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Productivity and Cost Analysis of a Mechanical Clamshell Dredging Vessel

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Abstract:

Dredging is essential for maintaining waterway accessibility and supporting maritime economies. This thesis focuses on clamshell mechanical dredging, analysing factors affecting production rates (equipment, sediment, and operations) and cost components (maintenance, fuel, labour). It develops Excel-based cost estimation models, enhancing efficiency and decision-making. These spreadsheets utilize an adjustable cycle time and bucket fill factor to estimate production rates, allowing for flexibility in production calculations based on the time required to complete one dredging cycle and the material's capacity to occupy the bucket. The findings of this study can contribute to the optimization of dredging operations, ensuring efficient resource utilization and informed decision-making in various industries that rely on clamshell mechanical dredging for sediment excavation and removal.

Key words: Dredging, Mechanical Clamshell, Cycle Time, Bucket Fill Factor

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1. Introduction

Since the dawn of civilization and the development of established communities, there has always been a necessity to move people, machinery, materials, and goods via water routes. Consequently, there arose a demand to deepen the channel depths of various water bodies to ensure accessibility to ports and harbours. Most major ports worldwide periodically require dredging to expand their entry channels and manoeuvring areas, as well as to maintain suitable water depths alongside their facilities. Additionally, these waterways often necessitate regular upkeep through dredging. In the context of river navigation, dredging is also essential for establishing and sustaining crucial connections to inland ports and amenities.

In essence, dredging has played and will continue to play a critical role in the economies of most countries across the globe. Maritime transportation remains the predominant mode for transporting a wide range of commodities and is continually growing. Navigation initiatives must keep up with the evolving demands of maritime transport to uphold and support local, national, and regional economies. (IADC, 2010).

Clamshell mechanical dredging is a specialized method used for excavating and removing sediments from water bodies, particularly in marine and coastal environments. This technique involves the deployment of hydraulic or mechanical dredges equipped with clamshell buckets, which allow for efficient and precise sediment excavation. As clamshell mechanical dredging continues to be a prevalent practice in various industries, understanding its production capabilities and associated costs becomes paramount for project planning and decision-making.

An important term, when discussing dredging projects is production. Production, also known as output, in the context of dredging, is the rate at which in-situ sediment is removed from the bottom, expressed in terms of unit volume per unit time (Paparis,2017). This definition of production is used throughout the thesis.

This thesis aims to explore the production rates and cost estimation considerations specific to clamshell mechanical dredging operations. By conducting a comprehensive analysis of the factors influencing production rates, including dredging equipment specifications, sediment characteristics and operational parameters, this research seeks to provide valuable insights into optimizing the efficiency of clamshell mechanical dredging operations. Additionally, by examining the various cost components associated with dredging projects, such as equipment maintenance, fuel consumption and labour. This study aims to develop Microsoft excel spreadsheet readily available for individuals outside the government and contractors' community. Focusing on the use of an adjustable cycle time and bucket fill factor to estimate the production rate. The cycle time is the amount of time required to complete one dredging cycle. The approach also permits variations in production because it considers the material's capacity to completely occupy the available volume. of the bucket (fill factor).

The introductory section of this thesis establishes the foundation for the subsequent chapters, outlining the objectives, significance, and structure of the study. It also provides an overview of clamshell mechanical dredging, including, equipment specifications, and common applications across different industries.

Objectives:

The primary objective of this thesis is to assess the production rates and cost estimation considerations for clamshell mechanical dredging operations. Specific objectives include:

Investigating the factors influencing production rates, including dredging equipment specifications (e.g., bucket size), sediment characteristics (e.g., type of sediment, bulking factor) and operational parameters (e.g., dredge cycle time, water depth).

Examining the various cost components associated with clamshell mechanical dredging projects including equipment maintenance, fuel consumption and labour.

Developing accurate cost estimation models based on the identified cost components to facilitate project budgeting and evaluation.

By addressing these objectives, this thesis aims to provide a comprehensive understanding of the production capabilities and cost considerations of clamshell mechanical dredging. The findings of this study can contribute to the optimization of dredging operations, ensuring efficient resource utilization and informed decision-making in various industries that rely on clamshell mechanical dredging for sediment excavation and removal.

1.1 Dredging definition and overview

Dredging is the removal of bottom sediments from streams, rivers, lakes, coastal waters, and oceans, and the resulting dredged material is then transported by ship, barge, or pipeline to a designated placement site on land or in the water where it is placed. Dredges can either be mechanical or hydraulic. (Randall,2016).

The primary aim is to maintain navigation channels at proper depths to allow a safe passage of vessels through the navigation waterways (canals, rivers, and harbours). Another objective would be to deepen existing navigable waterways, for example, several ports on the East Coast and Gulf Coast of the US have ongoing or planned dredging projects to deepen the existing ports to accommodate larger vessel traffic in response to the Panama Canal expansion, and the trend in the shipping industry toward larger cargo vessels (Bhadury, 2016). Moreover, land reclamation, such as the Chinese government's efforts in the South China Sea (Johnson, 2016), or removal of contaminated sediments. Also, to construct dams, dikes, and other control works for streams and seashore and to recover subaqueous deposits or marine life having commercial value.

These objectives are achieved by four dredging works:

a) Initial dredging: it is a job that is needed in the manufacture of a new port. This work has big funds and is done for long-established sedimentation.

b) Maintenance dredging: done at an existing port, with the aim to maintain navigation requirements in the port shipping channel. For instance, if the port is shallow the ships cannot dock. Therefore, dredging is carried out regularly at the port shipping channel.

c) Reclamation: aiming to move soil on the seabed from the dredging area to the embarkment area with the intention of increasing the area of landfill or other engineering needs.

d) Environmental dredging: dredging with reason to improve the environment of a water location. Included in this is moving soil or sediments affected by pollution.

Prior to dredging, an investigative survey and data collection must be carried out. The purpose of hydrographic implementation is to find out whether the depth of the bottom of the shipping channel has reached the depth design limit in accordance with the provisions for the shipping channel along with calculating the volume of material that must be dredged.

Hydrographic surveys (positioning, depth measurement and water level) are carried out before, during and after work.

In the dredging implementation, must consider the following method:

a) Dredging is carried out by not having a negative impact on the port environment and the surrounding environment.
b) The method used is adapted to the type of material, hydrographic survey, ecosystem and environment around the dredging site and the location of the dump.
c) The dredged material is prepared in such a way to prevent it from returning to the dredging area (resuspension).
d) Dredging is carried out by referring to the laws and regulations, national standardization, criteria and norms and other applicable provisions. (IJCIET,2018).

1.2 Overview of dredging types

The selection of dredging equipment for the implementation of certain projects is based on the availability of the dredgers fleet owned by the contractor as a candidate for the project (Pullar and Hughes,2009), or it can be rented. Thus, there are several aspects to be considered.

a) The effectiveness of dredging equipment adapted to the type of sedimentation.
b) The ability of dredging equipment to transport sediment from the dredging area to the disposal site.
c) The flexibility in the work of dredging related to the weather conditions at the project site.
d) Considerations of environmental aspect at the disposal site.
e) The efficiency of the project.

The dredgers, in general, are divided into two groups: hydraulic and mechanical, as demonstrated in figure 1-1.

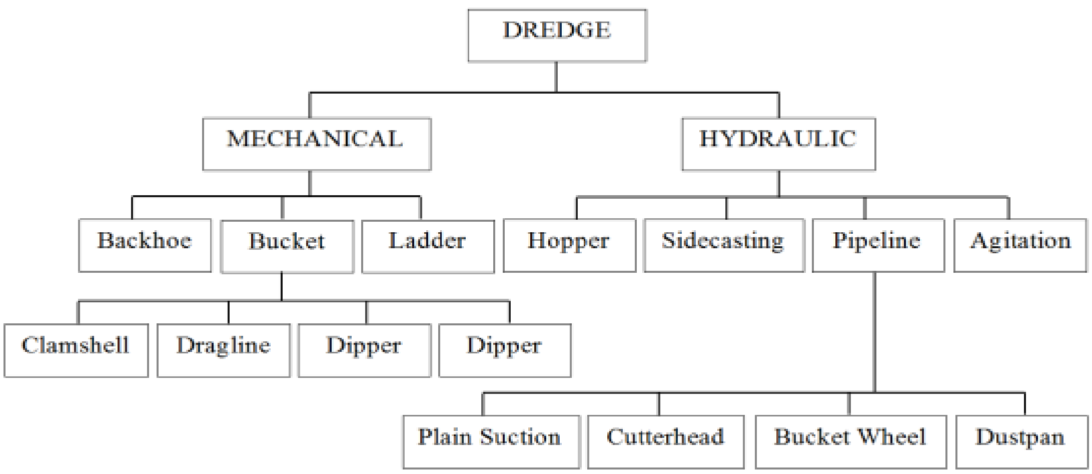

Figure 1-1 classification of types of dredgers

There are hopper dredgers, cutter head, dustpan, side casting and suction dredgers that use centrifugal pumps to pump such a dredged sedimentation and slurry from port and waterways. Meanwhile, for the mechanical dredgers, there are a bucket, clamshell bucket, backhoe, and dipper dredgers (Herbich,1992),

Hydraulic dredgers

In the hydraulic dredging process, the force from the water jet can be directed toward the dredgers or away from the dredgers. The water jet will take the mixture of water and soil which is drawn by dredger. The process of soil lifted hydraulically/ pneumatic with a centrifugal pump, with a jet pump, by using the air (airlift) and with pump seabed. Centrifugal pump used to raise (vertical) and transport (horizontal). The dredging pump is not much different from the large water pumps, only impeller designed to allow large chunks to pass them. Jet-water at high pressure leads into the suction pipe. Jet-water flow with a mixture of water and soil (slurry) and tube venture-energy jet of water is converted into a “high-pressure water.” The dredger effectiveness depends on the speed of the water jet and the characteristics of the material.

The dredger’s effectiveness depends on the speed of the water jet and the characteristics of the material. Suction head shape assortment, includes:

a) Head-suction-flat as the Suction Dredger.

b) Ship-pull like the Trailing Suction Hopper Dredger. (Figure 1-2).

c) Dustpan head as in Dustpan Dredger. Sometimes ship-pull dustpan head was equipped with a jet of water to help the "exploitation" easier. (Hardy, T. P.,2016).

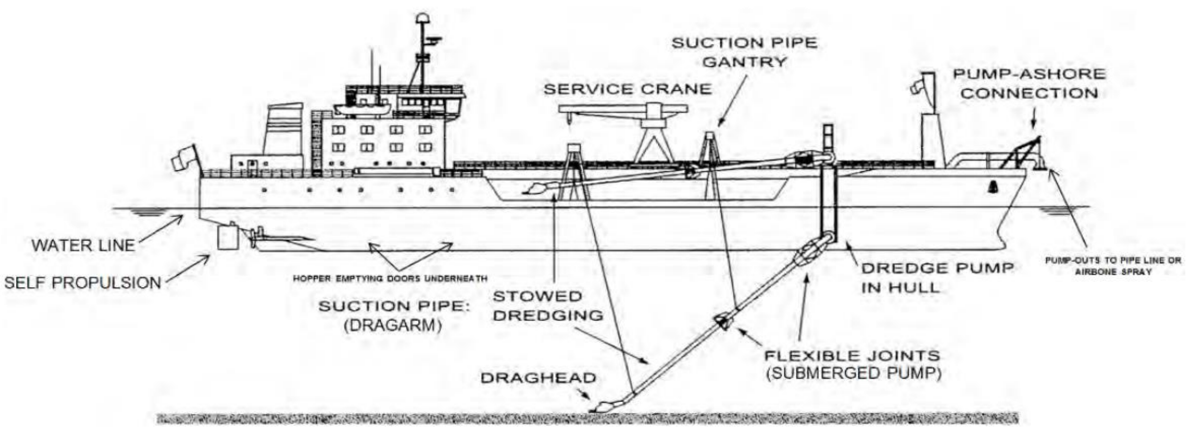

Figure 1-2 Typical characteristics components of trailing suction hopper dredger

Mechanical dredgers

They are suited for working in confined areas and are useful for removing the hand-packed material or debris, they are classified as dipper, bucket (clamshell), or bucket ladder dredges, depending on the means of excavation, with bucket dredges further classified as either clamshell, dragline, or backhoe, depending on equipment used.

Mechanical dredging is a preferred method for accomplishing environmental dredging as it extracts less water for a given in-situ sediment volume compared with hydraulic dredging methods. Most of the time, an environmental dredging project will use a specialised bucket that limits sediment resuspension during the dredging process. (Bergeron et al, 2000).

The main drawback of a mechanical dredge is its limited production rates. A hydraulic dredge generally can achieve sediment removal at a greater rate than a mechanical dredge.

The clamshell dredge has several advantages over its hydraulic counterparts. A mechanical dredge is well-suited for dredging in areas where manoeuvrability is restricted. It is also useful for projects with deep digging depths. Unlike a hydraulic dredge, whose digging depth is limited by the number of pumps and the length of the discharge piping, a mechanical clamshell dredge is limited by the length of the cable for raising and lowering the clamshell, also known as a grab. Therefore, for dredges of comparable size. A mechanical clamshell dredge has superior deep dredging capability (bray et al, 1997)

The clamshell mechanical dredge consists of a barge with a crane mounted on it: most clamshell dredges are not self-propelled and rely on tugboats for movement. However, to minimize the frequency of tugboat usage, most of non-propelled dredges will utilize spuds. A spud is a cylindrical or square pile that passes through the top of the dredge and can be lowered into the channel bottom. The spud allows the dredge to rotate about the point where the spud is lowered. A typical dredge will have three spuds, with one spud located towards the bow, and two towards the stern. The stern spuds are configurated, so they are symmetric about the centreline. Use of the spuds in conjunction with the ship’s anchor allows the dredge to “walk” itself forward without the use of a tugboat (Randall,2016). The self-propelled clamshell dredgers the vessel has a hopper in which it can store the dredged material.

For grab (clamshell) dredgers the method of anchoring and the positioning system plays a key role for the effectiveness of the dredger. At every pontoon position an area as wide as possible will be dredged. Looking from the centreline, the volume to be dredged at the position decreases with the angle to the centreline.

The positioning is important to localize the bit of grab. This helps the dredge master to place the next bit after the fore going. Releasing the aft wires and pulling the fore wires does the movement of the pontoon. When the dredgers have the spud poles, this movement is done by a spud operation, which is more accurate than executed by wires. The dredging process is discontinuous and cyclic. (CEDA,2003)

The dredger excavates the sediments, loads them in the barge or hopper. In case of the hopper, the vessel sales to the placement site, it unloads the hopper and then goes back to the dredging site. Which is called the dredging cycle (figure 1-3). However, for the barge, the vessel stays in the dredging site, only the barge goes and returns from the placement site. So usually, there are two barges, to avoid wasting production time.

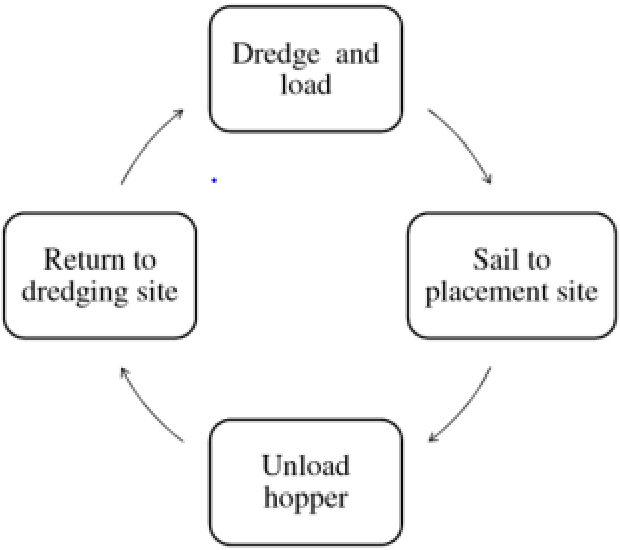

Figure 1-3 Dredging cycle of mechanical hopper clamshell dredger

Figure 1-4 is a scheme of a self-propelled Grab (Clamshell) Hopper Dredger GHD, that is used in Ravenna Port-Hub project. We can see the different essential components of the ship.

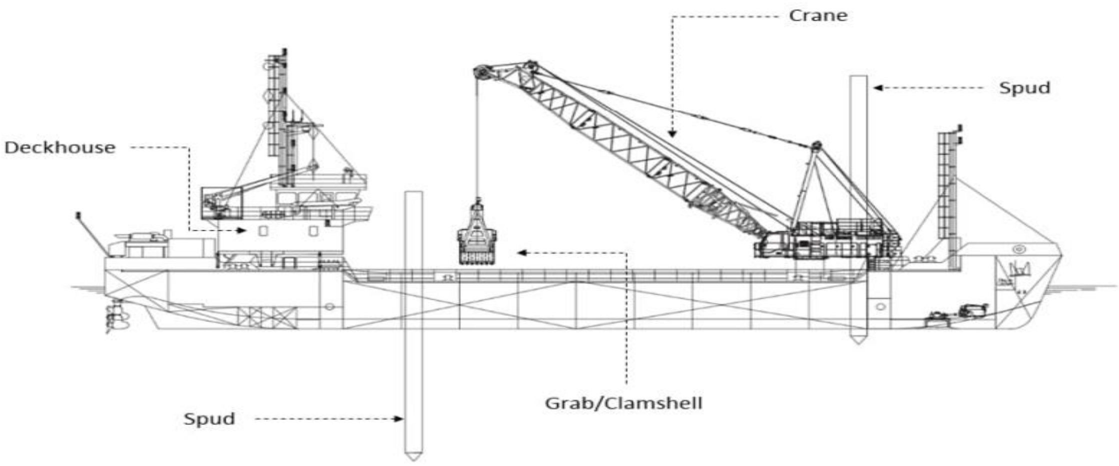

Figure 1-4 scheme of a Grab hopper Dredger "GHD" type

Figure 1-5 shows the various parts on a clamshell bucket. The hoist wire supports the weight of the clamshell and the sediment when it is full. The arm is what the actual bucket pivots around. During operation, the bucket is dropped or lowered into the sediment and then closed. The cutting edge penetrates and cuts the sediment. The bucket then closes and is lifted to the surface. There are some differences in clamshell buckets. The middle clamshell in the figure is a simple open bucket. Some buckets are closed with gaskets to prevent water from escaping. There are level cut clamshells such as the ones described by Bergeron (2000). These buckets are more useful for environmental dredging.

