimization and design

4.1. Fleet optimization

Nonlinear programming method was used to determine the optimum main dimension of the floating medical wastes treatment facility [9]. The objective function of the optimization model is to minimize the total production cost of ship [10] [11]. The formulation to determine the minimum total production costs is described in equation (4) to equation (6). There are three main constraints applied in this model such as main dimensions of ship from equation (7) to equation (10), main dimension ratio from equation (11) to equation (13) and ship stability requirements from equation (14) to equation (19).

The first constraint is obtained from the identification of space requirements on the ship as well as limitation to geographical conditions (wave height). The second constraint is applied to ensure the ship dimension has proportional shape. The last constraint is required to comply with the IMO stability standards.

$$\boldsymbol{Min\ TPC} = W_{ST}.C_{ST} + W_{E\&O}.C_{E\&O} + W_{ME}.C_{ME} \quad (4)$$

$$\boldsymbol{W_{ST}} = Lpp\ .B.D_A.C_s \quad (5)$$

$$\boldsymbol{W_{E\&O}} = L_{E\&O} \, . B_{E\&O} \, . H_{E\&O} \tag{6}$$

Subject to:

1. Main dimension

$$Lpp \geq 64{,}90 \tag{7}$$

$$B \geq 12{,}75 \tag{8}$$

$$2{,}48 < T \leq 5{,}88 \tag{9}$$

$$H \geq 5{,}48 \tag{10}$$

2. Main dimension ratio

$$3.13 \leq Lpp/B \leq 5.29 \tag{11}$$

$$2.49 \leq B/T \leq 8.87 \tag{12}$$

$$10.57 \leq Lpp/T \leq 30.48 \tag{13}$$

3. International Maritime Organization (IMO) stability standards

$$e_{30^\circ} \geq 0.555 \tag{14}$$

$$e_{40^\circ} \geq 0.09 \tag{15}$$

$$e_{30\text{-}40^\circ} \geq 0.03 \tag{16}$$

$$h_{30^\circ} \geq 0.2 \tag{17}$$

$$\Theta_{max} \geq 25 \tag{18}$$

$$GM_0 \geq 0.15 \tag{19}$$

Where:

TPC	= Total production cost of ship	(Rp)
W_{ST}	= Steel weight	(ton)
C_{ST}	= Steel price coefficient	(USD/ton)
$W_{E\&O}$	= Equipment and outfitting weight	(ton)
$C_{E\&O}$	= Equipment and outfitting price coefficient	(USD/ton)
W_{ME}	= Machinery weight	(ton)
C_{ME}	= Machinery price coefficient	(USD/ton)
Lpp	= Length of perpendicular	(m)
B	= Breadth	(m)
D_A	= Steel construction depth, defined as correction of depth (H)	(m)
C_S	= Steel coefficient	
$L_{E\&O}$	= Length of Equipment and Outfitting	(m)
$B_{E\&O}$	= Breadth of Equipment and Outfitting	(m)
$H_{E\&O}$	= Depth of Equipment and Outfitting	(m)
Lpp	= Length between Perpendicular	(m)
B	= Breadth	(m)
T	= Draught	(m)
H	= Depth	(m)

The optimization results depicts that the number of ships required are four units under the Self-Propelled Container Barge (SPCB) type. These ships will be used as floating medical wastes treatment facilities to cover the whole area in Maluku and Papua. The main dimensions of this floating facility are: LPP (length of ship) = 70,99 m; B (width of ship) = 13,80 m; T (draft) = 2,48 m and H (height of ship) = 5,60 m. The total production costs accrued IDR 84,95 billion.

Table 3. Optimization results

Item	Value	Unit
Lpp	70.99	m
B	13.80	m
T	2.48	m
H	5.60	m
Ship production cost	84.95	billion IDR
Number of ships built	4	unit

4.2. Fleet design

Hereby the General Arrangement of floating medical wastes treatment facility based on the calculation result:

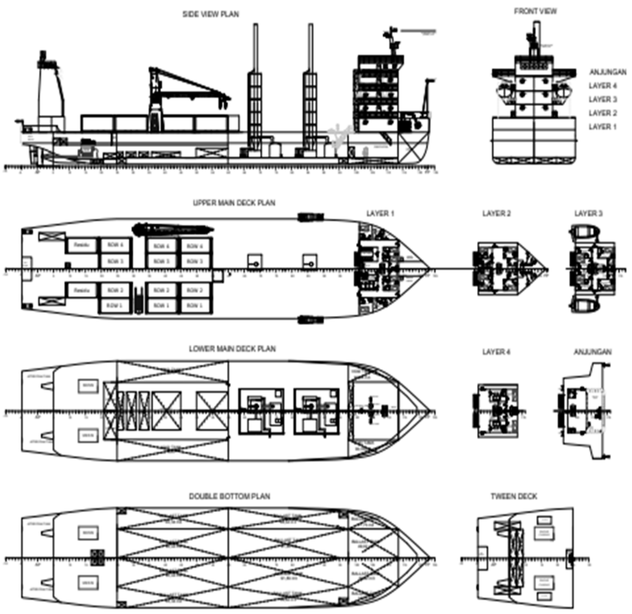

Figure 11. General arrangement of the floating medical wastes treatment facility

The layout and operation process on board can be seen in Figure 12. Part “A” as shown in Figure 12 is storage zone for medical wastes with a capacity of 12 TEUs. Part “B” is the medical wastes treatment zone, which consists of two incinerators and two medical wastes destroyers. Meanwhile, part “C” is the liquid wastes and residue storage zone of processed medical wastes. In part “C”, there are five main rooms namely: (1) residue storage room with size 6 m x 6 m x 1.5 m); (2) initial liquid wastes storage tank with size 6 m x 6 m x 1 m; (3) stabilization tank with size 1.8 m x 6 m x 1 m; (4) aeration tank with size similar to stabilization tank and (5) maturation tank with size 1.2 m x 6 m x 1 m.

Meanwhile, the process of medical wastes treatment on board can be seen through the notation of numbers in the side view plan in Figure 12, the detail as follows:

1. Wastes taken out from Storage Zone (A);
2. Wastes transferred from inside the container to the elevator using a forklift;
3. Wastes shredded in Medical Wastes Destroyer (B) and transferred into the incinerator (B);

4. The residue (fly ash) accommodated in the Residue Storage Room (C);
5. Liquid Wastes from treatment stored in the Initial Liquid Wastes Storage Tank (C);
6. Liquid Wastes in the Initial Liquid Wastes Storage Tank is processed in the Stabilization Tank, Aeration Tank, and Maturation Tank (C), and;
7. The wastes from the Residue Storage Room transferred into the Container (the transferred to the landfill sites inland), while the liquid wastes taken out by pumping it through the sea chest.

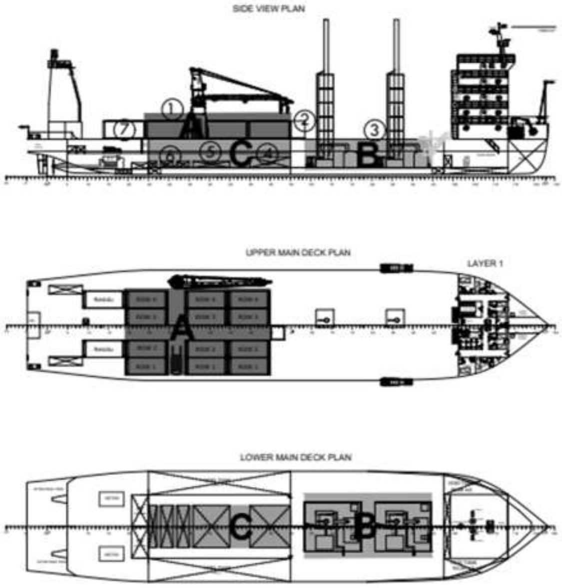

Figure 12. Layout and operation process on board of floating medical wastes treatment facility

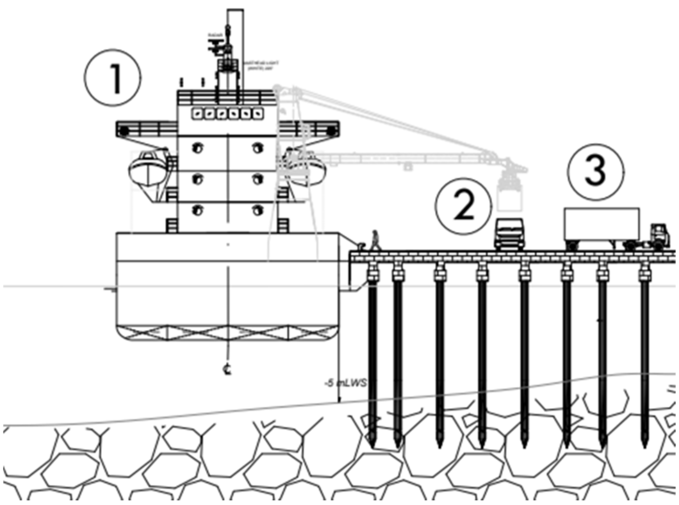

Figure 13. Side view of pick-up point berth

The process of loading and unloading medical wastes from and to the ship can be seen through the number notation in Figure 13, in detail as follows:

1. Ship is berthing in the jetty;
2. The container crane took the empty containers from the ship onto the truck or took the full containers from the truck onto the ship;

3. The truck carried out the receiving/delivery process to bring empty containers back to each healthcare facilities to store the medical wastes and/or deliver the full containers to the pick-up point.

