International Journal of Offshore and Coastal Engineering
Vol.9 | No. 2 | pp. 65 – 72 | November 2025
e-ISSN: 2580-0914

Submitted: May 2, 2025 | Revised: June 27, 2025 | Accepted: August 8, 2025

Model Planning of Maintenance Dredging (Study Case: East Java Pultipurpose Terminal at Lamongan Shorebase)

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ABSTRACT
As one of the important entities in the sea transportation process chain, the port has a vital role as a connection point between regions. East Java Multipurpose Terminal (EJMT) is one of the port terminals which will be used as a connection point for the distribution of goods, especially around East Java Province. The purpose of this paper is to obtain effective and efficient model scenario for maintenance dredging plan at EJMT. The method used in this research is optimization method with a non-linear algorithm approach to determine the minimum cost. The results of this study indicate that the dredging scenario using sediment traps is the most optimum with the total volume of material dredged is 107,671.61 m3. The total duration of the dredging work is around 7 days with total cost around 7.1 billion rupiah or equivalent to 65-70 thousand rupiah per cubic meter.

Keywords: *Dredger, Optimization, Dredging*

1. INTRODUCTION

One of the sea transportation sectors that supports the distribution of goods is the port. The port as a link in the transportation process from the point of origin to the destination or as a link from one region to another. East Java Multipurpose Terminal (EJMT) is a terminal used to serve loading and unloading of general cargo commodities, namely commodities / goods in the form of break bulk, project cargo¸ and so on. EJMT which is located at Jalan Raya Deandels 64-65 KM, Desa Kemantren, Kecamatan Paciran, Kabupaten Lamongan is also a new dock project so that in order to support the smooth running of ships for loading and unloading, adequate port facilities are needed, including shipping lanes, turning pools, and berthing pools.

This EJMT construction project takes approximately 1 year for capital dredging activities in the shipping channel area, rotary pool, and berthing pool. Dredging is work to change the shape of the bottom of the waters to achieve the desired depth and width [1]. The dredger design used can load a 40,000 DWT container ship which is the largest ship that will be able to dock at EJMT. The existing depth in these waters is still -7 to -10 meters below chart datum where the depth is still not enough to serve the specifications of the largest ship that will dock. According to company documents, the dredge design used in capital dredging activities is carried out to a depth of -13.5 meters below chart datum.

However, sometimes these dredging activities can affect the flow of currents and waves, causing sedimentation in the shipping channel, turning pool, and berthing pool. This sedimentation is also influenced by the longshore sediment current that occurs. The existence of sedimentation causes sediment accumulation in the shipping channel, berth pond, and rotary pool area. Sediments that accumulate continuously can eventually cause siltation and will result in limited ships going in and out of the port area so that it will continuously disrupt the flow of ship visits and goods at EJMT, so to overcome this problem dredging can be done as maintenance of this port facility.

In addition to sedimentation, the influence of siltation rate also greatly affects the magnitude of the dredge volume plan. East Java Multipurpose Terminal when conducting capital dredging activities does not increase the siltation rate value so that it affects the effectiveness of dredging work. In addition, in the process of maintaining this water facility, sedimentation reduction methods need to be carried out with the information needed is the amount of dredged sediment volume. In this study, the author conducted a modeling study to facilitate maintenance dredging planning for the East Java Multipurpose Terminal from dredger selection to efficient dredging time duration and optimal costs.

2. STUDY LOCATION

The East Java Multipurpose Terminal (EJMT) is a newly opened dock project in Lamongan Regency, east Java, Indonesia. EJMT is designed to serve loading and unloading of general cargo commodities. EJMT is located at Jalan Raya Deandels 64-65 KM, Desa Kemantren, Kecamatan Paciran, Kabupaten Lamongan. Approximately 60 kilometers from Surabaya as eastern Java's capital province as shown in Figure 1. To support the smooth operation of ships for loading and unloading processes at the new dock, adequate port facilities are required, including shipping lanes, turning basins, and berthing areas as shown in Figure 2.