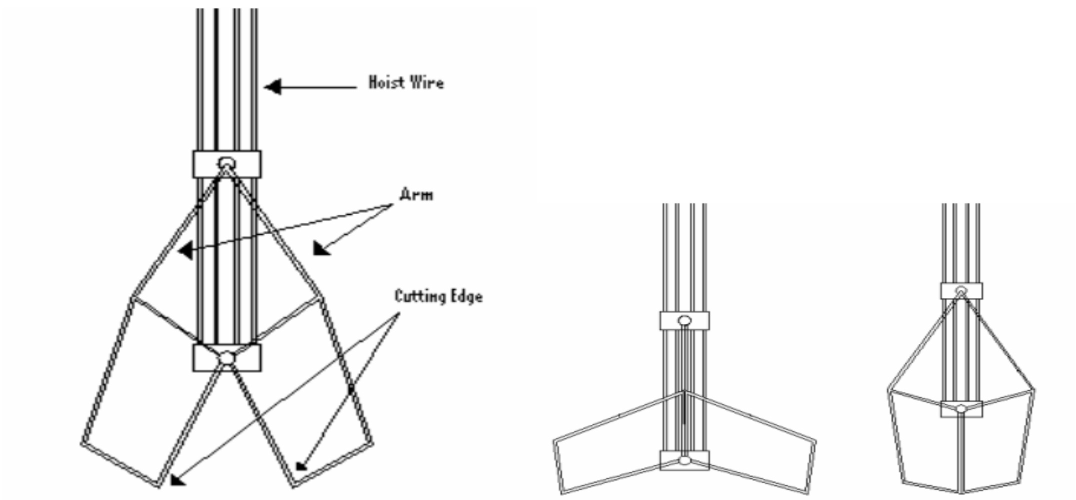

Figure 1-5 Operation of a Clamshell Bucket (Key Components, Open Position, Closed Position)

There are also other special buckets that are used for harvesting clams, these are made of mesh that allows sediments to escape. The figure displays the parts of a clamshell buckets as well as the bucket in the open and closed position. The bucket is lowered directly into the sediment in the open position. Once in the sediment, the clamshell is closed. Then, the bucket is lifted out of the sea floor of the waterway, and the sediment is then transported and placed in a barge or hopper in case a Grab Hopper Dredge (GHD). The right side of the figure shows the clamshell in the closed position. (Tsinker,2004)

The principle of this hoisting operation is given in the Figure 1-6 below. For a good crane-working behaviour the cable cranes have two motors:

- The hoisting motor, which drives the hoisting winch and
- The closing motor, which controls the closing and the opening of the grab. To avoid spinning of the clamshell a so-called tag wire is connected to the clamshell.

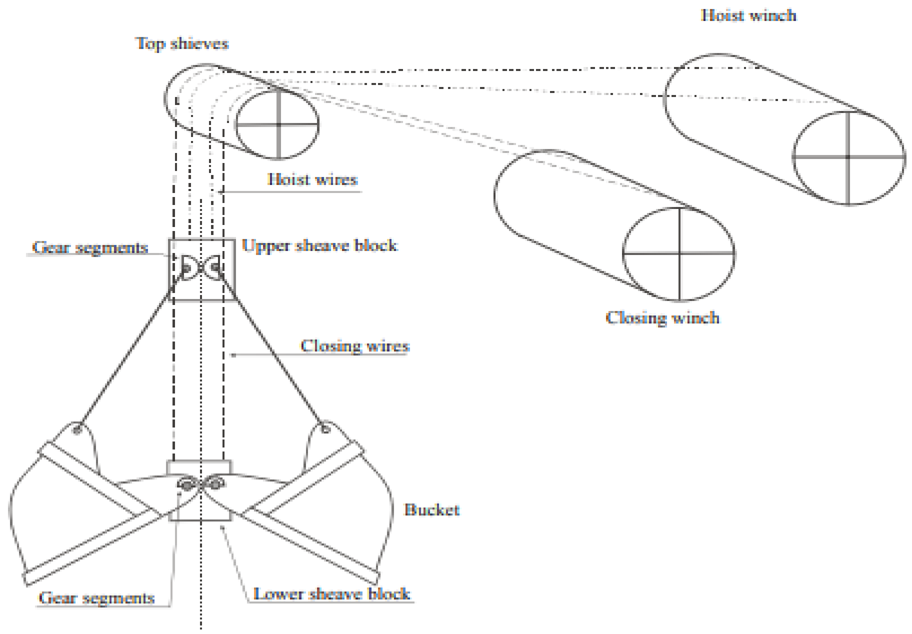

Figure 1-6 hoisting operation of the clamshell dredger

An important characteristic of mechanical dredges are the bucket and the bucket size, Figure 1-7 shows the distribution of bucket sizes for mechanical dredges for the United States in 2003 (IDR,2003). From the figure it is apparent that most buckets are smaller than 11 m^3, and there are several buckets between 11 and 23 m^3. After 23 m^3 there are just a few buckets. The largest bucket found is 38 m^3.

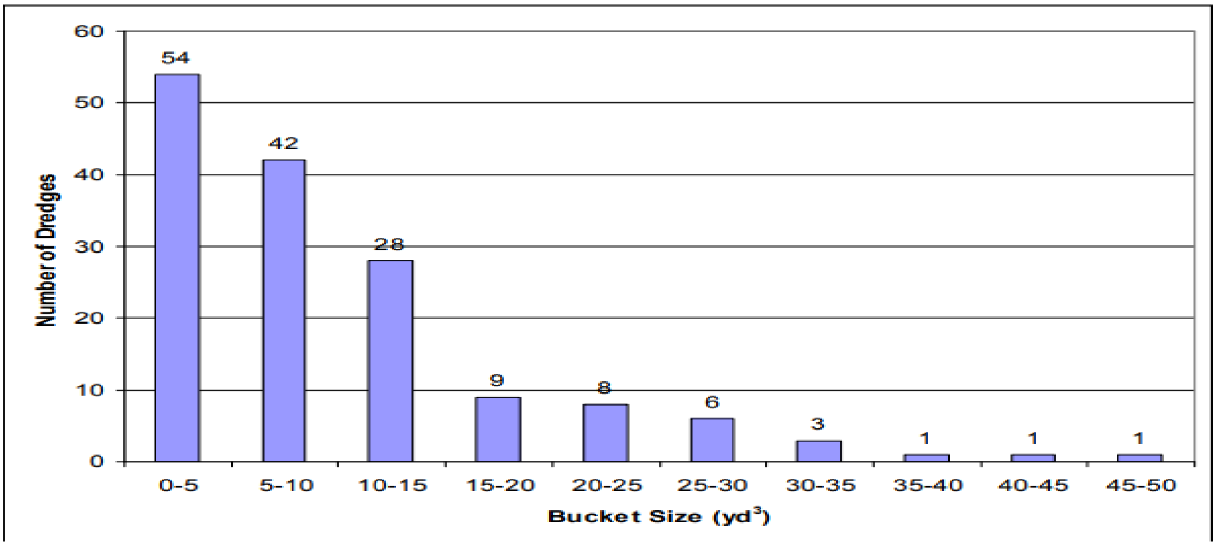

Figure 1-7 Distribution of Bucket Sizes in the USA (Multiply by 0.765 for m3)

The clamshell most common and is used in are silty, clayey, and sandy materials. In mud the yaws in general have flat plates without teeth. In sand, clay and gravel, the yaws are fitted within each other grabbing teeth. As shown in the figure 1-8. The two halves, shells, rotate around a hinge in the lower sheave block and relate to the upper sheave block by rods.

The closure/hoist cable is referred several times between the head and the disc block to generate enough closing force. For the removal of the contaminated soil closed clamshells are used to avoid spillage.

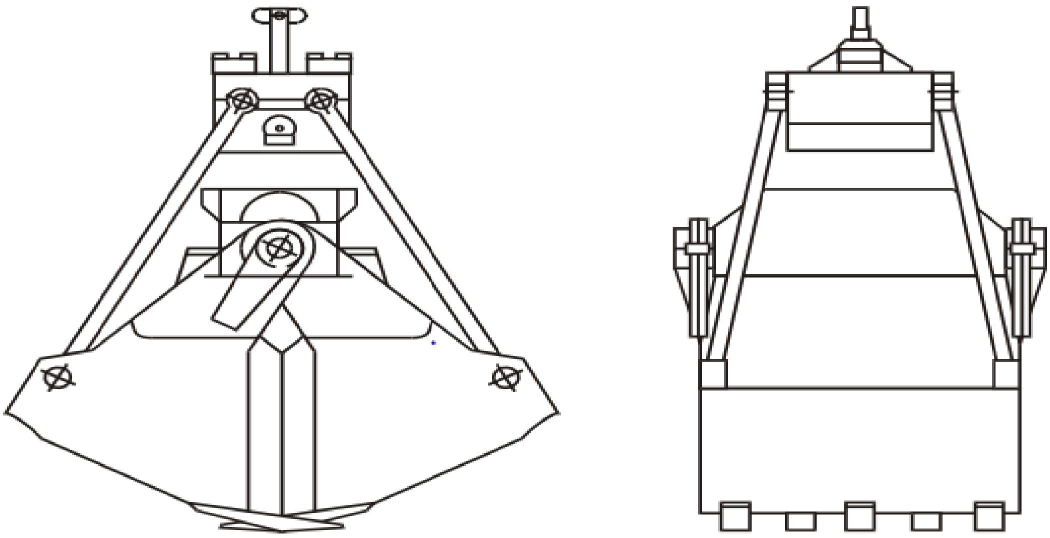

Figure 1-8 Flat plates clamshell

The orange peel grab is often used for the removal of large irregular pieces of rock and other irregular pieces. This type of grab has 8 yaws that in general do not close very well. The cactus bucket is used in the occurrence of both coarse and fine material at the same time. This grab has 3 or 4 yaws that close well in the closed position and form a proper bucket. The size of the bucket depends on the required production capacity of the crane. Both demonstrated in the figure 1-9 respectively.

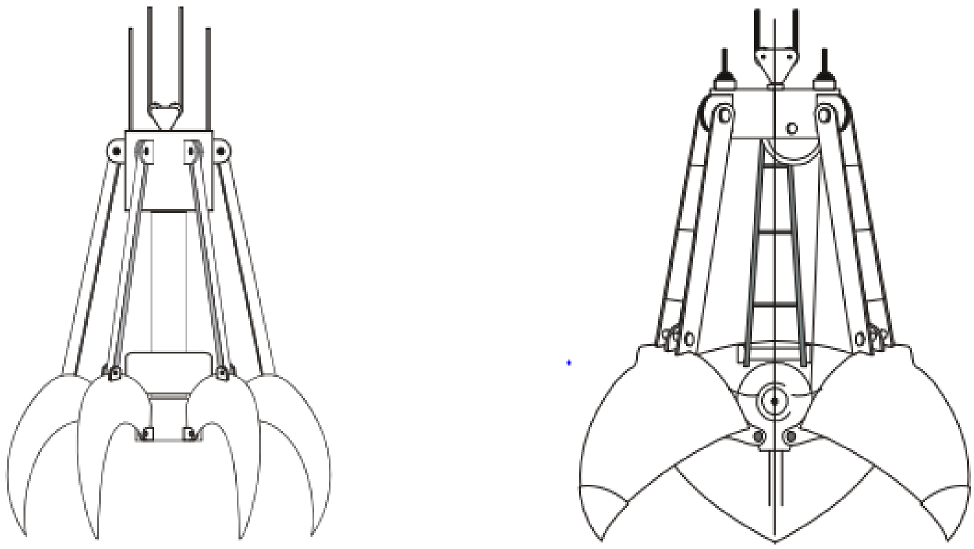

Figure 1-9 Orange peel and Cactus grab

2 Project overview

As part of the project "Port Hub of Ravenna of I phase" is planned to deepen the channels

Candiano (up to the San Vitale docks) and Baiona with reuse of the extracted material, the adaptation of the existing operating docks and the new Container Terminal, located in the Trattaroli peninsula in implementation of the P.R.P. in force in 2007.

The goal is to combine the development of the port with the need to create a depth uniform seabed, without altering the conditions of competitiveness of any of the terminal operators present in the port and at the same time producing a quantity of material resulting from the excavations compatible with current reuse capacity.

In particular, the project envisages, among other things, the deepening of the following areas:

- marine channel and outer port at -13.50 m a.s.l.
- Candiano canal at -12.50 m asl up to the San Vitale docks.
- Baiona dock up to -12.50 m a.s.l.
- evolution basin in the outer port and docks serving cruise traffic at -10.00 m.s.l.m.
- backdrops under the quays and on those whose interventions have been carried out based on existing projects previously authorized at levels -12.50 m/-11.50 m in relation to works carried out there.

In summary, the dredging of 4,742,000 m3 is expected in the final project (quantity on a natural desk) "Of which the immersion at sea is expected for 1,374,000 cubic meters; the remaining 3,368,000 cubic meters ..., like a final destination, for the filling - up to the highlighting - of some logistics areas on the ground ".

In the executive project, the outcomes of updated Bathymetric reliefs and a further campaign of characterization on the one hand have identified the suitability of the quality of the sediments for the immersion at sea for all the characterization cells (included between 379 and 402) of the Marine Canal of approach to the port of Ravenna - for a quantity of material equal to 1,200,000 m3 without O.D., and on the other, they determined the need to deposit all the remaining dredge material to the ground From the edge of the Foranee dams (cell 378) to the Darsena San Vitale in the port of Ravenna.
The overall dredging volume to be allocated to the ground is approximately 3,318,000 m3
Such the dredging will be implemented mechanically, through by self-propelled self-loading/unloading dredges "grab hopper dredger GHD" type. The material will be deposited

in suitable modular tanks of provisional decanting and accumulation located long two different port plates. Depending on the type (parameters that fall within the limits of the "column A and B of Tab.1 ALL. 5 Title V Part IV of cited Legislative Decree no. 152/2006 ") The sediments will be located in different tanks.

2.1 Field of application and objective

The operational executive phases that are intended to implement/adopt for the dredging of deepening of the Candiano channel, of the Darsena Baiona, of the Evolution Basin in Avamporto and darsene at the service of traffic Cruise - by means of "GHD - Grab Hopper Dredger" type motor ships, equipped with Hydraulic rope excavator - material I tended for reuse in logistics areas on the ground (L2 and S3) and in "Cava la Bosca" are described. Therefore, not considering the dredging areas more external than the port (in -depth analysis at -13.50 m of the marine channel and the forefoot) as intended for immersion at sea.

From the executive project approved the overall volume of the sediment to be subjected to mechanical dredging is approximately 3,318,000 m^3 of silt - clay material located in different areas as part of the port of Ravenna. more exactly from the mouth of the breakwaters (area 1) to Darsena Sapir (zones 2 - 3 - 4 and 5).

2.2 Materials characteristics

To provide an updated picture of the quality status of the sediments, compared to previous one's investigations, dating back to 2014, which had not been carried out in accordance with the new sector regulations (Ministerial Decree n.173 of 15 July 2016 on the handling of marine sediments), In the 2019 a detailed characterization campaign of the dredged areas was carried out, in accordance with the provisions of the technical annex to the D.M. 173/2016, through the identification of n. 3 types of unit areas: typology 1 (50x50m mesh) close to the buildings inside the port, type 2 (100x100 mesh) in the central areas of the port; typology 3

Figure 2-1Management of the dredging areas of the Ravenna Port HUB project

(200x200 mesh) in the zones outside breakwaters. 403 unitary meshes were therefore identified.

The interpretation of the available analytical results of the characterizations of the dredged material intended exclusively for re-use on land, according to dredged sediment management options as by-products envisaged in Legislative Decree 152/2006 (pursuant to the criteria defined by article 184-bis), they have highlighted parameters that fall within the limits of "column A and B of table 1 Annex 5 Title V Part IV of the aforementioned Legislative Decree no. 152/2006".

Therefore, based on these investigations it is confirmed that the sediments to be dredged can be deposited on the ground in the logistics areas (L2 and S3) and in the "La Bosca" quarry. Only the material that will fall within the limits of "Table I column A of Annex 5 to Title V Part IV of Legislative Decree 152/06" will be used for the environmental restoration of the "La Bosca" quarry. These sediments, before being transferred to their final destination, will be "sample" characterized within the intermediate storage tanks (ref. PUT).