5. Determining total costs

Total costs of ship are all costs incurred by each ship for one year operation, consist of fixed costs and variable costs. The fixed cost component consists of capital costs and operational costs, while variable costs are costs incurred by the ship when the ship operates a voyage such as fuel costs and port charges. Hereby the detail of determining total cost of floating medical wastes treatment in four provinces:

Table 4. Determining the total cost per each province

Item	Unit	Maluku	North Maluku	Papua	West Papua
Capital cost	billion IDR/year	7.31	6.99	7.67	6.44
Operating cost	billion IDR/year	3.25	3.11	3.41	2.86
Voyage cost	billion IDR/year	4.87	4.66	5.12	4.29
Cargo handling cost	billion IDR/year	0.49	0.47	0.51	0.43
Additional cost	billion IDR/year	0.32	0.31	0.34	0.29
Annual Total Cost	billion IDR/year	**16.24**	**15.54**	**17.05**	**14.31**

Additional cost is incurred by electricity, handling wastes equipment and reefer container during the operational of this floating facility. Furthermore, the result of annual total cost for each province can be seen in Table 5 as below:

Table 5. Total cost

Province	Value	Unit
Maluku	16.24	billion IDR/year
North Maluku	15.54	billion IDR/year
Papua	17.05	billion IDR/year
West Papua	14.31	billion IDR/year
Annual Total Cost	**63.14**	billion IDR/year

The total costs of floating medical wastes treatment facilities in Maluku, North Maluku, Papua and West Papua is 63.14 billion IDR/year. The production cost was included in these total costs under the capital costs.

6. Conclusion

- Medical wastes management in Maluku and Papua have not met the standard due to the lack of hospitals with licensed incinerators, unavailability of third-party company that planned to operate an incinerator in Maluku and Papua until the year of 2022 and the most appropriate wastes processing in these regions were carried out by conducting wastes shredding, open burning and landfilled.
- Maluku produced about 56,08 tons/month of medical wastes and its hub point is in Namlea, while North Maluku gained about 25,32 tons/month and its hub point is in Ternate. On the other hand,

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Papua and West Papua produced 26,90 tons/month and 55,70 tons/month of medical wastes, simultaneously and those hub points are in Jayapura and in Fak-fak.

- Considering the number of medical wastes in each province so that the nonlinear programming method was used to determine the most optimum main dimensions of floating facility. The result obtained that the number of floating facilities required was four SPCB-type with costs overall by 63.14 billion IDR/year. Furthermore, the main dimensions of this floating facility are: Lpp=70,99 m, B=13,80 m, T=2,48 m, and H=5,60 m. These floating facilities would be operated by a multi-port relay pattern starting from hub point in each province.

References

[1] Direktorat Kesehatan Lingkungan. (2020, January 15). *Pantau Data Pengelolaan Limbah Media (PLM)*. Opgehaald van Direktorat Kesehatan Lingkungan, Direktorat Jenderal Kesehatan Masyarakat, Kementerian Kesehatan Republik Indonesia: http://kesling.kesmas.kemkes.go.id/limbahfasyankes

[2] Malayadi, A. F. (2017). *Karakteristik dan Sistem Pengelolaan Limbah B3 Laboratorium Universitas Hasanuddin Kota Makassar.* Makassar: Fakultas Kesehatan Masyarakat Universitas Hasanuddin.

[3] WHO. (2014). Safe management of wastes from health-care activities: 2nd Edition. Malta: World Health Organization.

[4] Huang, C.-H. Chen, W.-J., Ma, M. H. -M., Lai, C.-L., Lin. F.-Y., & Lee, a. Y.-T. (2001, September). *Ambulance Utilization in Metropolitan and Rural Areas in Taiwan.* Journal of the Formosan Medical Association. Dipetik Juli 14, 2021, dari https://bit.ly/3g3bNcO.

[5] Bdour, A., Altrabsheh, B., Hadadin, N., & Al-Shareif, M. (2007). Assessment of medical wastes management practice: A case study of the northern part of Jordan. Waste Management, XXVII, 746-759.

[6] KLHK RI. (2015). *Peraturan Menteri Lingkungan Hidup dan Kehutanan RI No. PermenLHK/56/2015 tentang Tata Cara Dan Persyaratan Teknis Pengelolaan Limbah Bahan Berbahaya Dan Beracun Dari Fasilitas Pelayanan Kesehatan.* Jakarta: Kementerian Lingkungan Hidup dan Kehutanan RI.

[7] Firmansyah, Y. (2020). *'Penentuan Lokasi External Warehouse Dengan Menggunakan Metode Center of Gravity (Studi Kasus Di PT. RPZ Surabaya)'*. Jurnal Manajemen Industri dan Logistik, 4(1), pp. 58-66

[8] Craig B. Smith. (2007). *Extreme Waves and Ship Design, 10th International Symposium on Practical Design of Ships and Other Floating Structures,* Texas,USA.

[9] Lazuardi, S. D., van Riessen, B., Achmadi, T., Hadi, I., & Mustakim, A. (2017). Analyzing the national logistics system through integrated and efficient logistics networks: A case study of container shipping connectivity in Indonesia. In Applied Mechanics and Materials (Vol. 862, pp. 238-243). Trans Tech Publications Ltd.

[10] Yunianto, I. T., Lazuardi, S. D., & Hadi, F. (2018, March). Freight calculation model: a case study of coal distribution. In IOP Conference Series: Earth and Environmental Science (Vol. 135, No. 1, p. 012013). IOP Publishing.

[11] Watson, DGM. (1998). *Practical Ship Design.* Oxford: Elsevier Science.

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