Figure 1. EJMT Layout

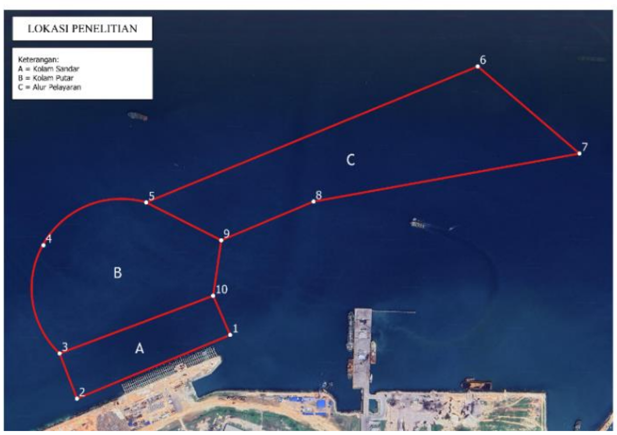

Figure 2. EJMT Capital Dredging Work Layout

Table 2. Coordinate Point of Dredging Location

	UTM Coordinates	
Point	*Easting*	*Northing*
1	656287,6500	9241230,2670
2	655826,2130	9241040,9820
3	655774,4420	9241176,4470
4	655726,7500	9241500,0530
5	656036,3130	9241627,4700
6	657035,1220	9242031,4190
7	657340,5150	9241769,7140
8	656539,9670	9241628,5530
9	656261,8490	9241513,4020
10	656236,8830	9241347,4260

3. METHODOLOGY

The stages of this research are carried out according to the flowchart below. This research begins with the stage of identifying the existing problems related to the planning of dredging from the conditions of capital dredging activities where the silting of the basin occurs continuously, thus affecting the work productivity of the dredging process.

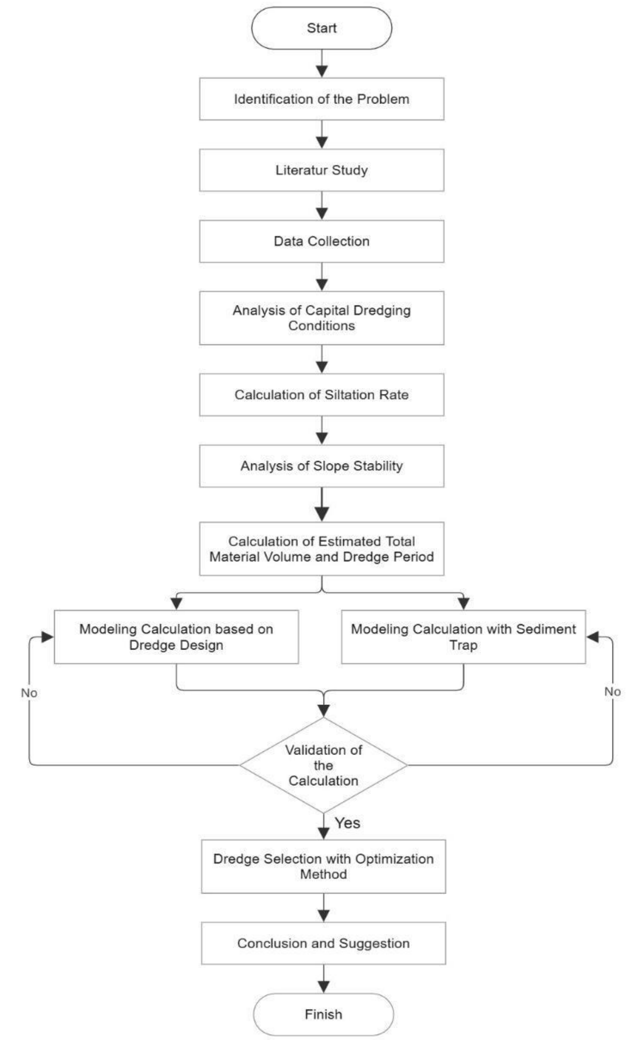

Figure 3. Flowchart of Work

Next, a literature study stage is conducted in order to obtain information to address the issues that will be faced. Several sources of literature studies used for this research come from books, journals, scientific articles, or from relevant regulations.