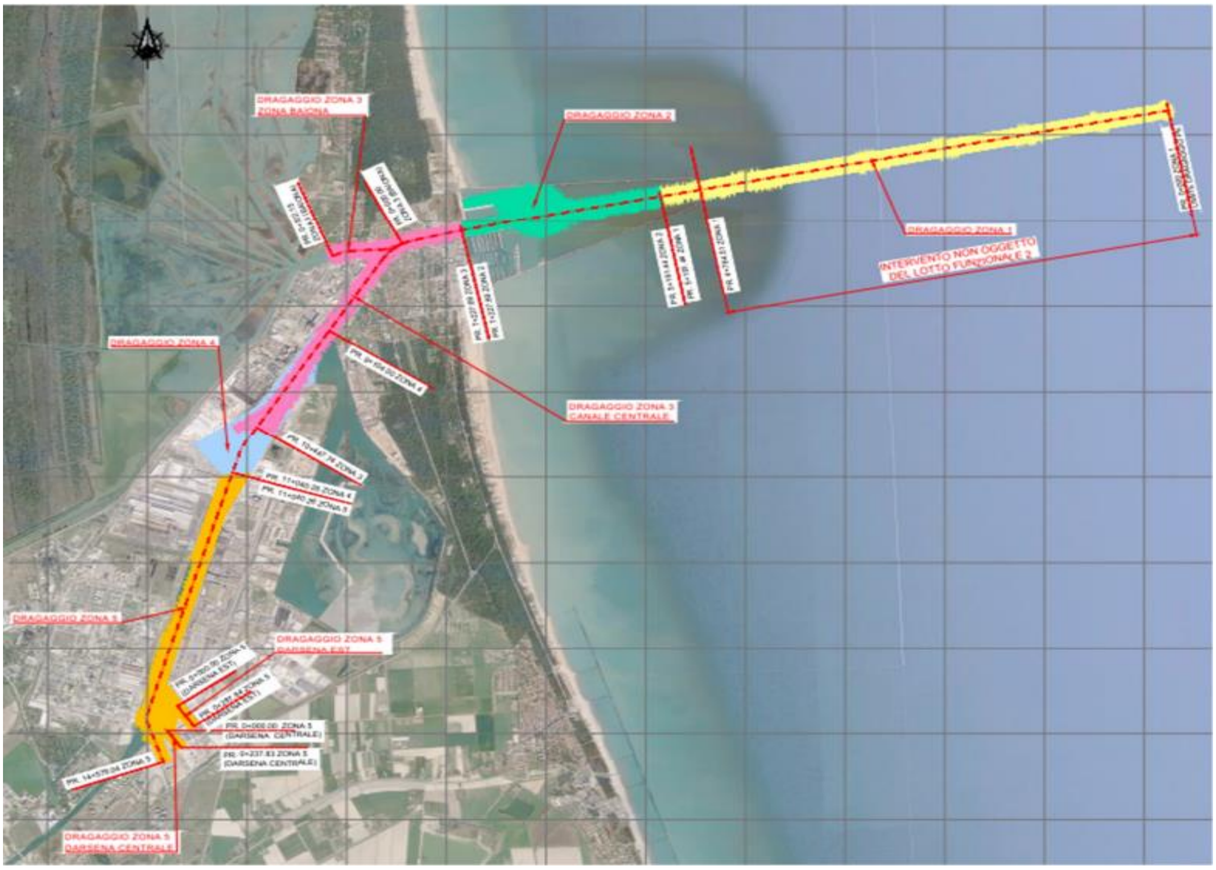

Figure 2-2 General plan of areas subject to mechanical dredging and onshore management of materials

3 Literature review and methodology

3.1 Literature review

Production of dredges is determined in several ways depending on the type of dredge. Bray et al (1997) first introduces production and cost estimating techniques that are available to the public and is useful in quantifying project costs that are not readily available. The authors approach dredge production estimating by identifying the dredge productive unit, dividing it by the appropriate cycle time-that is the amount of time required for the dredge to complete one cycle- and applying applicable modifications factors. The authors also provide techniques for calculating production rates for various dredge types, including the mechanical clamshell dredge. The production rate estimate methodology that this thesis relies on these techniques. And one of the focuses of this thesis is to determine the sensibility of production rate to cycle time.

Additionally, Bray et al (1997) explore the variety of costs one must consider when estimating a dredging project, and provide techniques for calculating these costs, such as mobilization and demobilization, plant capital costs, and plant running costs. Of a particular usefulness in developing the cost estimating program were the techniques for estimating fuel and lubricant costs, maintenance and repairs, capital costs of dredges, insurance, overhead, and financial charges.

The Center for Dredging Studies (CDS) developed the first publicly available general estimation program for dredges (Miertschin and Randall, 1998). This estimating program was developed for cutter suction dredges, and later expanded to include hopper dredges, (Belesimo, 2000) and clamshell dredges (Adair and Randall, 2006). Over the past twenty years, the CDS has built upon these estimating programs, with the completed program published by Wowtschuk (2016).

Adair (2004) used the techniques from Bray et al (1997) in developing the estimating program. It improves upon the concept of bucket fill factor, representing for the percentage of the bucket filled with sediments during a given dredge cycle, depending on the sediment type, bucket velocity, and fall velocity, this value can vary considerably. Dense or hard sediments make it difficult for the clamshell to close, and the sediment may contain large voids. Clays are difficult for a bucket to cut. If the bucket does not reach its maximum depth, it cannot fill completely. By applying the work of Bray et al (1997) as well as Emmons (2001) that did not allow for factors such as the rate of a bucket being raised or lowered, swing rate, as well as bucket opening and closing time. It is important to be able to vary the individual components of the dredge cycle in mechanical clamshell dredging. In these projects it is common to limit the velocity that the clamshell is allowed to travel through the water column. Slowing down the bucket velocity reduces re-suspension and reduces the sediment from re-suspension when the bucket strikes the bottom. Besides bucket velocity, time to open the bucket, time to close the bucket, and the water depth. The combined time to complete all these tasks is the cycle time, which is combined with bucket volume to define production rate (m^3/h).

Cycle time and fill factor are therefore the dominant parameters in mechanical dredge production. The cycle time provides the time required for each dredge cycle and the fill factor determines the amount of sediment removed each time. These factors are combined to estimate the maximum production rate for a clamshell dredge.

3.2 Methodology

This thesis will use a quantitative analysis method, by reviewing the implementation of the dredging project at the Port hub of Ravenna to deepen the channels Candiano (up to the San Vitale docks) and Baiona.

The procedure is divided into four phases. The first phase is estimating the cycle time. First, we must determine the parameters affecting the cycle time. These parameters are water depth, bucket fall and lift velocities, bucket close and open time, swing angle and swing velocity. (Adair, 2004).

Second, default values of these parameters are determined. For instance, the average swing angle is 120 degrees (Emmons, 2001). The method must allow the alteration of each parameter depending on the specification of the dredging operation. Accounting for particular cases such as environmental dredging, or a special bucket size. During an environmental project, the bucket ascends at one third of its normal rate. This provides a cycle time that works for both normal and particular cases.

The second phase for this method is to determine the bucket fill factor. The fill factor is the percentage of the total volume of the bucket that is filled with sediment. For certain materials, the bucket is not completely full. (Bray et al, 1997) provides limited data for fill factor for small dredges that are less than 8 m^3. The fill factor for this method, which is developed by (Adair, 2004), comes from curve fitting these data points with limited data points for larger dredges. This provides the method for estimating production for a broad range of mechanical clamshell dredges. Accounting also for six different sediment classifications: mud, loose sand, compact sand, sand and clay, stones, and broken rocks. Mud refers to fine sediments such as silts and clays, with a particle size of less than 0.075 mm (0.003 in), sands refer to particle sizes of 0.075 mm to 4.75 mm (0.003 in to 0.187 in), stones and broken rocks are particles larger than 4.75 mm (0.187 in) (Briaud, 2013). Once the production rate is determined, the project duration can be calculated by dividing the volume of sediment to be removed by the production rate. (Paparis,2017).

The third phase is to develop a cost estimating method that uses the output from the production calculations to determine project cost. For this phase standard estimation and values, used in previous related research and papers, are applied.

The final phase is to use the program to estimate the cost of other projects available to the public, compare it to the winning bid and the government estimation. A sensitivity analysis for the cost estimation program. The sensitivity analysis is done to determine how cost varies when influencing parameters are varied, such as bucket size, fill factor or the sediment type. Once the estimations are verified. The spreadsheet form can be used for a quick estimation of any mechanical clamshell dredging project.

4 Production estimation procedure

The production estimate determines how long it will take to complete a dredging project, given the equipment being used for the project, the conditions of the sediment being dredged, and the requirements for dredged material placement. Once the production rate is determined, the estimator can then determine the costs associated with the project (Bray, et al, 1997).

4.1 Cycle time (Tc_{ycle}):

The cycle time is the total time required for the dredge to empty, move to the desired location, fill the bucket, and empty it. With the increase of the cycle time, the project length will increase also the cost. The terms are defined as swing angle (θ_{sw}), swing angular velocity(ω_{sw}), bucket fall velocity (u_f), the time to close the bucket (t_g), the bucket lift velocity(u_l), the time to empty the bucket(t_e), the water depth (d), and the freeboard height of the barge (h_b).

$$Tcycle = 2*(\theta sw/\omega sw) + tg + te + uf\,(d + hb) + ul\,(d + hb) \qquad 4\text{-}1$$

4.2 Swing Angle (θ_{sw})

The first parameter is the swing angle. It is the difference between the location where sediment is dropped into the hopper and the location where the sediment is excavated. Swing angle is expressed in degrees for these calculations. An average value for swing angle is 120 degrees. This value is doubled when the total cycle tine is calculated to account for the swinging to and from the excavation site.

4.3 Swing Speed (ω_{sw})

swing speed is the rate that the mechanical clamshell dredge rotates to and from the excavation site and the hopper. This is consistent with the swing speed of large cranes, and a default value is 21 degrees per second.

4.4 Fall velocity (u_f)

The rate or speed at which the bucket is lowered to the bottom is the fall velocity. The bucket can be dropped in freefall or lowered at a controlled rate.

4.5 Grab Time (t_g)

The grab time is the time required to close the clamshell on the sediment and is given in seconds. A common grab time value is one second, and it can be adjusted for buckets of diverse sizes.

4.6 Lift velocity (u_l)

The velocity that the bucket is raised through the water column is the lift velocity. During environmental dredging, the lift velocity is decreased to control re-suspension. Re-suspension occurs when sediment leaves the bucket, sediment leaking out of the bucket, the impact of the clamshell of the bottom. This is a problem in environmental dredging where contaminated sediments are being excavated. A common value for the list velocity is about 0.3 m/s during environmental dredging is 1 m/s during normal dredging.

4.7 Empty time (t_e)

The empty time is the time required for the sediment to leave the bucket after opening. An average value is 2.6 seconds, which is the suggested default value.

4.8 Depth (d)

For cycle time the average depth is used. This the average excavation depth for the project. The depth is multiplied by the lift and the fall velocity to determine the amount of time the bucket is in the water column.

4.9 Freeboard Hight of the Barge or hooper(h_b)

The barge freeboard height is the height above the free surface elevation that the bucket must be lifted. The freeboard height includes the height of the side of the barge plus any additional height necessary to clear the deck of the barge or hopper and any sediment. This freeboard height is then added to the depth to find the total distance that the bucket must travel vertically.

4.10 Bucket fill factor

(Adair, 2004) developed an exponential curve combining data from (Emmons, 2001) and (Bray, 1997). The factor stays below 1 for the bucket size up to 50 m3. If the fill factor values become greater than 1 it means the bucket is picking up a volume of sediments greater than its capacity. Since Adair (2004) classified the sediments into 6 categories, which are used to calculate bucket fill factor and bulking factor. The classifications are mud that consists of sediments such as loss silt, clays, and other fine-grained sediments. Loose sand that is not compacted. Compacted sand is dense that has been loaded or compacted. Sand and clay are a mixture of sands and clays. Stones are made of small rocks from gravel and cobbles. Broken rock is any sediment larger than cobbles. For these six categories, he developed respective equations:

The equation 4.2 is the bucket fill factor f_m related to the bucket size C for mud:

$$fm = 0.0474 * ln(C) + 0.7255 \qquad 4\text{-}2$$

With small buckets the fill factor is commonly between 75 and 85 percent. Once the bucket is 40 m^3 or larger the fill factor is greater than 90 percent. The curve also fits the criteria that the fill factor is never greater than 1. It is also apparent from Figure 4-1 that it is important to be accurate with bucket size below 10 m^3. The fill factor varies rapidly in this zone and can cause large errors in the production estimation program if an incorrect bucket size is used.

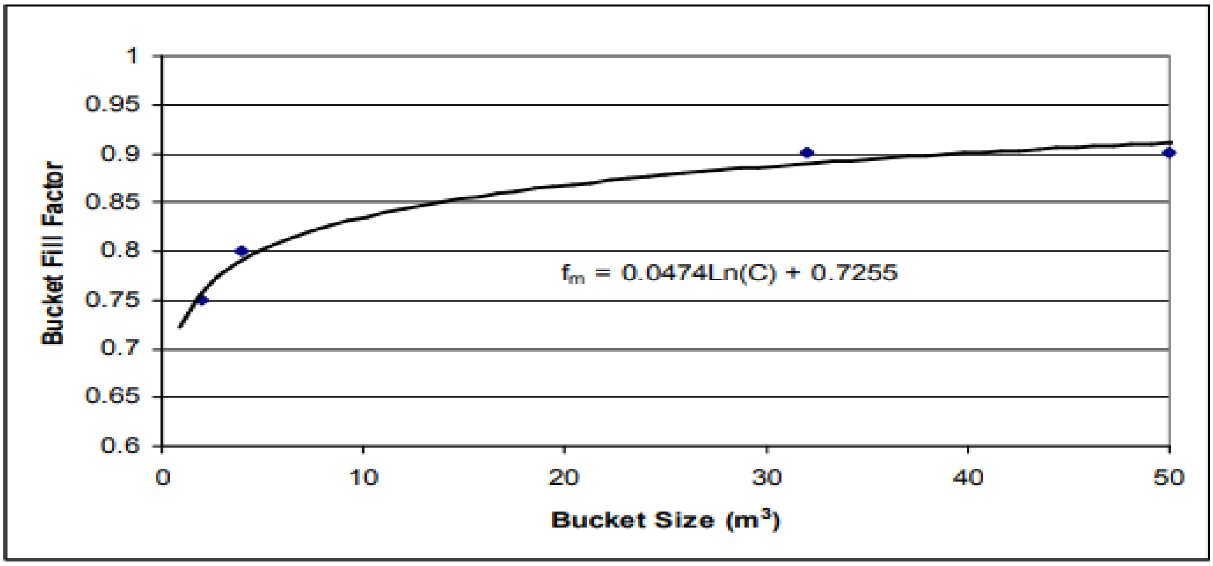

Figure 4-1 Fill Factor for Mud

Figure 4-2 is the fill factor curve for loose sand. Equation 4.3is the bucket fill factor curve for loose sand: fm = 0.0614*Ln(C) + 0.6607 4-3

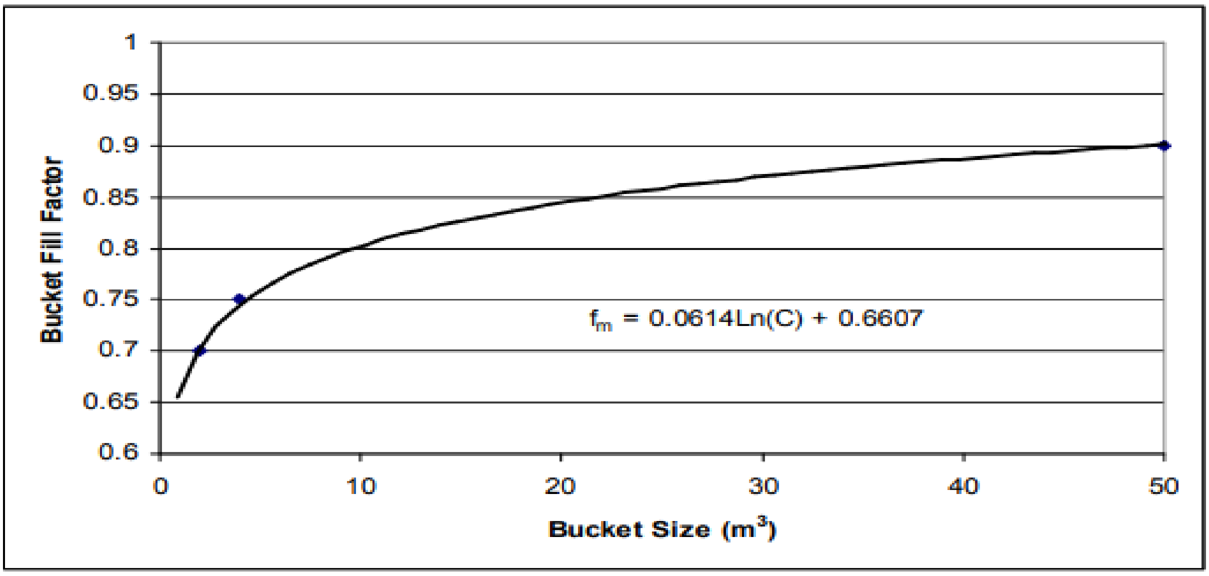

Figure 4-2 Fill Factor for Loose Sand

The curve begins at 0.65 and reaches 0.9 for 50 m^3 buckets. One point is used at 50 m^3 to keep the function below 1. It follows the same trend as the fill factor for mud with a very steep slope in the range with small buckets.

The fill factor curve for compact sand is displayed in Figure 4.3. Two additional points were used at 40 m^3 and 50 m^3 to keep the function below 1. The reason for this is that the initial slope is greater than the first two cases. With the two points the fill factor reaches 0.9 at 50 m^3. The slope is relatively small once the bucket is larger than 20 m^3. Equation 4.4 is the expression for compact sand:

fm = 0.0933*Ln(C) + 0.5517 4-4

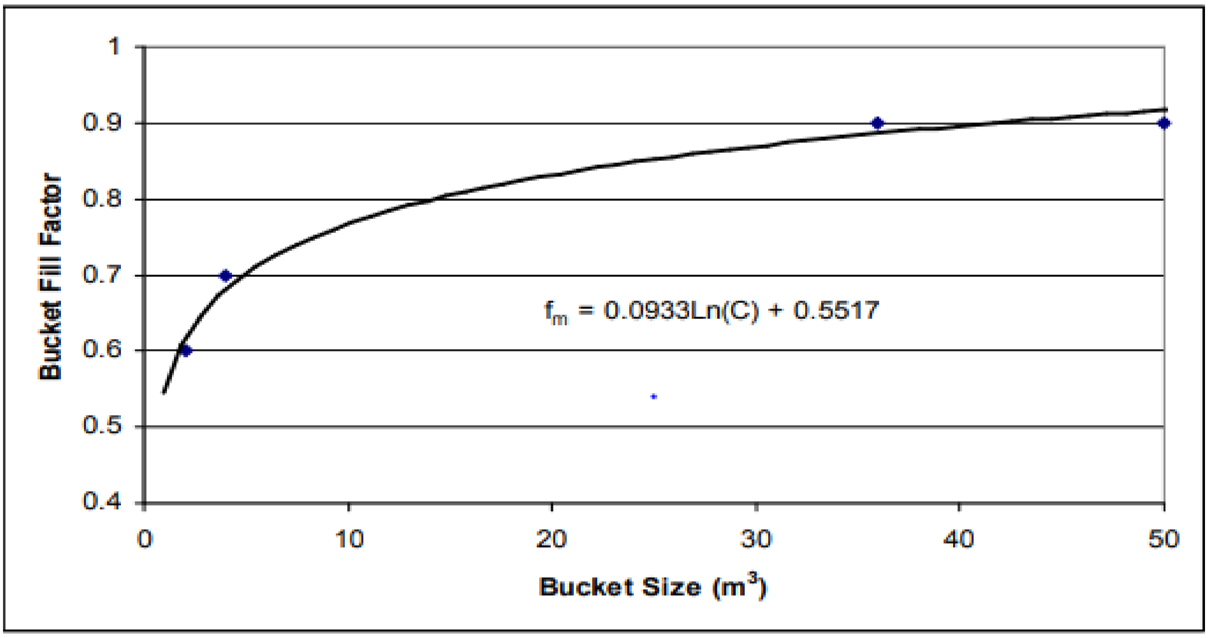

Figure 4-3 Fill Factor for Compact Sand

For sand and clay the fill factor reaches 0.9 in Figure 4-4. There is one point placed at 50 m^3 to keep the curve below 1. The fill factor reaches 0.8 by 20 m^3. Between 20 m^3 and 50 m^3 the slope is nearly linear. The sand/clay mixture continues the trend of rapid change between 0 and 20 m^3. Equation 4.5 is the curve for sand and clay.

fm = 0.1228*Ln(C)+0.4214 4-5

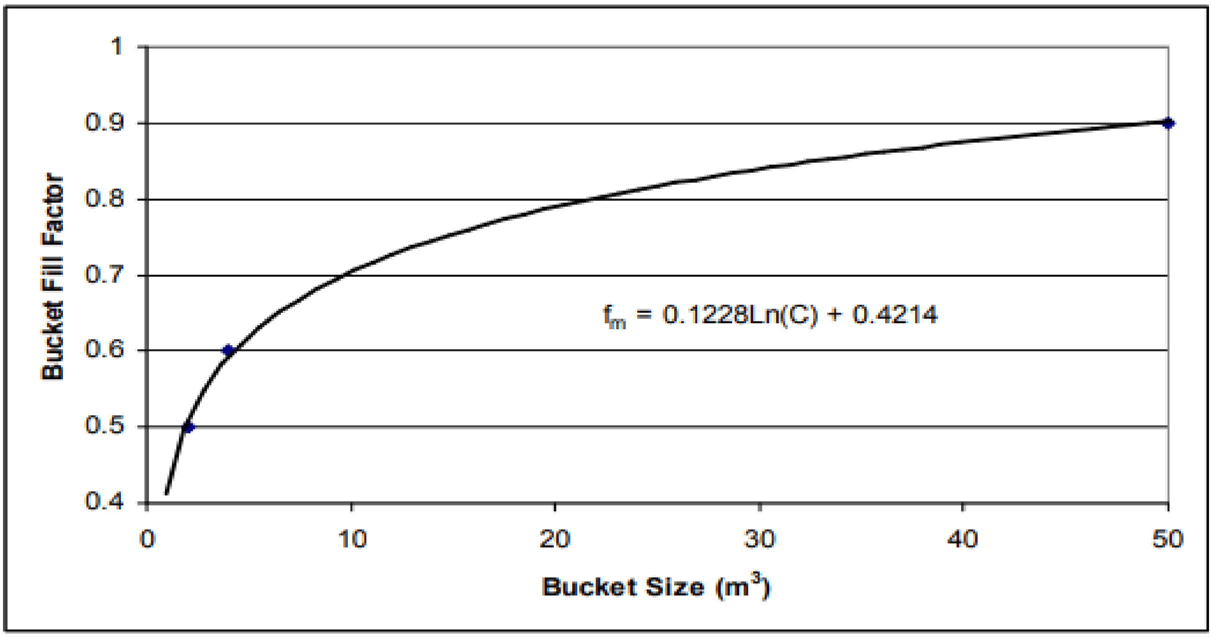

Figure 4-4 Fill Factor for Sand and Clay

The stone curve in Figure 4-5 is the first to not require an additional data point. When fitted to a natural log the fill factor stays below 1 from 0 to 50 m^3 with the initial value as 0.25. Stones normally have a small fill factor for small buckets. The reason is that it is difficult for small light buckets to penetrate stones. The fill factor has a range from 0.25 at 0 to 0.81 at 50 m^3. The expression for the stone fill factor curve is Equation 4.6:

fm = 0.1443*Ln(C) + 0.25 4-6

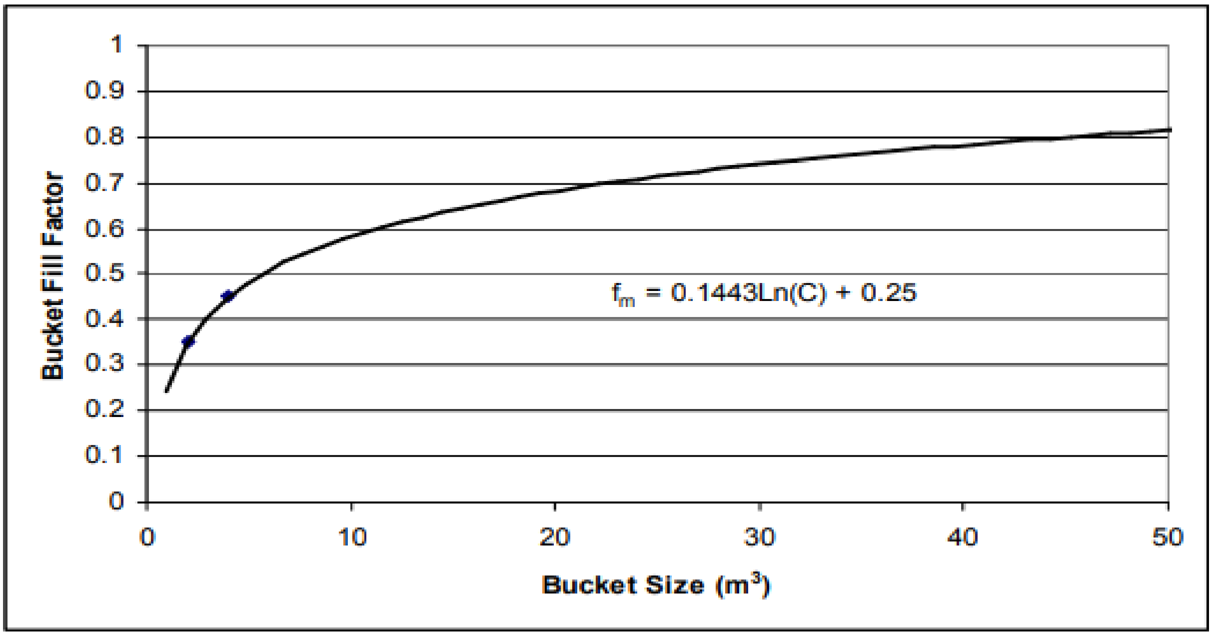

Figure 4-5 Fill Factor for Stones

Broken rock is the most difficult sediment type to excavate, and it is very irregularly shaped. This sediment type also contains the largest variation in sediment sizes. The third reason broken rock has a low fill factor is that large voids can form between rocks. Figure 4-6 shows the fill factor curve for broken rock. The initial value for broken rock is 0.1 and at 50 m^3. The fill factor approaches 0.7. Like the stone curve it is not necessary to force the curve below 1. The equation for the broken rock bucket factor is Equation 4.7:

$$fm = 0.1443 \, Ln(C) + 0.1 \qquad 4\text{-}7$$

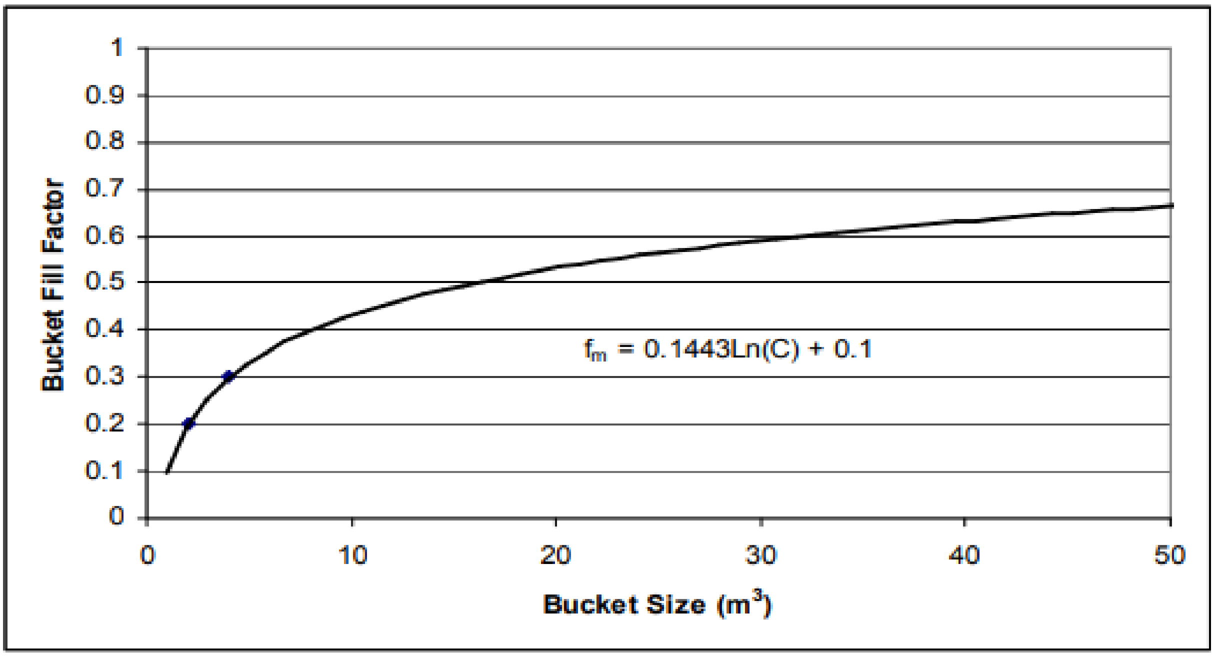

Figure 4-6 Fill Factor for Broken Rock

4.10.1 Comparison of methods for estimating bucket fill factor

Adair (2004) compared Bray (1997) method (1), which provides two values for fill factor for each sediment type. However, it is valid only for relatively small buckets (<10m^3). Emmons (2001) method (2) that accounts for the bucket size and sediment type. And his method (3) that is already discussed previously. The method 1 and 3 use the same sediment classifications, which is also used in this thesis, the method 3 uses a slightly different classification. The three methods include sand, so the comparison is based on sand.

Figure 4-7 shows a comparison between the bucket fill factor and the bucket size, the range used for the comparison is up to 50 m^3. From the graph we notice the method 2 begins above 1 and the drops below 1 at approximately 5 m^3. The curve stays close to 1 up to 40 m^3 and then starts decreasing to reach 0.9 around 50 m^3. For the methods 3, it starts near 0.7 and gradually increases to 0.9 from 30 to 50 m^3. Method 1 is divided into two parts, method 1a which is the range of the small buckets, where it is effective. However, in the second part, Method 1b, once it passes that range it exceeds 1 and keep increasing. So, it is not designed to work past a certain point.

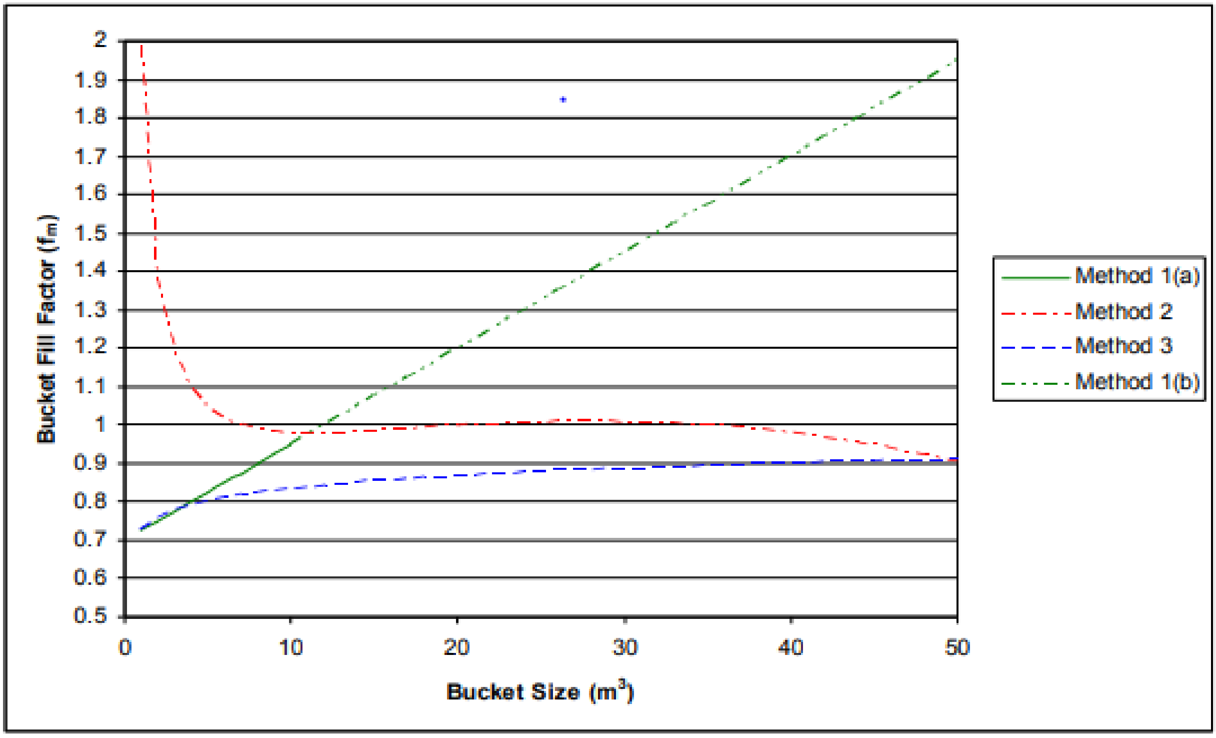

Figure 4-7 Comparison of bucket fill factors

Figure 4-8 is the relationship between the three fill factor methods. The purpose of the graph is to display the relationship between the size of the bucket, and the amount of sediment the methods predicts to be dredged. The graph is over a full range of bucket sizes up to 50 m^3. The predicted amount of sediment dredged (Pe) is the fill factor (fm) for a specific method multiplied by the actual size (C). Equation 4.8 is the relationship between the predicted amount of sediment dredged and the fill factor.

$$Pe = (C)(fm) \qquad 4\text{-}8$$

Whenever the curve for a method is less than the actual size curve the fill factor is less than 1, and when the curve for a fill factor is greater than the actual size the fill factor is greater than 1. All three methods appear to be collinear up to 20 m^3. At about 20 m^3 method 1 begins to diverge from the actual bucket size, and it becomes unusable because the predicted amount of sediment dredged becomes larger than the actual size of the bucket. The other two methods function well to 50 m^3.