Data collection in this research is an important phase, where the data in this research is primary data obtained through direct communication or observation at the study site. The data needed for this research includes final sounding bathymetry data from the last dredging or post-dredged, dredging pdesign, data on dumping area locations, specifications of the largest vessel to be served by EJMT, soil type data, as well as data on the types of dredging vessels along with the rental costs of each dredging vessel.

Information on dredging vessel rental prices was obtained from several dredging service provider companies.

For this analysis stage, a calculation analysis is carried out for the capital dredging conditions considering several factors such as the volume of sediment that has been removed, the volume of sediment deposition caused, the siltation rate factor, and potential constraints that may occur during the dredging.

The calculation of the siltation rate itself is carried out so that the addition of the total estimated volume of dredging for maintenance activities is in accordance with the existing field conditions. This calculation stage requires data on the volume of sediment accumulation at each progress of sounding. In addition, slope stability analysis is also conducted to understand the stability of the slopes due to the accumulation of sediment during each sounding task. The slope stability is assessed based on the safety factor value calculated with the help of GeoStudio software.

For the estimation calculation of the total dredging volume, it is based on 2 (two) predetermined scenarios. Scenario 1 is conducted using a dredging design that corresponds to capital dredging without a sediment trap, while scenario 2 is a dredging design with a sediment trap.

In each scenario, a dredging period calculation is performed to determine when maintenance dredging activities need to be carried out again. This calculation requires input in the form of sediment volume for each scenario as well as sedimentation rate calculations that have been conducted previously.

The first thing to do at this stage is to estimate the duration of dredging work, which aims to determine the total duration of the dredging work until its completion. After obtaining the total duration of the dredging work, the next step is to calculate the total cost of the work. The rental price of the dredger used in this calculation already includes operational costs such as crew salaries, crew supplies, lubricating oil, and so on, excluding fuel costs.

Model validation is conducted to ensure that the calculation model and the compiled data along with the results are correct or if improvements are still needed. The calculation model can be considered accurate if the calculations between combinations of ships result in different times and costs, indicating that all components in the calculation are interconnected.

The next step is the selection of the dredging vessel using the Optimization Method. This stage is the core phase of the research conducted to calculate the total cost and time required for maintenance dredging activities. The selection of the vessel is performed using a nonlinear programming optimization method. The objective of this model is to determine the vessel that is appropriate with the minimum cost.

The decision variables at this stage are the type and capacity of the selected dredger, while the constraints for this method are that only one dredger can be selected for each type and capacity, the dredging location must be deeper than the draft of the dredger to ensure safe passage for the dredger, and the dredging capability of the selected vessel must be deeper than the initial design depth. The optimization process is carried out continuously until it stops, indicating that the specified objective function has been achieved, which is the minimum cost.

The conclusion is the final stage of this study where the results obtained from this research will be explained in the form of an estimated total dredging volume, the selection of the most optimal dredging vessel, as well as the calculation of an efficient duration of time with optimal costs for the planning activities of maintenance dredging in the upcoming period.

RESEARCH DESCRIPTION

2.1 Sedimentation, Siltation Rate, & Slope Stabilization

Sedimentation is the process of sediment carried away by a flow of water that settles in a place. Meanwhile, sediment itself is composed of rocks, minerals, and organic materials that scientifically always exist in rivers, lakes, estuaries, and sea water. Sediments can be categorized based on particle size, mass density, shape, sedimentation speed, resistance to erosion, and so on [2]. There are several main factors that control the distribution of sediment in coastal areas, namely sediment sources, wave energy levels, and coastal slopes. The presence of sediment deposits in large quantities results in silting of the waters so that maintenance dredging is needed for existing port facilities.

Meanwhile, the siltation rate can be interpreted as the rate of sediment re-deposition or solid material from inside and outside the dredge site that occurs during dredging. Siltation rate can be influenced by several factors, such as current, sediment material type, flow type, and the dredging technique used. But sometimes it is also influenced by the slope stability of the dredge design used. Slope is an important parameter for determining the cross-section of a harbor pond that can affect the volume of dredging. The more gentle the slope, the better the slope will be so that landslides of dredged material in the pond can be minimized but result in additional dredge volume.

The Directorate of Ports conducted research to determine the slope and siltation rate at several locations in Indonesia. However, in this study, the authors validated the recalculation of siltation rate and slope values used for maintenance dredging model analysis. The following is the equation used to calculate the siltation rate [3].

$$Siltation\ Rate\ (\%) = \frac{Sediment\ Vol.\ 2 - Sediment\ Vol.\ 1}{Sediment\ Vol.\ 2} \quad (2.1)$$

2.2 Dredging

Dredging is the work of changing the shape of the bottom of the waters to achieve the desired depth and width [1]. Dredging has several types according to function and use, including capital dredging, maintenance dredging, and remedial dredging [4]. Initial dredging is carried out in port construction work, maintenance dredging is carried out periodically to maintain water depth and maintain safe ship navigation, while remedial dredging is carried out for special reasons such as depth errors during initial dredging.

Dredging is broadly divided into three main processes, namely excavation, transportation, and disposal. Dredging methods are carried out with mechanical dredgers and hydraulic dredgers. Mechanical dredgers use the same method as land-based excavation equipment, while hydraulic dredgers suck up soil mixed with seawater through a suction pipe and then the soil in the pipe is flowed to a temporary stockpile on the dredger.

The basis of dredger selection is important for more efficient and economical yield improvement and optimization of dredging activities. There are usually several parameters considered for determining the type of dredger, such as the type of dredged material, the initial depth of the dredging site, the depth of the dredging plan, the wave height at the site, and the density of ship traffic at the site. However, in this study, the type of vessel used refers to capital dredging activities, namely by using a clamshell dredger assisted by a split hopper barge and trailing suction hopper dredger.

2.3 Dredge Design

The determination of the dredge design is very important and is required to consider the ships that will dock to the port area. The dredge design planning is determined from the largest ship that will be served in the area by considering meteorological and oceanographic conditions [5]. In this research, the author uses references from Christino Boyke with his book entitled Port and Terminal Planning. The following is one of the calculations for the rotary pool area requirements [6].

Table 1. Turning Basin Area Requirements

Condition	Area Requirement (meter)
Ship with tugboat and bow thruster assistance	4 x Loa
Ship with tugboat assistance	2 x Loa
Ship with main propeller, rudder, and bow thruster assistance	1,5 x Loa

For dredge design depth planning, it usually depends on the area owner considering the existing sedimentation rate. Generally, if a site has a large sedimentation rate, the design depth of the dredge planned is also large so as not to require frequent maintenance dredging periods with a short time frame.

2.4 Dredge Volume Calculation

In determining the calculation method for the volume of excavation or embankment in an area can be done by the cut and fill method. This method can be done using AutoCAD Civil3D software. Before the method is carried out, it is necessary to divide each section/block called the cross section method. After obtaining the cut and fill volume, the volume calculation is carried out using the simpson rule method.

Simpson's rule method is used to find the area and volume of irregular figures. The accuracy of the answer obtained from this method depends on the distance from the coordinates and how close the division of the curve is. The following is the Simpson rule I equation used [7].

$$V = \frac{h}{3}(a_1 + 4a_2 + a_3) \quad (2.2)$$

$$V = \frac{3}{8}h(a_0 + 3a_1 + 3a_2 + a_3) \quad (2.3)$$

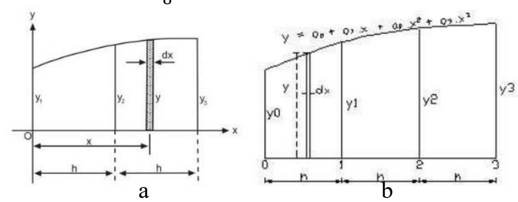

Figure 2. (a) Curved Planes (Simpson's Rule I), (b) Curved Planes (Simpson's Rule II)