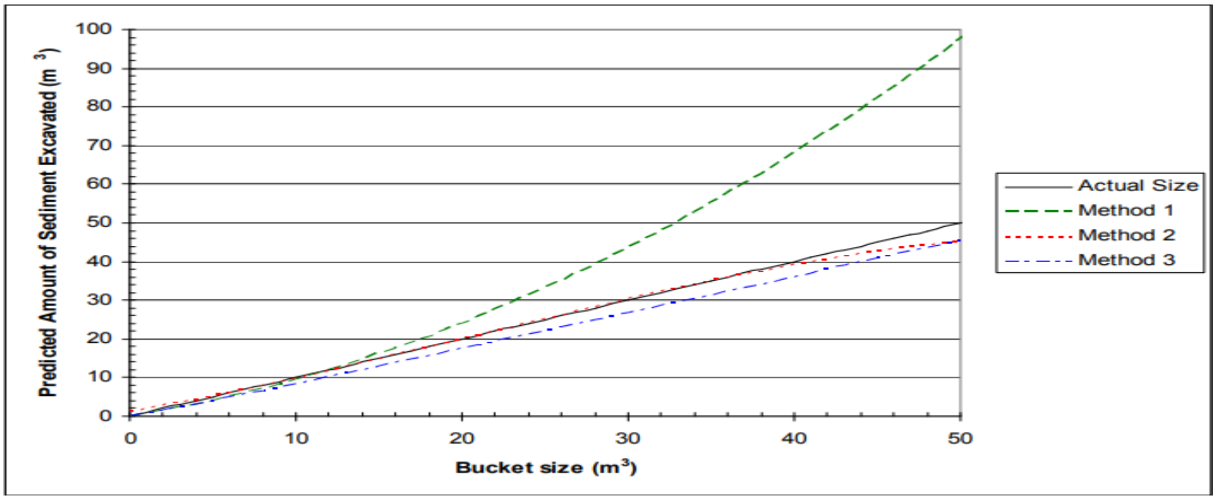

Figure 4-8Comparison of Predicted Amount of Sediment Excavated Using the Different methods.

Figure 4-9 demonstrates the relationship between the three methods and the actual size for buckets from 0 to 10 m^3. Method 2 is nearly collinear with the actual size between 6 $m^3$and 10 $m^{3,}$ up to 6 m^3 method 2 predicts the factored size to be greater than the actual size. Up to 5 m^3 method 1 and method 3 are similar. Both methods stay well below the actual size in this range. At 5 m^3 method 1 begins to approach the actual size curve. Method 3 stays significantly less than the actual size curve until after 10 m^3 Method 3, developed by (Adair,2004), provides the best results for both large and small buckets.

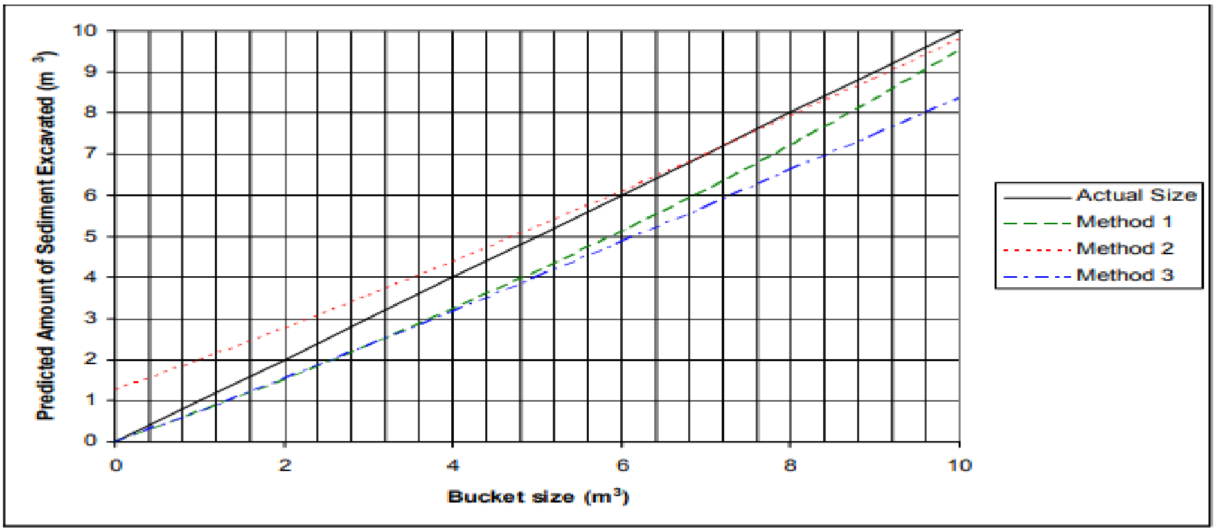

Figure 4-9 Fill Factor Comparison for Small Buckets

4.11 Production estimation and delay factors

Once cycle time (T_{cycle}) and bucket fill factor (f_m) are calculated, they are used to evaluate the nominal production (P_{nom}). Bray (1997) defines nominal production as:

$$P_{nom}=\frac{3600}{Tcycle} C\ f_m \quad 4\text{-}9$$

Equation 4.9 is the nominal production m^3 per hour. Nevertheless, the nominal production can be delayed for several reasons, for instance, the time required to empty the hopper or advance the dredge.

The first delay factor (f_a) to consider is the time to advance the dredge. (Bray et al, 1997) defines this as:

$$f_a=\frac{1}{1+\frac{taPnomB}{zA}} \quad 4\text{-}10$$

in equation 4.10, t_a is the time required to advance the dredge, B is the bulking factor that is dependent on the sediment type and water content, A is the average area dredged, and z is the average thickness of the material. The second major delay is the time for changing hopper barge (f_h)

$$fh=\frac{1}{1+\frac{tafaPnomB}{H}} \quad 4\text{-}11$$

All the variables in equation 4 11 are the same in equation 4.10 with the addition of the hopper capacity H in meters, and t_{he} is the time required to change the hopper. Once the delay factors are calculated, the actual production (P_{act}) can be calculated:

$$P_{act}= P_{nom}f_af_h \quad 4\text{-}12$$

P_{act} is the actual production rate of the dredge (m^3/h). However, it does not include delays due to harsh weather, passing vessels or equipment malfunction. (Bray et al, 1997) account for these factors and since these factors vary depending on the project, (Paparis, 2017) estimated 85%. The actual production rate used for developing the cost estimate is 85% of the calculated production rate.

5 Cost estimation procedure

The development of the cost estimate is based on the estimation of the production rate demonstrated previously. The estimated volume to be produced is divided by the daily production rate, in order, to determine the number of days needed for the project completion. We also need to determine the daily project cost. That includes crew and labour, fuel and lubricants, repairs and maintenance and mobilization/ demobilization. After multiplying the daily cost with the project length, we add depreciation, insurance bonding and profit, to estimate the total project cost. All that with the appropriate inflation, currency, and location factors.

The contact contains line items regarding the cost, dredge and dispose of certain in-situ volume of bottom sediment. Usually, there is one more option item, which allows the dredging for an additional volume of material, environmental monitoring, and deployment of environmental controls. The contract allows for an over-dredging allowance. The contractor is allowed a certain depth of removal beyond the target dredging depth, where the contractor will be paid on cubic meter basis. Figure 5-1 demonstrates this concept, known as the dredging prism. Since the purpose of dredging is primarily the maintenance or deepening of navigation channels, the dredging prism ensures that the desired channel depth is achieved without requiring a level of precision that is not feasible for a dredge to achieve. (US Army Corps of Engineers)

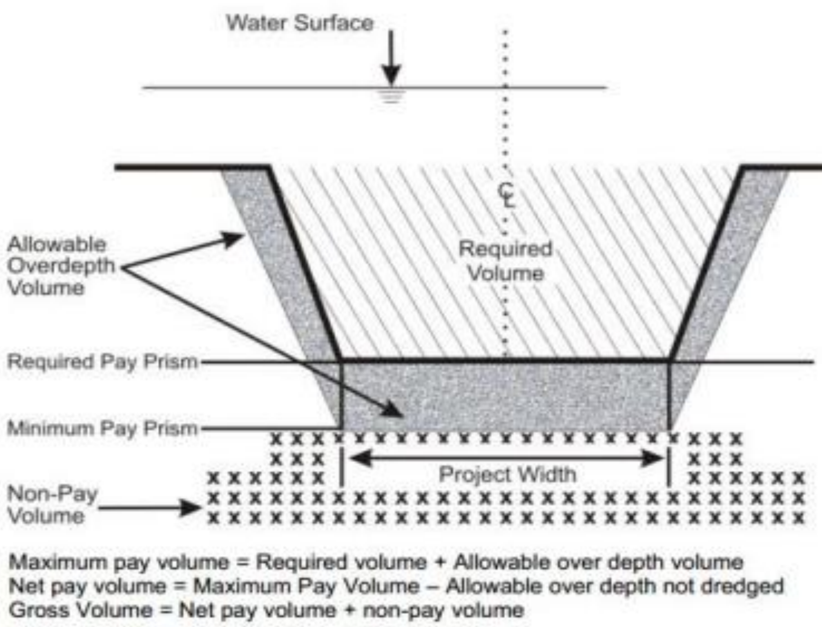

Figure 5-1 Dredge prism illustration

5.1 Operation cost

Operating costs are one of the most important costs to be determined, and they are the summation of costs associated with operating during the timespan of project execution. The duration of the project is determined by dividing the average production rate, which is measured in cubic meters per hour. By the estimated volume of sediments to be dredged. The operation costs are the summation of crew and labour, fuel and lubricants, maintenance and repairs, insurance, and depreciation. The information around these costs is not available to the public. However, Bray et al (1997) provide an insight into the capital costs of clamshell dredges, and present varied sizes and varieties of dredging plants, to provide an indication of the average relative costs. Also provide assumptions and parameters that can be applied to each of the cost factors estimations purposes.

It is necessary to convert prices from one currency to the other, depending on the inflation rate, year, and location. For that we need cost index. In this case, PPI index was chosen because the intent is to measure price changes related to shipbuilding costs.

To account for the inflation rate, a sub-index was used in the equation 5-1:

$$E = \frac{Inew - Iold}{Iold} * 100\% \qquad 5\text{-}1$$

Where E is the inflation rate, I_{old} is old the index value, I_{new} is the new index value. For the current and old index values, the average values for the year 2022 and 2015 were used respectively, from Producer Price Index by Industry: Ship Building and Repairing.

After developing the exchange and inflation rates, they were applied to the capital cost data from Bray et al (1997) as follows in the equation 5-2:

$$CC_{€} = CCf * \frac{1+E}{X} \qquad 5\text{-}2$$

Where $CC_{€}$ is the current capital cost in euros, CC_{f} is the capital cost value from (Paparis, 2017), in Dollars, X is the exchange rate in terms of Dollars to Euros. Based on this formula, a capital cost of approximately 17,7 million euros was obtained for a clamshell dredge.

5.2 Fuel and lubricants

The cost of fuel and lubricants is a substantial portion of the operating costs for a dredging project. The process for determining the fuel and lubricants costs of a dredging project is based on the installed horsepower of the dredge. (Paparis,2017).

For this parameter, the dredges installed horsepower from the characteristic's brochure were used, the operating hours per day, a conversion factor that equates horsepower usage to fuel consumption, and the price of the MGO (Marine Gas Oil) fuel European annual average was obtained. To compare the results obtained by the program with other projects, a default installed horsepower value was established by using an average value of installed horsepower as reported in a directory of dredges (Richardson, 2016), and a fuel consumption rate of 0.182L/hr per installed horsepower was adopted (Bray et al, 1997). The MGO. Lubricant costs were assumed to be 10% of fuel costs. The result is the daily fuel and lubricants costs.

5.3 Mobilization and demobilization

Mobilization and demobilization cost is the price associated with the transportation of dredging equipment to and from the job site. (Wowtschuk,2016). These are difficult to predict for any given project. As Randall (2000) outlines, the difficulty comes from the fact that no two dredges are the same distance away from a job site or in the same readiness to mobilize. Moreover, the cost varies with the distance, time of year and type of contract. Most of clamshell dredges are not self-propelled, they need to be transported, and they may require set-up or tear down. There is also the cost of transporting personnel to and from the job site. Due to the variability of mobilization costs, Paparis (2017) developed a default value for dredging mobilization and demobilization, based on a review of eight clamshell dredging projects. The default value is a percentage of a winning bid value that was for mobilization/non-mobilization costs.

It was determined by taking the value of the mobilization/demobilization contract line item and dividing it by the total remaining contract value (e.g., total contract value minus the mobilization and demobilization costs). This process was applied for each of the eight contracts, and the median value of the results, 10,2%, was used.

5.4 Crew and Labour

Labour consists of personnel necessary for the operation of the dredge, it is another sizeable portion of a dredge's operation costs. The size of the crew varies depending on the project and job conditions. Typical crew size of a mechanical clamshell dredge, hourly wages rates were obtained from Department of Labour and Industrial relations or American Society of Professional Estimators. (Fricklas, R.L.,2013). For each hourly rate, a job-specific workman's compensation rate is applied to the "bare" wage rates, as well as an additional "wage overhead" rate to account for items such a payroll taxes, unemployment insurance, risk insurance, and public liability costs. The result is a “burdened” hourly rate, which is then multiplied by the number of hours worked per day to develop a daily labour cost.

5.5 Maintenance and repairs

(Bray et al,1997) define maintenance needs in two categories: routine maintenance and running repairs, as well as major repairs and overhaul. Minor repairs entail work that can be done during operations with minimal interruption and recommended as a daily cost of 0.000130 time the capital cost of a mechanical clamshell dredge. The major repairs cost per operating day is 0.000250 of the capital cost.

5.6 Depreciation and insurance

Depreciation is the rate at which the dredge losses value over time and will depend on the owner’s fiscal policy. For simplification, linear depreciation to zero is used with an assumed service life of 25 years. To calculate the daily depreciation in the program, the annual depreciation is then divided by the average number of working days per year. (Bray et al, 1997) recommend an average annual insurance premium of 2,5% of the insured value of the dredging plant. For the purposes of this estimating program, the insured value is assumed to be the same as the capital cost of the dredge. The annual insurance cost is then divided by the number of working days per year to obtain a daily insurance cost to use in a project estimate.

5.7 Overhead and Bonding

The additional operating expenses of a dredge that cannot be conveniently identified or traced are covered by overhead cost. Overhead costs include job office, engineering, quality control costs. (Fricklas, R.L.,2013). Naturally, overhead costs vary from contractor to another, but (Bray et al, 1997) recommend 9%. Bonding is a guarantee of performance of work and a protection against losses for the client, (Belesimo,2000) recommends a project bonding cost between 1 and 1,5 % of the operation cost. The overhead and bonding can be combined to be 10% of the operating cost. The profit is determined by the individual contractor, and it defers from one job to another. (Paparis,2017).

5.8 Cost factors

Fuels costs and wages are location and time dependents, they must be adjusted to reflect the location and year differences, as mentioned above, subindices were obtained for the specific industry (Ship Building and Repairing PCU336611336611), to be as accurate as possible. Whereas, the location factor, we need to change from the United States of America to Italy, and for that OECD price level indices were used. So, the total cost estimate may be adjusted to produce results more accurate to a specific location or time period. When it comes to comparing the projects within the USA, yearly inflation and other location factor were used, that are more region related, since they belong to the same country, they were provided by the US Army corps of Engineers (USACE).

5.9 Rental equipment

Because of the large capital investment involved and the unique expertise required, it is not unusual for dredging contractors to rent some of their equipment, such as additional tugs, scows or even a dredger; in case one the contractor's dredger is not available.

5.10 Additional costs

There are additional costs that common to the dredging projects but do not fall into any of the above cost categories. These costs vary greatly from project to project and may include site surveys, environmental protection devices.

6 Applications

All the parameters mentioned above to calculate the production rate and the project cost are included in 4 spreadsheets, the first one for zone 1+2+3, the second for zone 4, third for zone 5 (both will be just an estimation since the production did not start yet), the final spreadsheet will be a comparison with data that were available publicly of other projects. The program is based on the limited information in dredging projects and default values that were estimated throughout the years. However, with the available data such as the volume to be dredged, the bucket size, depth, and hopper capacity, we can provide an estimation of the production rate and cost of the project. Since, location and yearly cost factors were implemented, we can study or estimate the output of any clamshell dredging project. Even with specific job, it would suffice just to modify the default values. The spreadsheets are colour coded, the yellow cells refer to the default values acquired as an average from other dredging projects when project related data are not known, the blue cells refer to the data of the project using clamshell dredge, collected from the company (DEME group). The light blue is for each dredger and the darker blue is for the three of them together. The green cell refers to the automated values based on the calculation explained in the previous sections. Finally, the light green cells are for the results that we are seeking.

6.1 Data entry and calculation

The calculations were based on the data provided for the month ofApril,2023 regarding the volume to be dredged and which zone to be dredged. As shown the table below. In this project three dredgers were used (Angelo B, Cavour, Gioacchino Bacheto), for the zone 1+2+3. For one the month of March, the delay includes, traffic, maintenance, and repairs, waiting for fuel, third party intervention shown the table 6-1 below.

Table 6-1 time registration for the three dredges

Time registration(h)	Gioacchino Bacheto	Angelo B	Cavour
Sailing empty	0,46	0,37	0,47
Sailing loaded	0,48	0,37	0,52
Operations	1,62	1,49	1,46
Unloading	1,14	1,05	1,32
Hours per day	10,30	11,23	9,44
Delay %	23,90	11,26	27,14

Table 6-2 data related to the project

	Volume to be dredged (m^3)	Volume dredged (m^3)	Volume to be dredged from 30 of April $^{(m3)}$	Depth (m)
Zone 1+2+3	1876000	602150	1428410	12
Zone 4	694000,00	0		12
Zone 5	748000,00	0		12

In the excel spreadsheet there is a drop-down list to choose which dredge to use for the calculations and the data will be auto filled from the table 6-3 below. The data were gathered from the characteristics brochure of each dredge provided by the company.