2.5 Type of Vessel Charter

The existence of this ship charter activity is due to the existence of business actors who lack transportation modes. Lease agreements between national business actors and shipowning companies or intermediaries on behalf of the owner are also made possible by laws and regulations in Indonesia. In general, ship charter is divided into 2 types, namely time charter and voyage charter. Time charter is a lease scheme where the charterer pays the ship's rent to the owner within a certain period of time, for example one year. Whereas voyage charter is a charter scheme that is based on a specific trip. In this scheme, the charterer pays rent based on the amount of cargo delivered on a particular contract.

2.6 Optimization Method

This optimization method is a way to maximize or optimize something that aims to manage something that is done. This method includes analytical and numerical techniques to solve problems, especially in the context of complex and non-linear functions and objectives. There are several methods to solve non-linear programming problems, such as Lagrange Multipier, Karush-Kuhn-Tucker condition approach, Quadratic Programming, and Separable Programming.

4. ANALYSIS AND DISCUSSION

4.1 Capital Dredging Condition

Conditions from capital dredging activities are analyzed to obtain several values that will be used for the next stage. At this stage several calculations are carried out, such as the total volume of dredges and sediment deposits, calculation of sedimentation rates based on the volume of sediment deposits, data on the vessels used, and constraints or disturbances during capital dredging activities.

The calculation of the total dredge volume obtained results in 902,681.97 m^3 while the volume of sediment deposits obtained results in 68,969.43 m^3. The volume of sediment deposits for each progress sounding bathymetry in September, October, November and December will be used for the calculation of the sedimentation rate, until it is obtained for the sedimentation rate at EJMT of 4,221.30 m^3/month. This sedimentation comes from several rivers adjacent to the EJMT location, such as the Brondong River, Bengawan Solo River, and PT Lintech Duta Pratama whose references have been obtained by the author and other small rivers.

The dredger used in capital dredging activities is 1 Clamshell ship with the assistance of 2 Split Hopper Barge ships for the location of the berthing pool and rotary pool, while 1 TSHD ship for the shipping channel. However, in operation, these vessels have several obstacles or disruptions that occur due to internal and external factors from the ship. Internal factors from the ship include dredger maintenance such as ship repair, ship bunkering, anchor damage due to fishermen's activities, checking internal ship equipment, repairing the ship's electrical system, etc. As for factors external to the ship, such as the EJMT area which must be sterilized for bathymetry sounding activities, bad weather, etc. From the analysis of constraints and disturbances that occur, it is found that constraints will occur for dredger maintenance for 21% of the total dredging days and bad weather for 16% of the total dredging days. The percentage of these constraints will later be used as a margin or addition to the calculation of operational time for maintenance dredging later.

4.3 Soil Data

Soil data in this study was obtained from the results of a drill log survey with several drill location points. Here are some locations of drill log test points.

Figure 5. Drill Log Test Point Location

From the picture above, it is obtained that the locations of the drill log test points are EJTM-01, EJMT-02, EJMT-04, and EJMT-06. From the analysis carried out, the results for rock formation are a combination of poorly graded sand or silt, clayey sand (SC), and silica sand (SM).

4.4 Calculation of Siltation Rate

The calculation of siltation rate is an important aspect of dredging activities, especially the lifting of sediment from the bottom of the water to maintain the required depth of the channel or harbor pond. Siltation means the accumulation of sediment deposits, such as mud, clay, or sand that can reduce depth during capital dredging activities.

This siltation rate calculation analysis is from the results of sediment deposits that exist during capital dredging activities based on sounding bathymetry every month. Calculation of the siltation rate value using equation 2.1. From these calculations, it is known that the largest siltation rate is 3.45% which is ROUNDUP so that the siltation rate is 4% where later the siltation rate will be used as an addition to the dredge volume.

4.5 Analysis of Slope Stability

Slope is the inclination or slope of a land surface that has a significant impact on the design of port pond cross-sections and can affect dredge volumes. Frequent landslides can be detrimental to dredging work, so determining the slope is an important challenge because if it is too steep it can increase the risk of large landslides, while if it is too gentle it can affect dredging efficiency.

In this slope stability analysis, soil data at the EJMT-04 location was taken and N-SPT correlation with soil cohesion, soil specific gravity, and soil shear angle were used for input in GeoStudio software. The following is the soil data from the correlation data.

Table 3. Input Soil Data

Depth (meter)	N-SPT	Cohesion (kN/m^2)	Spesific Gravity (kN/m^3)	Shear Angle (°)
9,8 – 10,6	14	0	18,55	34,5
10,7 – 12,6	9			
12,7 – 13,5	1	0	11,56	19

The slope stability analysis performed on GeoStudio software will produce a stable factor of safety value with a value >1.5. This analysis was carried out with several experimental variations of the British Standard BS 6349-5:2016 standard codes for slope inclinations of 1:4, 1:5, 1:6, 1:7, 1:8, and 1:9. From the results of the analysis experiments conducted, it was found that the factor of safety value for the slope of 1:9 indicates that the slope is stable with a value of 1.695.

4.6 Scenario 1

The dredge design used in this calculation refers to the initial design determined by the owner of EJMT with an elevation of -13.5 meters. The following is an illustration of the EJMT dredge design.

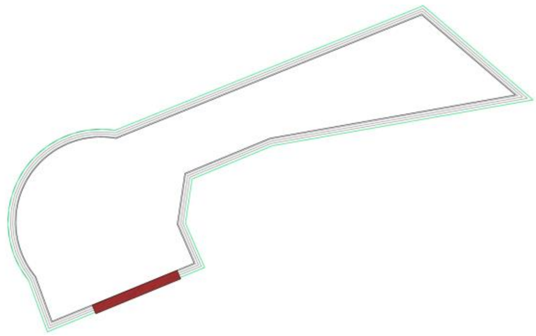

Figure 6. Dredge Design Illustration

Validation analysis for this dredge design was carried out from the reference book Perencanaan Pelabuhan dan Terminal by Christino Boyke. From the results of the calculation of the dredge design dimensions, it was found that the initial dredge design determined by the owner was appropriate and fulfilled the validation of the dredge design dimensions calculation. In this process, the calculation of the safe depth required for ships to pass through the port facilities is also carried out and an elevation value of -12.98 meters is obtained.

Furthermore, the calculation of the dredging period in scenario 1 requires some input data in the form of estimated sedimentation rates and the total volume of sediment deposits from overlaying post-dredged data and safe depth design. The following are the results of the calculations that have been carried out.

Table 4. Dredging Period in Scenario 1

No	Location	Sediment Fill Volume (m^3)	Dredging Period
1	Berthing Pool	34.117,81	Every 8 months
2	Turning Basin	169.252,12	Every 40 months
3	Shipping Channel	214.557,37	Every 50 months

This was followed by the calculation of the dredge volume obtained through the overlay of the design safe depth of the ship whose elevation is -12.98 meters with the initial dredge design whose elevation is -13.5 meters. Overlay is done with the help of Civil3D software and with the cross section method. This dredge volume calculation also adds the previously described siltation rate value of 4%. The following is the volume of dredged material for maintenance dredging activities in scenario 1.

Table 5. Dredging Volume in Scenario 1

No	Location	Dredging Vol. (m^3)
1	Berthing Pool	128.852,01
2	Turning Basin	306.607,85
3	Shipping Channel	443.289,48

After knowing the total volume of dredged material and the dredging period, a calculation model of the time and cost required for dredging can be made. The calculation of operating time is used in order to determine the total days to rent a dredger by considering several constraints that occur, while for the calculation of costs to determine the amount of costs that must be incurred for dredging activities. The following is an example of the results of the calculation of time and costs required for maintenance dredging activities in scenario 1.