Table 6-3 dredge characteristics

Dredger type	bucket size (m^3)	Hopper capacity (m^3)	Volume dredged (m^3)	daily working hours (h)	Horsepower (HP)	Fuel (L/day)
Angelo B	9,60	1000	402950	11,23	3202	1290
Cavour	5	500	92750	9,44	850	450
Giochino Bacheto	7,10	800	106450	10,30	2400	1050
total	21,70	2300	602150	10,32	6452	2790

After choosing which dredge, we need to choose what type of sediment is being dredged, it is one of the key factors, since it also affects the production rate. Therefore, the cost of the project. In the project the type of sediment is Clay, so in this thesis, Sand and Clay was chosen as a default value. It can still be modified depending on the specifics of the project. from there we will have the bulking factor, which is the amount of sediment is expected to swell (bulk) when it is excavated. This value is used to predict how often the hopper is filled. The fill factor, which is calculated for each type of sediment using the bucket size, and the capacity factor that accounts for the actual capacity of the bucket being used, multiplying it with the bucket size to obtain the adjusted capacity (C adjusted).

Table 6-4 Sediment types and other factors

Soil type		Bulking factor (B)	Fill Factor (Fm)	capacity factor
Mud	1	1,15	0,86	1
Loose Sand	2	1,10	0,84	0,72
Compact Sand	3	1,30	0,82	0,72
Sand and Clay	4	1,25	0,78	0,72
Stones	5	1,30	0,67	0,36
Broken Rock	6	1,50	0,52	0,36

The default values for cycle time parameters are based on values from (Adair,2004). Table 6-5 provides a summary of the default values used the estimation of production rate. Later on, there will be another column to the adjusted values, if the project data are available and different from the default ones.

Table 6-5 cycle time parameters

Factors	default	
average swing angle	120	Degree
swing speed	21	degree/s
lift velocity	1	M
grab time	1	S
fall velocity	1	m/s
time to empty clamshell	2,60	S
Height of freeboard	2	M

6.2 Production estimation

In the table 6-6 below, we have two calculation columns and one for the default values in case data is not available for a certain parameter or they can coincide. The first column is for a specific dredge that is selected from the drop-down list mentioned before, and the maximal daily production rate will be calculated, then the number of days needed to dredge the whole volume if the dredge operates alone.

The second column calculates the summation of the three of them, because they are used at the same time, an average is taken when needed (e.g., the daily working hours), the actual production rate is then calculated, and the number of days needed to finish the project.

In the table 6-6 we can find inputs that were not identified before, such as, (A) which is the area that the dredge can excavate before it has to more, or otherwise called cells (e.g., cell 345), because each zone is divided into cells. (z) is the thickness of the material to be dredged (h) is the freeboard height is the distance needed for the sediment to be emptied in the hopper. The delay factors that should be accounted for like; the time needed to advance the dredge (fa).

Table 6-6 production rate estimation zone 1+2+3

parameters	Value		Defaults	Units	
Sediment type	4	4	4		
A	10000	30000		m^2	average area dredged
Z	2	2	2	M	thickness of material dredged
H	1000	2300		m^3	Hopper capacity
C	9,60	21,70		m^3	Capacity of the bucket
V	1428410,00	1428410,00		m^3	volume to be dredged
D	12	12		M	depth
H	2	2	2	M	offboard height
Ta	0,33	0,33	0,33	Hrs	time to advance the barge
Sa	120	120	120	Deg	average swing angle
Th	1	1	0,25	Hrs	time to change the hopper
B	1,25	1,25	1,25		Bulking factor
Fa	0,99	0,99			delay factor for advancing the dredger
Fh	0,64	0,65			delay factor for changing the hopper
Fm	0,78	0,78	0,78		fill factor
Fc	0,72	0,72	0,72		Capacity factor
C adjusted	6,91	15,62		m^3	modification factor
Volume dredged	402950	602150		m^3	volume of sediments dredged
CT	43,03	43,03		seconds	Cycle time
Pnom	451,07	1019,61		m^3/hr	Nominal production
Pmax	286,73	653,12		m^3/hr	Max production
	14795,38	33700,73		m^3/week	
Total dredging time	4981,69	2187,07		Hrs	
	443,61	211,93		days	
		212			

This was for the ongoing project zone 1+2+3; the company estimation was 215 days. Therefore, we can say that is a good production rate estimation. There are two other zones, zone 4 and zone 5. Which, they were planned, estimated and to be executed in the future.

For these two zones, the volume to be dredged in zone 4 is 694000 m3 and zone 5 is 748000 m3. the rest of the parameters are the same, regarding the sediment type, the dredgers used, the bucket size, as illustrated in the table 6-7 and table 6-8 respectively.

Table 6-7 production rate estimation zone 4

Value		Defaults	Units			
4	4	4				
10000	30000		m^2	average area dredged		
2	2	2	M	thickness of material dredged		
1000	2300		m^3	Hopper capacity		
9,60	21,70		m^3	Capacity of the bucket		
694000,00	694000,00		m^3	volume to be dredged		
12	12		M	depth		
2	2	2	M	offboard hight		
0,33	0,33	0,33	Hrs	time to advance the barge		
120	120	120	Deg	average swing angle		
1	1	0,25	Hrs	time to change the hopper		
1,25	1,25	1,25		Bulking factor		
0,991	0,99			delay factor for advancing the dredger		
0,64	0,65			delay factor for changing the hopper		
0,78	0,78	0,78		fill factor		
0,72	0,72	0,72		Capacity factor		
6,91	15,62			modification factor		
	602150		m^3	volume of sediments actually dredged		
43,03	43,03		seconds	Cycle time		
451,07	1019,61		m^3/hr	Nominal production		
286,73	653,12		m^3/hr	Max production		
14795,38	33700,73		m^3/week			
2420,38	1062,60		Hrs			
215,53	102,97		days			
	103					

Table 6-8 production rate estimation zone 5

Value		Defaults	Units	
4	4	4		
10000	30000		m^2	average area dredged
2	2	2	M	thickness of material dredged
1000	2300		m^3	Hopper capacity
9,60	21,70		m^3	Capacity of the bucket
748000	748000		m^3	volume to be dredged
12	12		M	depth
2	2	2	M	offboard hight
0,33	0,33	0,33	Hrs	time to advance the barge
120	120	120	deg	average swing angle
1	1	0,25	Hrs	time to change the hopper
1,25	1,25	1,25		Bulking factor
0,99	0,99			delay factor for advancing the dredger
0,64	0,65			delay factor for changing the hopper
0,78	0,78	0,78		fill factor
0,72	0,72	0,72		Capacity factor
6,91	15,62			modification factor
	602150		m^3	volume of sediments actually dredged
43,03	43,03		seconds	Cycle time
451,07	1019,61		m^3/hr	Nominal production
286,73	653,11		m^3/hr	Max production
14795,38	33700,73		m^3/week	
2608,71	1145,28		Hrs	
232,30	110,98		days	
	111			

The company estimation was 104 and 112 days for zone 4 and zone 5 respectively. So, again the program estimation was satisfactory. In the next part, we will start the cost estimation of the project based on the data obtain from these tables.

6.3 Cost estimation calculations

The data to estimate the cost of dredging project are not available to the public. However, a handful of papers, research and appendices form certain projects gave the opportunity for the calculation of the cost. Therefore, default values were used as per the production rate estimation. The program allows the change of data if accurate information were to be known.

We start by calculating the capital cost of a clamshell mechanical dredging project, (Paparis, 2017) estimated it to be 14,5 million dollars in 2015. To convert that amount to 2023, inflation was calculated using cost indices (I_{old}, I_{new}) for 2015 and 2022 respectively, obtained from the Bureau of Labour and Statistics Data, as explained in the cost estimation procedure section. Then, the currency was accounted for by changing from US Dollars to Euros based on the currency exchange in this year (0,93). The capital cost for a dredging project for the year 2023 is estimated to be around 17,7 Million euros, as shown in the table 6-9 below.

Table 6-9 Capital Cost

Capital cost		
I_{old}	203,89	2015
I_{new}	231,98	2022
inflation	0,14	
Capital cost	17715555,42	Euros

The second step was to calculate the fuel consumption. For this calculation as explained in the Fuel and Lubricants section, two tables are provided. One specific to this project as showed in the table 6-10, since the Fuel consumption per day was obtained, the working hours per day was calculated and the fuel price for the MGO (Marine Gas Oil) was obtained from the EMEA average Banker values (0,8635 Dollars/L), from these data the Fuel cost per day is estimated to be 2409,265 Dollars/day.

Table 6-10 Fuel calculation for the project

Fuel calculation		
Fuel consumption	2790	L/day
Fuel price	0,86	dollars/L
Fuel cost per day	2409,17	dollars/day

A second table using default values provided by (Bray et al, 1997), in the table 6-11. Where the consumption rate is estimated to be 0,0481 gal/HP-hr, an average installed horsepower of 2038 HP, and sixteen working hours per day. These calculations were made for the year 2015, so the price of the fuel back then was used, 2,74 Dollars. So, the fuel cost per day was 4297,5 Dollars/day. And this table will be used for the next section.

Table 6-11 Fuel estimation with default values

Fuel calculation		
Consumption rate	0,048	gal/HP-Hr
Average HP	2038	
	98,03	gal/hr
Fuel consumption	1568,45	gal/day
Fuel price	2,74	Dollars
Fuel cost per day	4297,54	dollars/day

Now, that we calculated the capital cost and fuel consumption, we can calculate the daily cost of the project first. The table 6-12 contains the costs that will be summed to estimate the total daily cost. The fuel is already calculated, for the lubricants and as pointed in a previous section, it is determined to be 10% of the fuel price per day. Next, Minor and Major repairs were evaluated by multiplying the capital cost by 0.000130 and 0.000250, respectively. For the daily insurance, the capital cost was multiplied by 25% and divided by the estimated number of days needed to dredge the total volume of sediments. A depreciation of 25 years of lifespan was estimated, and then divided by the working days per year. For this project we have a total of fourteen crew members working on board of the three dredges, defaults values were used to estimate the daily cost of the crew and labour. Finally, equipment rental, including the dredges was evaluated based on standard rental prices. All these costs were summed to obtain the operational cost. However, we need to account for other factors, such as, overhead and bonding. A rate of 10% (9% overhead and 1% bonding) was considered to be multiplied by the total cost. Another factor to be added is the profit, which was taken to be 10%. In the end we obtain the total daily cost of 61,50 thousand dollars per day.

Table 6-12 Total daily cost

Daily cost		$
	Fuel	2409,17
	Lubricants	240,92
	Minor repairs	2303,02
	Major repairs	4428,89
	Insurance	2089,10
	Depreciation	2413
	Crew and Labor	11972
	Equipment Rental	25000
	Total	50856,09
	Overhead and bonding rate	0,10
	Overhead and bonding	5085,61
	Total cost with overhead and bonding	55941,70
	Profit	5594,17
Total daily cost		61535,87

Afterwards, we calculate the total cost for the duration of the project. First, we calculate the total production cost, by multiplying the total daily cost by the number of working days. Then, we need to account of the mobilization and demobilization. In order to do that, we multiply the total production cost by 10,2%. Form that, the total project cost is around 14,4 million dollars.

For the last part of the calculations, we need to use the cost factors for the year, since the project is in 2023, another cost factor for location, because the project is in Italy. The yearly cost indices are the same as the capital cost. For the location OECD data were used and after that it was multiplied by the currency exchange rate from dollars to euros (0,93).

In this case no additional costs were obtained so they were not accounted for. In other estimations if they were to be available, they can be added.

The final estimation of the total adjusted cost of the clamshell mechanical dredging project is about 9,86 million euros as shown in the table 6-13. Divided by the volume to be dredged gives us the cost of 6,9 euros/m^3.

Table 6-13 Total Project Cost

Total Production cost				13045604,48	
	Mob/ Demob rate			0,10	
Mob/Demob				1330651,66	
Total Project cost				14376256,14	
Year factor				1,14	
	Year adj Cost			16355723,48	Dollars
Location factor				0,60	2022
	Location Adj Cost			9856613,20	Euros
Additional Costs					
	Rock/Debris removal			0	
	Government-directed standby time			0	
	Environmental Monitoring			0	
	Other project-specific costs			0	
Total Adjusted Cost				9856613,20	Euros

So far that was the application of the programme on the project of Port hub of Ravenna, the production estimation was close to the project's estimation. Whereas the cost, on the other hand, we cannot tell if the program's estimation was accurate or not since, data is not provided due to confidentiality. Therefore, in the next section, the program's estimation will be verified by comparing its results with other projects conducted in the United States of America, where their information was publicly available.

7 Comparison and Sensitivity analysis

7.1 Comparison

To check the validity of the program's results, it will be compared to other projects cost estimations and to a similar estimation made by (Paparis,2017). The data of these projects were obtained from (Paparis,2017), which gathered them from the US Army Corps of Engineers (USACE) that oversees most dredging projects in the United States. Specifically, from the Navigation Data Center (NDC), and these data include the listing of awarded dredging contracts, which contains information such as the type of dredge used, the amount of material estimated to be dredged, the government estimate the winning bid and contractor. For this comparison we will be using data related to the estimated volume to be dredged, year for the cost index and the government and winning bids.

For the average depth, (Paparis, 2017), used project information regarding channel layout and channel depth available through the USACE district websites and correlated with navigation chats that are available from the National Oceanic and Atmospheric Administration (NOAA) Office of the Coast Survey (OCS,2017).

Eight dredging projects were selected from the NDC. These projects were selected based on availability of corresponding bid abstracts and completeness of information. The projects selected do not have any job specific tasks or extra costs (debris removal, standby time, etc).

The table 7-1 shows the projects location, four of them from Ohio but different harbours, each has a location factor calculated, we have the year of execution and its factor to account of the inflation. The volume to be dredged so we can calculate the days needed and then the cost of the projects, the depth of each project, and that also shows also, how it plays on the bucket size chosen, and ultimately on the cost of the project.

Table 7-1 Projects information

City	location factor	Year	Volume	depth	yearly factor	Bucket size
New York	1,13	2014	54283	3	0,99	4,50
Pennsylvania	1,14	2014	191139	7,60	0,99	11,50
Ohio	0,94	2014	229366	7,30	0,99	11,50
Ohio 2	0,94	2014	210253	8,50	0,99	11,50
Ohio 3	0,94	2014	126151	8,50	0,99	7,65
Ohio 4	0,94	2014	76455	8,50	0,99	7,65
Oregon	1,13	2015	198784	10,70	1	7,65
California	1,24	2015	133797	10,70	1	7,65

The same spreadsheet was used for this section too. Although only the default values were used, since they are average values based on several studies and dredging projects. Some were mentioned before, such as, the sediment type and the factors related to it (Table 6-4), the values used to calculate the cycle time (Table 6-5), and fuel consumption (Table 6-10).

For the production rate, California was taken as an example, to show the changes compared to the project we had in the last section. The Table 7-2 shows some changes. For instance, the average area dredged is 1142,7 m^2. Hopper capacity as 3440 m^3. the values of the volume to be dredged changes with changing the location from the drop list, where we can choose the harbour.

Table 7-2 Production rate estimation

parameters	Value	Defaults	Units
Sediment type	4		
A	1142,70	m^2	average area dredged
Z	2	M	thickness of material dredged
H	3440	m^3	Hopper capacity
C	7,65	m^3	Capacity of the bucket
V	133797,00	m^3	volume to be dredged
D	10,70	M	depth
H	2	M	offboard height
Ta	0,33	Hrs	time to advance the barge
Sa	120	Deg	average swing angle
Th	0,25	Hrs	time to change the hopper
B	1,25		Bulking factor
Fa	0,94		delay factor for advancing the dredger
Fh	0,97		delay factor for changing the hopper
Fm	0,78		fill factor
Fc	0,72		Capacity factor
C adjusted	5,51	m^3	modification factor
Volume dredged	0	m^3	volume of sediments dredged
CT	40,43	seconds	Cycle time
Pnom	382,57	m^3/hr	Nominal production
Pmax	346,59	m^3/hr	Max production
Total dredging time	386,04	Hrs	
	28,60	Days	
	29		

the next step is to calculate the cost estimation. In this case also, default values were used. As shown in the table 7-3.

Table 7-3 Cost estimation

Daily cost	$		
Fuel	4297,54		
Lubricants	429,75		
Minor repairs	1882,52		
Major repairs	3620,24		
Insurance	1207		
Depreciation	2413		
Crew and Labor	8878		
Equipment Rental	5312		
Total	28040,05		
Overhead and bonding rate	0,10		
Overhead and bonding	2804,005		
Total cost with overhead and bonding	30844,05		
Profit	3084,41		
Total daily cost	33928,46		
Total Production cost	983925,34		
Mob/ Demob rate	0,11		
Mob/Demob	100360,38		
Total Project cost	1084285,72		
Year factor	1	0,99886	
Year adj Cost	1084285,72		
Location factor	1,24		California
Location Adj Cost	1344514,29		
Additional Costs			
Rock/Debris removal	0		
Government-directed standby time	0		
Environmental Monitoring	0		
Other project-specific costs	0		
Total Adjusted Cost	1344514,29	Dollars	
Price per m3	10,0	Dollars/m^3	

The same estimation was generated for each project, tabulated as shown below in table 7-4, and compared to the winning bid, the government estimation and Paparis, that used the same estimation approach. This comparison will demonstrate the accuracy of the program and whether it is dependable or not.