Table 6. Operating Time in Scenario 1

ALTERNATIVE VESSEL OPERATING TIME TSHD 8 SCENARIO 1			
No	**Description**	**Time Required**	
1	Dredging Time	1,00	hours
2	Material Disposal Time	0,17	hours
3	Sailing Time	1,30	hours
4	Time of One Dredging Cycle (Trip)	3,00	hours
5	Number of Dredge Trips	278	times
6	Total Number of Days for Dredging	34,4	days
7	Dredger Mobilization Time	1,4	days
8	Total Dredge Days	36	days
9	Bathymetry Sounding Activity	3	days
10	Bad Weather	6	days
11	Dredger Maintenance	8	days
12	Total Days to Charter a Dredger	52	days

Table 7. Dredging Cost in Scenario 1

COST REQUIRED FOR ALTERNATIVE SHIP TSHD 8 SCENARIO 1	
Description	**Total Cost**
Dredger Charter Fee	IDR 22,766,401,139
Fuel Cost	IDR 4,839,042,787
Bathymetry Sounding Cost	IDR 103,425,000
Total Cost for TSHD 8 Ship Alternative	**IDR 27,708,868,926**

In the results of the above calculations, the total cost required in scenario 1 using the alternative TSHD 8 ship is IDR 27,708,868,926, with a cost per cubic meter of IDR 62,507.

4.7 Scenario 2

In this scenario, the dredge design utilizes a sediment trap. Sediment traps or what can be called sediment traps, are traps / dams for sedimentation that are temporary or permanent that function to collect, capture and store sediment due to construction activities or as a flow barrier to reduce high water rates. In this research, a sediment trap design reference from PT APBS in the Surabaya West Shipping Channel is used with a sediment trap width of 30 meters and a height of 1 meter.

The following is an example of a cross section and top view of the dredge design with a sediment trap.

Figure 7. Sediment Trap Cross Section

Figure 8 shows the cross section of the dredge design when using a sediment trap with a slope of 1:9 which is in accordance with the analysis in the previous section. The location of the sediment trap placement is below the slope and parallel to each side of the dredge design. The existence of sediment traps close to the slope is expected that avalanches from the slope will fall into the sediment trap. So that the volume of sediment deposits is the volume of sediment traps located along the dredge design.

In scenario 2, the division of each pool work object and also the channel is carried out. This dredge period calculation requires input data in the form of estimated sedimentation rates and sediment fill volumes. The following is the volume of sediment deposits and the dredging period for each pond and channel.

Table 8. Dredging Periode in Scenario 2

No	Location	Sediment Fill Volume (m^3)	Dredging Period
1	Berthing Pool	15,180.78	Every 3 months
2	Turning Basin	36,123.19	Every 8 months
3	Shipping Channel	52,226.42	Every 12 months

Followed by the calculation of the dredge volume which is from the volume of sediment piles or sediment trap volume with the addition of the siltation rate value. The dredge volume for scenario 2 is as follows.

Table 9.Dredging Volume in Scenario 2

No	Location	Dredging Vol. (m^3)
1	Berthing Pool	15,788.01
2	Turning Basin	37,568.12
3	Shipping Channel	54,315.48

In this scenario, only TSHD 8 vessels are used for dredging, because TSHD vessels are easier and more flexible to dredge at sediment trap locations and loading productivity and productivity are greater than with Clamshell and Split Hopper Barge vessels. From the calculation of dredging operational time in this scenario, it is obtained that the total days needed to rent a dredger for the object of dredging work is 8 days. So that the dredging costs in this scenario can be obtained as follows.

Table 10. Dredging Cost in Scenario 2

COST REQUIRED FOR ALTERNATIVE SHIP TSHD 8 SCENARIO 2	
Description	**Total Cost**
Dredger Charter Fee	IDR 5,961,385,619
Fuel Cost	IDR 1,346,341,494
Bathymetry Sounding Cost	IDR 0
Total Cost for TSHD 8 Ship	**IDR 7,307,727,113**

In the results of the above calculations, the total cost required in scenario 2 using the alternative TSHD 8 ship is IDR 7,307,727,113, with a cost per cubic meter of IDR 69,331.