Table 7-4 Projects comparison

Project	Winning Bid ($)	Government Estimate ($)	Thesis ($)	Paparis ($)	Gov vs Bid	Thesis vs Gov	Thesis vs Bid	Paparis vs Bid
Barcelona Harbour	602,200	552,050	506,439	647,861	-8,33	-8,26	-15,9	7,6
Erie harbour	868,980	1,330,700	1,064,419	1,123,416	53,13	-20,01	22,49	29,3
Fairport Harbour	1,640,000	1,846,500	1,018,107	1,231,146	12,59	-44,86	-37,92	-24,9
Huron Harbour	1,165,150	1,231,800	983,000	1,192,673	5,72	-20,20	-15,63	2,4
Lorain Harbour	773,200	1,310,050	842,572	1,041,344	69,43	-35,68	8,97	34,7
Toledo-Maumee River	436,700	736,600	526,607	632,245	68,67	-28,51	20,60	44,8
Coos Bay Upriver Dredging	2,862,160	3,824,852	1,774,490	1,761,572	33,64	-53,61	-38	-38,5
Suisun Bay	1,769,330	2,991,377	1,344,514	1,456,005	22,01	-37,72	-24,01	-17,7
Total	10,117,720	12,991,377	8,060,149	9,086,262	28,40	-37,96	-20,34	-10,19
Mean Absolute Error					34,19	31,11	22,94	24,99

We start with Paparis compared to the winning bid, we notice that three of the Paparis estimations were within 20 percent of the winning bid, two were between 20 and 30 percent of the winning bid, three were between 30 and 40 percent of the winning bid. For the government compared to the winning bid, we see that three estimations were within 20 percent of the winning bid, one within 20 and 30 percent, one was between 30 and 40 percent, and the remining three varied from the winning bid by greater 50 percent. Finally, the thesis program, it has three estimations within 20 percent of the estimation bid, three were between 20 and 30 percent and two between 30 and 40 percent of the winning bid.

From this comparison we can deduce that the government estimates are higher than the winning bid in seven out of the eight projects, due to the use of a more conservative estimate, because of regulations and funding purposes. To ensure the availability of an adequate funding once the project is approved and ready to be executed.

The thesis estimate is also compared to the government estimates, the thesis was always lower than the government estimate as expected. One within 20 percent, three within 20 and 30 percent, two within 30 and 40 percent and two more than 40 percent of the government estimation. A bar graph was plotted to illustrate better the differences between the four estimations in figure 7-1.

From the graph we can see that the thesis program estimation was lower in five projects out of eight than the winning bid, showing a significant difference in the Coos Bay Upriver and Fairport Harbour. The thesis is lower than Paparis estimation in seven out of eight projects.

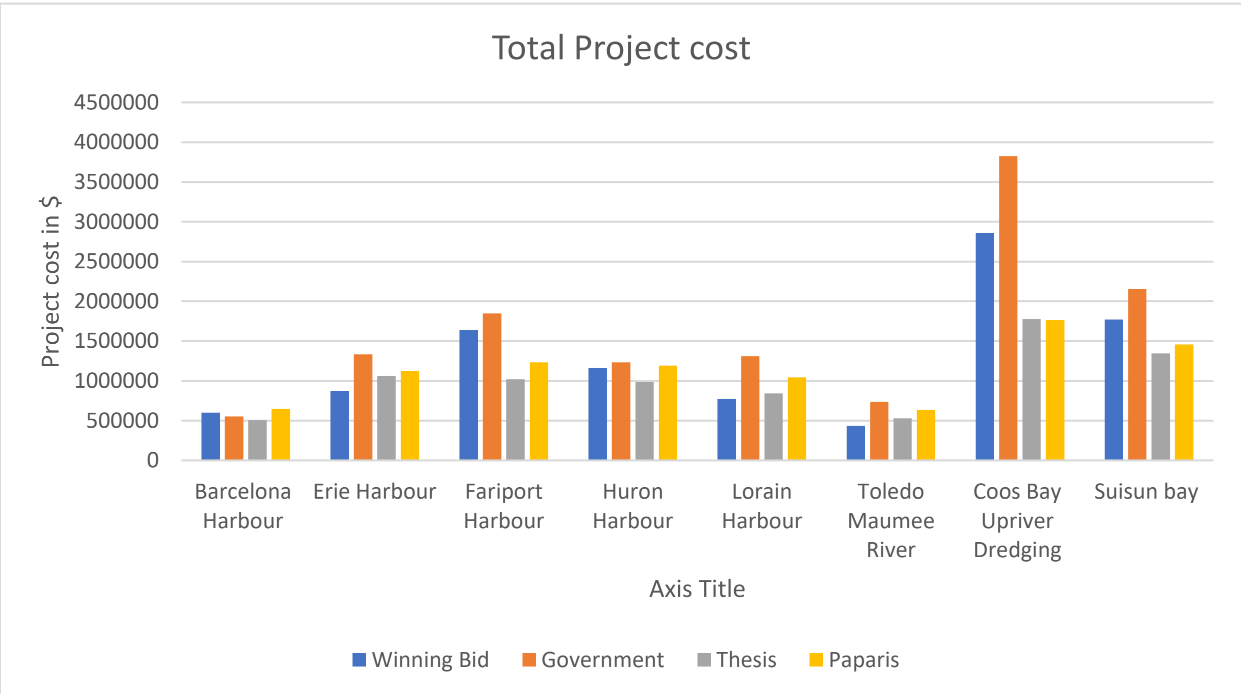

Figure 7-1 Total Cost comparison

To double check the validity of the program, we will compare this time, the production cost only, without accounting for the location, year, or mobilization/demobilization costs, just the production costs associated with contract line items on the bid abstracts that were dredging, and placement related. With the same four estimations as shown in the table 7-5 below.

Table 7-5 Production cost comparison

Project	Winning Bid ($)	Government Estimate ($)	Thesis ($)	Paparis ($)	Gov vs Bid	Thesis vs Gov	Thesis vs Bid	Paparis vs Bid
Barcelona Harbour	508,500	465,450	459,564	587,896	-8,47	-1,26	-9,62	15,6
Erie harbour	832,000	1,186,000	965,898	1,019433	42,55	-18,56	16,09	22,5
Fairport Harbour	1,559,000	1,739,000	923,872	1,117,193	11,55	-46,87	-40,74	-28,3
Huron Harbour	1,135,000	1,141,000	892,015	1,082,281	0,53	-21,82	-21,41	-4,6
Lorain Harbour	701,500	1,208,750	764,584	944,959	72,31	-36,75	8,99	34,7
Toledo-Maumee River	398,000	679,500	477,865	573,725	70,73	-29,67	20,07	44,2
Coos Bay Upriver Dredging	2,114,500	3,115,100	1,610,245	1,598,523	47,32	-48,31	-23,85	-24,4
Suisun Bay	978,900	1,258,825	1,220,067	1,321,239	28,60	-3,08	24,64	35
Total	8,227,400	10,793,625	7,314,110	8,245,249	31,19	-32,24	-11,10	0,22
Mean Absolute Error					35,26	25,79	20,68	26,16

From the second comparison we notice a decrease in the absolute error in the thesis compared to the government from 31.1 percent to 25.8 percent. However, still lower in all the eight projects than the government estimation. Furthermore, compared to the winning bid, the absolute error was reduced from 22.9 percent to 20.7 percent with three projects within 20 percent, five within 20 and 30 percent and one 40 percent of the winning bid. The error between the thesis and the winning bid did not change more than 10 percent for individual projects apart from the Coos Bay Upriver project.

The government estimation absolute error increased by 1.2 percent compared to the winning bid. Paparis estimation absolute error increase from 24.9 to 26.2 percent. Finally, the government had four projects estimate close to the winning bid compared to just two in the total cost comparison. Nevertheless, there was an increase in the absolute error from 33.2 to 35.3 percent.

We can see also from figure 7-2, the bar chart plotted for the total production cost that the thesis program was lower in four projects than the winning bid, as the first comparison there is a significant difference with Fairport Harbour and Coos Bay Upriver. In both projects the mobilization and demobilization had a large portion of the bid. For instance, the Coos Bay Upriver, it was 25 percent of the project bid. The thesis program underestimated the total cost of the project by 38 percent and the total production cost by 23.8 percent, which is a significant difference, since we did not account for the mob/demob in the second comparison The thesis estimation was lower than Paparis estimation seven out of the eight projects.

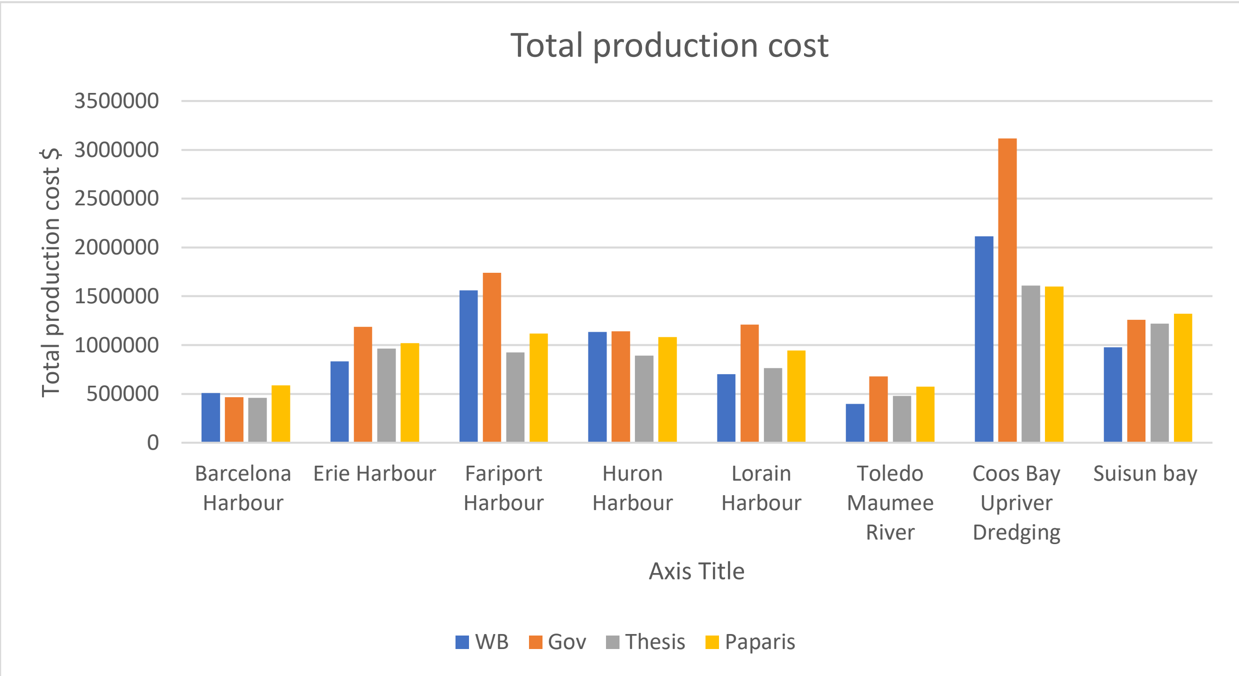

Figure 7-2 Production Cost comparison

7.2 Sensitivity analysis

Calculating the production rate and the total cost of the project included many variables such as the dredging depth, the bucket size and sediment type. The aim of the sensitivity analysis is to change these variables, one by one and keeping the other parameters constant, and see how they affect the total cost of a dredging project. We will apply the analysis on the case study in hand -the Ravenna port-hub project- with a volume of 1428410 $m^{3,}$ default sediment is sand and clay and 12 m of depth.

We change first the type of sediment, we choose in the program between the sediment input parameters: mud, loose mud, compact sand, sand and clay, stones, and broken rock. As demonstrated in the figure 8-1. keeping the other parameters constant (bucket size, hopper capacity, dredged depth).

The sediments type has a major effect on the total cost of the project because each sediment type has its own bulking factor, fill factor and capacity factor as shown in previous chapters, and that reduces the bucket capacity, which reduces the production rate, leading to longer dredging period, therefore, more cost. Specially the case of stones and broken rocks we can notice the sudden increase in the cost. For this reason, we omit stones and broken rocks from the sensitivity analysis, as shown in the figure 8-2. Nevertheless, the cost of the project is still affected if we deal with the other types of sediments.

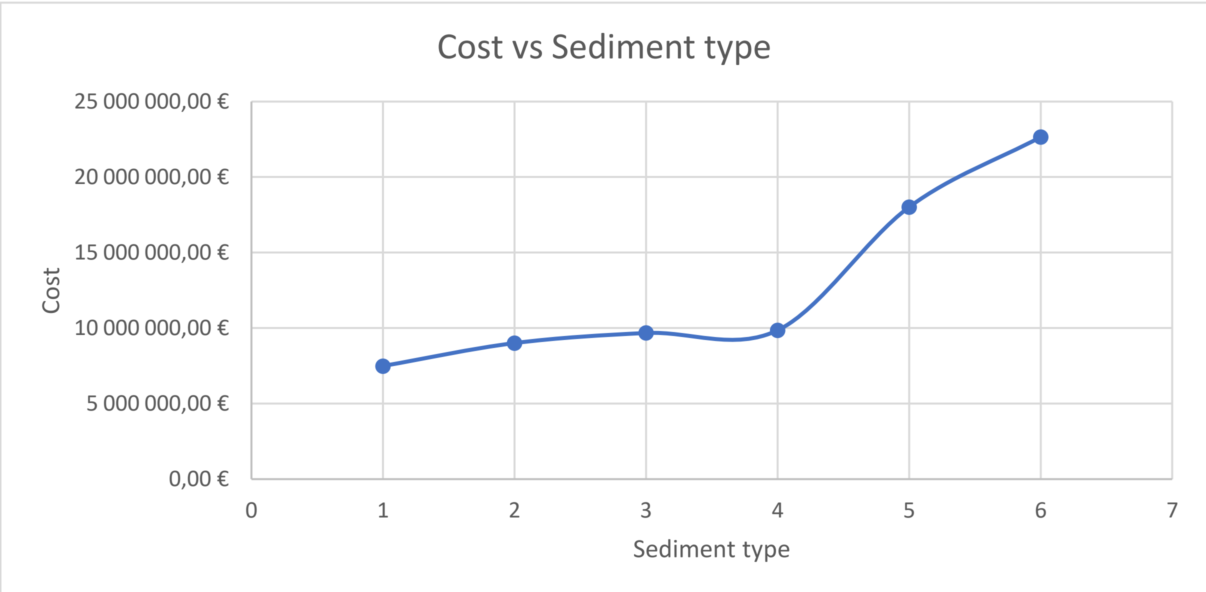

Figure 7-3 Cost vs Sediment type

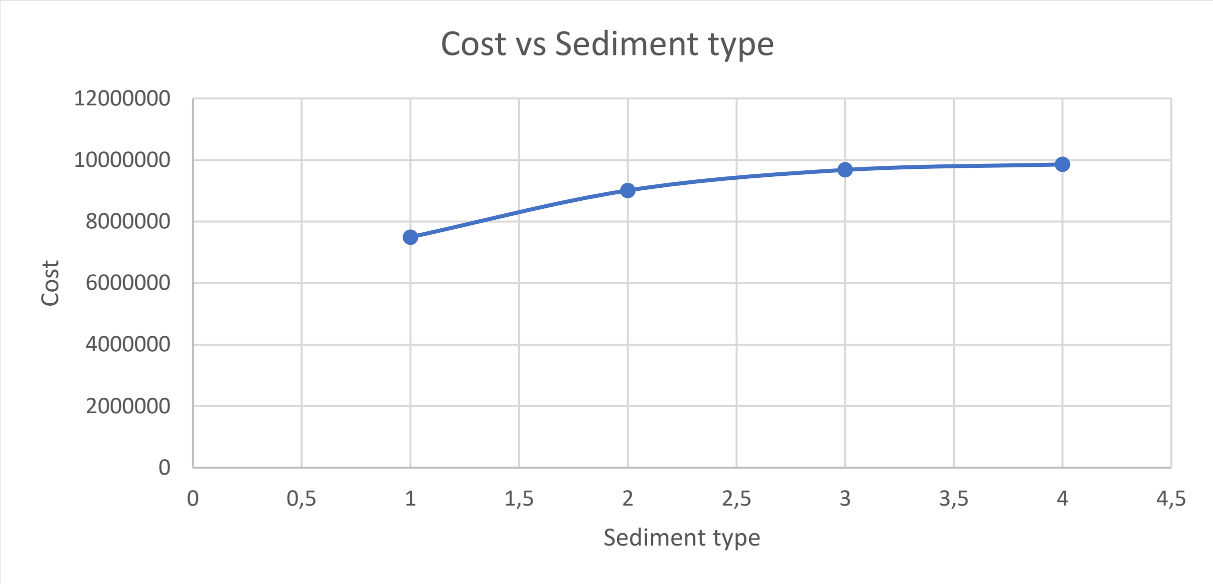

Figure 7-4 Cost vs Sediment type without stone and broken rock

The second sensitivity analysis will be related to the bucket size, keeping the other parameters constant (sediment type, hopper capacity, dredged depth). The bucket size will be varied from small to large sizes, starting from 2,32 to 4,6 m^3 taken as small bucket sizes and from 5 to 38,1 m^3 as large bucket sizes.

As we can notice in the figure 8-3, the cost is high when it comes to small bucket sizes, because it will take more time to dredge the required volume. The project went from costing 71.7 million euros using 2,32 m^3 bucket size, to 12.5 million euros using 38.1 m^3 bucket size.