4.8 Optimization Results

The calculation model for each scenario has been carried out which includes the calculation of the time and costs required for maintenance dredging activities. However, when viewed from the analysis of the calculation of the operational time and costs required for each scenario using the TSHD 8 alternative vessel, scenario 2 using sediment traps is cheaper but the maintenance dredging work carried out is shorter for scenario 2 than scenario 1. However, the results of the calculation model are still not optimal so it is necessary to carry out an optimization method to validate the calculation model carried out. Optimization will be carried out using Microsoft Excel software with the help of plugin tools in the form of Solver.

The optimization method used has a type of non-linear programming which is a branch of mathematical optimization that focuses on problems where the objective or control function is non-linear. The optimization results obtained from Solver are expected to show the most optimal scenario with a predetermined objective function. Here are some of the functions needed for optimization in Solver.

1. The objective function in this study is the minimum total cost of maintenance dredging activities.
2. The decision variables in this study are the type and capacity of the selected dredger.
3. There are 3 (three) limitations to this optimization problem as follows:
   The selected ship can only be 1 (one) in each type and capacity of the dredger
   The depth of the dredge location ≥ Draft of the dredger
   Dredging capability of the selected vessel ≥ Dredge design depth

The following are the results obtained from optimization scenario 1 and scenario 2 which show the capacity and type of vessel selected, the time required, and the minimum cost for maintenance dredging activities.

Table 11. Optimization Results Scenario 1

Optimization Results Scenario 1			
Description	**Berthing Pool**	**Turning Basin**	**Shipping Channel**
Dredging Volume	128,852.01 m^3	306,607.85 m^3	443,289.48 m^3
Total Days to Charter a Dredger	40 days	76 days	40 days
Number of Ships Used	1	1	1

Optimization Results Scenario 1			
Description	**Berthing Pool**	**Turning Basin**	**Shipping Channel**
Ship Code	CS 4	CS 5	TSHD 10
Number of Helper Ships Used	2	2	-
Helper Ship Code	SHB 3	SHB 3	-
Dredging Period	Every 8 months	Every 40 months	Every 50 months
Total Cost Required	IDR 9,162,832,223	IDR 19,416,281,269	IDR 23,451,207,494
Cost per Cubic Meter	IDR 71,111	IDR 63,326	IDR 52,902

Table 12. Optimization Results Scenario 2

Optimization Results Scenario 2			
Description	**Berthing Pool**	**Turning Basin**	**Shipping Channel**
Dredging Volume	15,788.01 m^3	37,568.12 m^3	54,315 m^3
Total Days to Charter a Dredger	3 days	7 days	7 days
Number of Ships Used	1	1	1
Ship Code	TSHD 6	THSD 6	TSHD 9
Dredging Period	Every 3 months	Every 8 months	Every 12 months
Total Cost Required	IDR 1,086,337,225	IDR 2,692,433,167	IDR 3,537,721,392
Cost per Cubic Meter	IDR 68,807	IDR 71,668	IDR 65,132

Based on the optimization results above, the comparison of scenario 1 and scenario 2 is that scenario 2 is more suitable because it has the minimum cost, shorter work duration, and less project risk compared to scenario 1. Dredging work for scenario 2 is expected to be more profitable for EJMT because dredging is only carried out in the sediment trap of the dredge design so that it does not affect ship traffic and also the logistics activities of ships that want to dock to load and unload goods at EJMT.

When viewed from the total cost of dredging, both from the total cost or cost per cubic meter, it is lower than scenario 2 than scenario 1, this shows better efficiency. The duration of the dredging work in scenario 2 is faster than in scenario 1 so that it can reduce the potential risk of the project. Projects that are faster in duration tend to be more efficient in resource management and have lower risks than projects with longer durations. So by choosing scenario 2 which has a faster duration of work and the minimum cost, the company can complete the work faster and avoid cost escalation due to economic changes or other external factors.

CONCLUSION

Based on the analysis and calculation of research on maintenance planning models that have been carried out, the conclusion that can be obtained is that scenario 2 is more effective in terms of economics, risk, duration, and impact given during maintenance dredging activities.

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