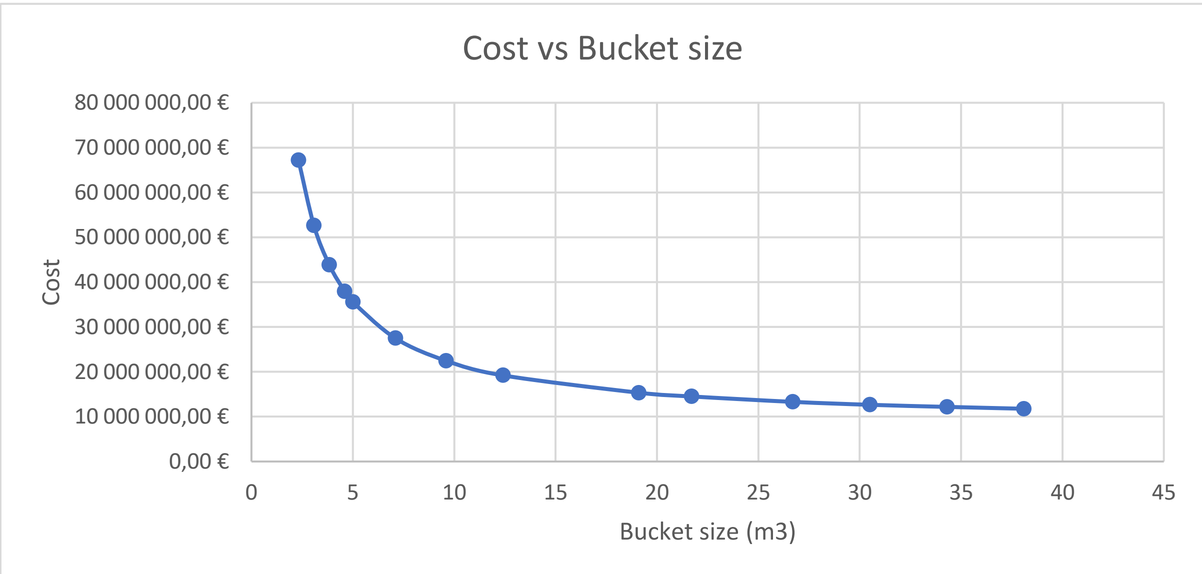

Figure 7-5 Cost vs Bucket size

In this study also, we separate the small bucket sizes, the small ones, and large ones, in the figures 8-4 and figure 8-5, respectively.

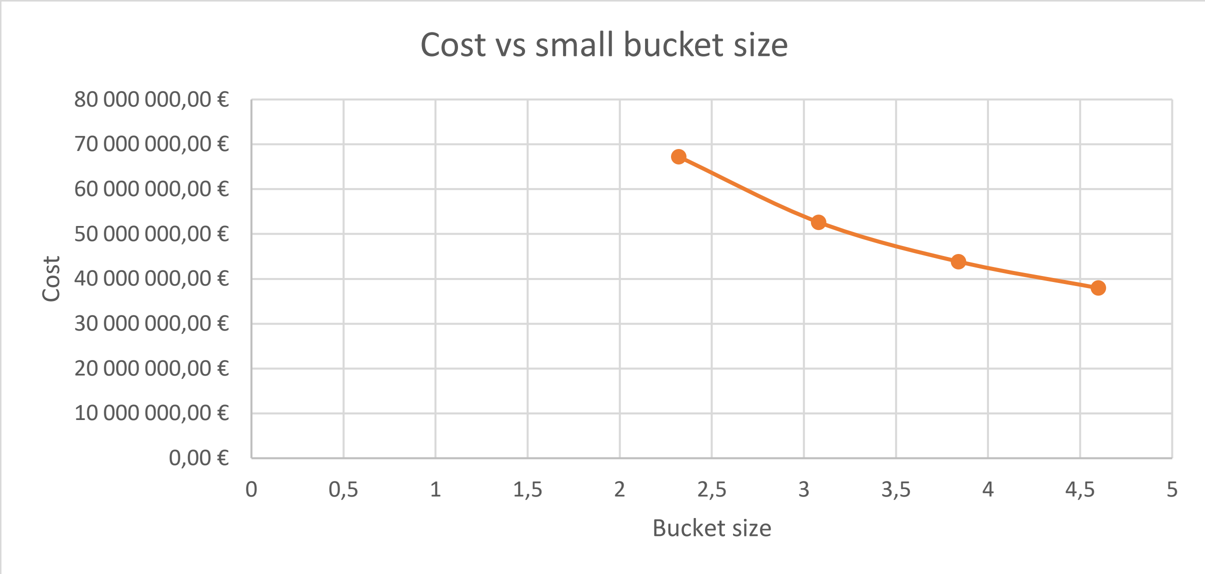

Figure 7-6 Cost vs small bucket size

the inflated cost and the quick reduction of the cost between small and large bucket sizes for the same sediment type, in this case sand and clay, is related to the bucket fill factor as mentioned in the equation 4-5. Demonstrated by (Adair,2004), the bucket fill factors are logarithmic functions of bucket size. Therefore, the smaller the bucket size the bigger the change. Thus, we can say that fill factor affects the sensitivity analysis.

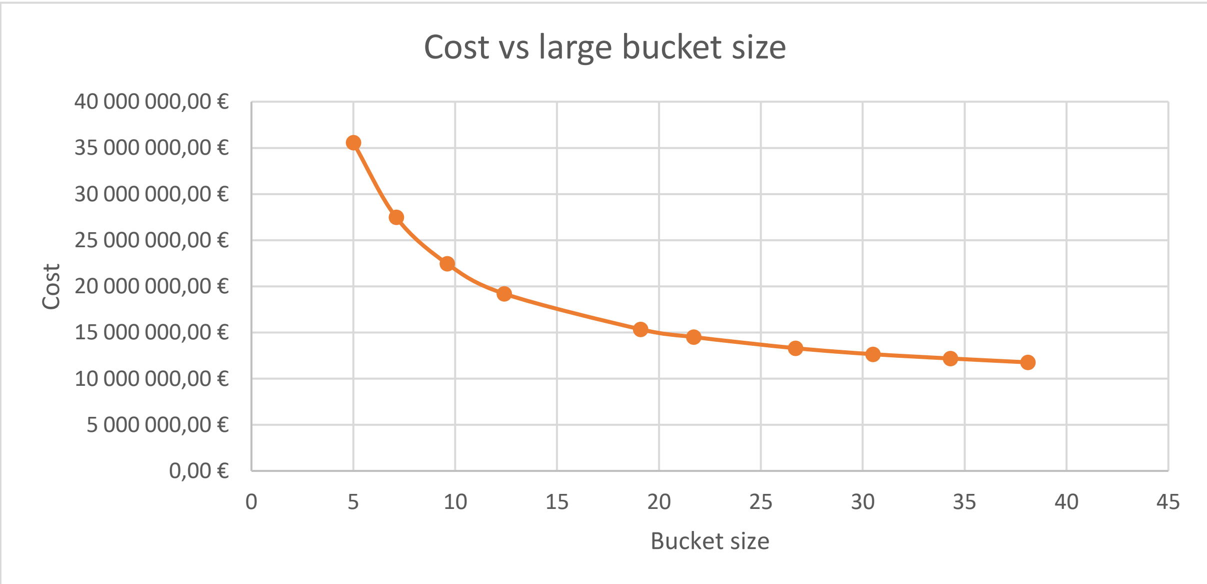

Figure 7-7 Cost vs large bucket size

The next parameter to analyse is the dredging depth, the study started from a 7,6 m depth to 16,8. And again, as the other studies, the other parameters were kept constant. The results in figure 8-6.

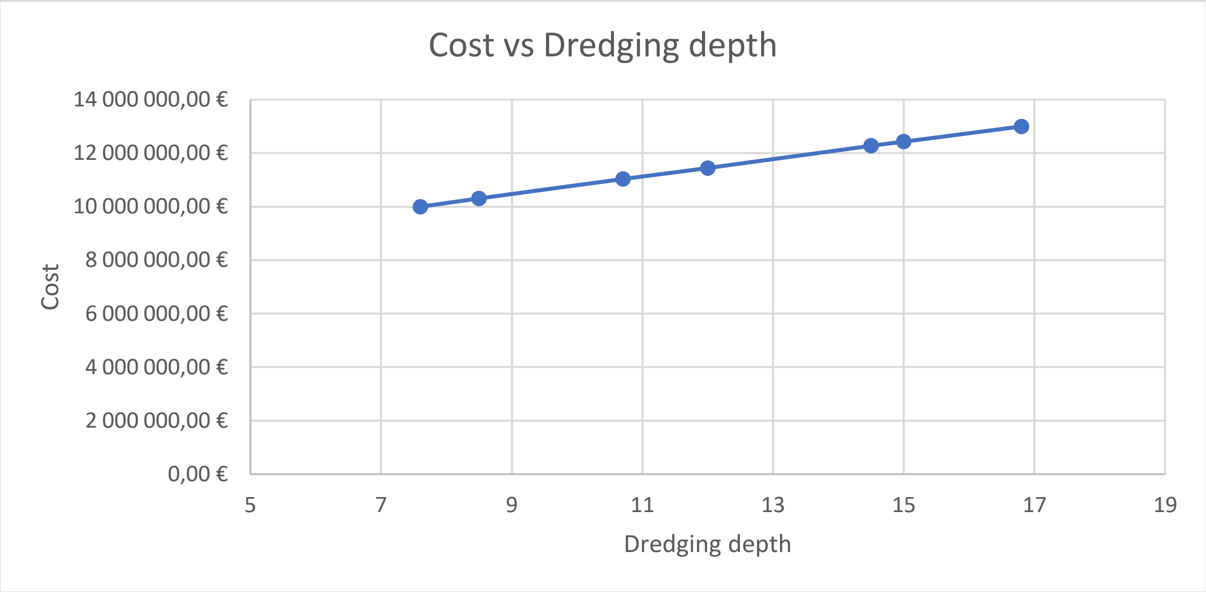

Figure 7-8 Cost vs Dredging depth

From the graph in figure 8-6 we can see that there is a linear relationship between the dredging depth and the cost. Since the dredging depth directly affects the cycle time. So, if we increase the depth we increase the cycle time, therefore, decreasing the production rate, leading to the increase of the project duration and eventually the total project cost.

The next and final sensitivity analysis is the working hours per day, we start with 8 hours to 24 hours, including 10.32 hours that is the estimated working hours per day for the project.

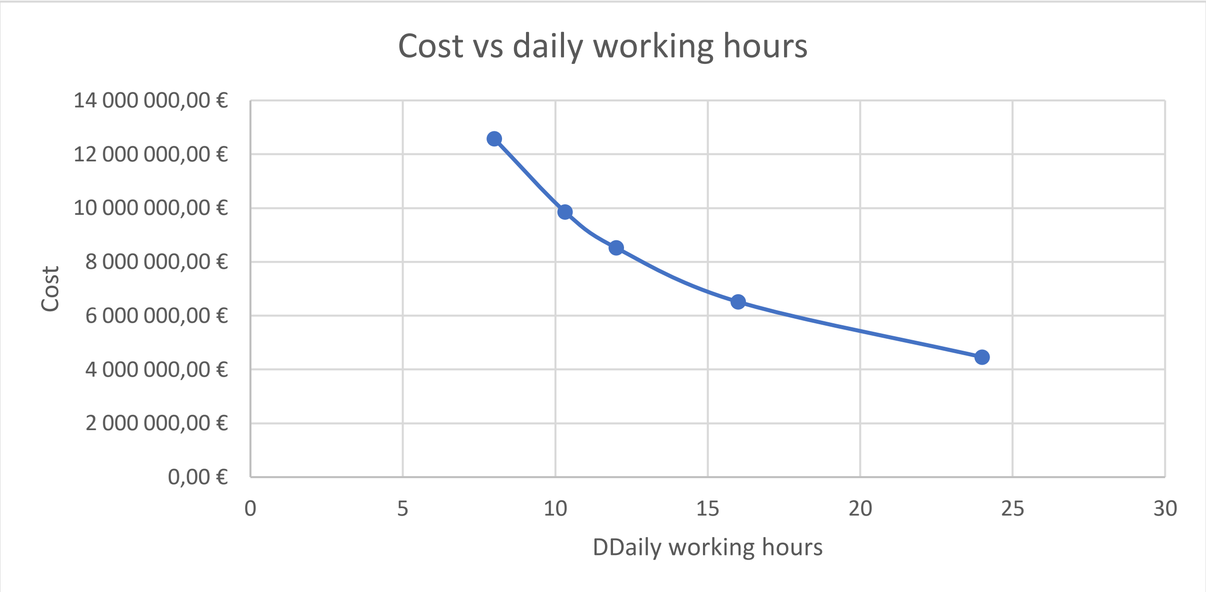

Figure 7-9 Cost vs daily working hours

From the figure 8-7 we can see that there is a noticeable reduction of the project cost. For instance, from 8 hours to 16 hours, we have a reduction of 50 percent. However, in this analysis we did not account for the efficiency reduction. Because, in the case of double shift or continuous dredging, the operating crew must do nightshifts, which adds a complexity to the operation. Moreover, the vessels will work non-stop, increasing the risk of malfunctioning. These factors may lead to a reduction of production rate and increase the cost of the project.

8 Conclusion and Recommendations

For any given project, planning and estimating the cost of the project is an important step to give a clear vision of the projects and their expenditures. In this thesis, we tried to implement an excel spreadsheet to estimate the production rate and the total cost of a mechanical clamshell dredging project.

The program structure followed previous estimating programs done by (Adair,2004), for the bucket fill factor and cycle time, which are essential to the calculation of the production rate of the clamshell dredger, for the cost estimation techniques by (Wowstschuk,2016), and (Paparis,2017) combined both works. Hellas, as mentioned in the previous chapters, when it comes to the cost estimation, some data is not available to the public, to compensate for that; the unknown data were replaced by default values based on previous clamshell mechanical dredging projects. However, if the data were to be found, the program gives the opportunity to use them for better accuracy.

The production rate method was developed by (Bray et al,1997), improved later by (Adair,2004), where he accounted for large bucket sizes and how the fill factor changes with the size change. The production rate estimation is influenced by sediment type, cycle time, hopper capacity. Moreover, other factors, such as bulking factor, bucket fill factor, delay factors, and the latter vary depending on the depth, the hopper capacity, the distance from the disposal site. Once the production rate is determined, we can calculate the number of days needed to complete the project, by dividing the production rate by the working hours per day. In the case of Ravenna Port-Hub project, the program estimation was 212 days, whereas the company estimation was 215 days. We can say that for this part, the results were satisfactory, from that we can estimate the daily cost and finally the total project cost.

Regarding the cost estimation, to verify the accuracy of the program, it was compared with the winning bid and government estimation of eight clamshell dredging projects from the United States. The program absolute error of the total cost of the project, when compared to the winning bid, was 22,94 %, whereas the government compared to the winning bid was 34,19 %. The program estimation was close to the one of the winning bids.

Afterwards, we did not account for mobilization/demobilization costs and other costs. Basically, a production cost comparison. We noticed that the absolute error between the program and the winning bid was reduced to 20,68 %. Nevertheless, the government estimate increased to 35,26%. Based on the results, we can say that the program was closer to the winning bid than the government estimated. However, in some projects, we underestimated the cost, it is recommended to overestimate the cost, to avoid any unpredicted events or delays.

The thesis program, based on the results obtained, is able estimate or predict clamshell mechanical dredging projects with reasonable accuracy. But the more data and information obtained about the project, we will have better estimation and better understanding of the cost.

Based on the sensitivity analysis, the bucket size is an important parameter. Therefore, the choice of the bucket size is crucial, and the program allows the insertion of different bucket sizes for a better comparison. It goes without saying, acquiring the appropriate data about the bucket size will give more accurate estimation. Another factor is the sediment type, which accounts for multiple factors, such as, the bulking factor, capacity factor, and the fill factor affecting the bucket size, affecting the cost of the project.

Most of the parameters were set as default values, due to the scarcity of data regarding these data due confidentiality. To have a more accurate and concise estimation of the production rate and the cost of the project, some parameters must be known. For instance, the crew size, always depend on the size of the project, we can put an average number of the crew members based on the usual tasks related to the clamshell mechanical dredging projects. However, it would be more beneficial to have the exact number and their daily cost, because the cost changes through the years and the jobs.

The capital cost would be more accurate and benefit from the up-to-date cost information that account for the increase of cost in dredging construction due to inflation, technological development. Nevertheless, the data and the approach made available by Bray et al (1997), is the best fitted to give an estimation and quantify these costs.

The spreadsheet can also be extended for backhoe mechanical dredgers. Using the same estimating methodology from Bray et al (1997) and other recourses, to make the program more diverse and versatile.

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Appendices

Appendix A-1: calculation spreadsheet for zone (1+2+3). The figure below shows the calculations of the production rate and the cost related to the project of Ravenna Hub in the zone 1+2+3, including all the factors. As mentioned before, the spreadsheet in colour coded to differentiate the different inputs and outputs.

Based on the data of April 2023	
Angelo B	
(yellow)	default input
(blue)	Project input
(green)	automated calculation
(light green)	Final resulst

Dredger type	bucket size	Hopper capacity	Volume dredged	daily worl	Horse p	Fuel L/day
Angelo B	9,6	1000	402950	11,23	3202	1290
Cavour	5	500	92750	9,438	850	450
Giochino Bachet	7,1	800	106450	10,3	2400	1050
total	21,7	2300	602150	10,3227	6452	2790

Soil type		Bulking factor (B)	Fill Factor (Fm)	capacity factor
Mud	1	1,15	0,86	1
Loose Sand	2	1,1	0,84	0,72
Compact Sand	3	1,3	0,82	0,72
Sand and Clay	4	1,25	0,78	0,72
Stones	5	1,3	0,67	0,36
Broken Rock	6	1,5	0,52	0,36

cycle time			
Factors	time	default	
average swing angle	120	120	degree
swing speed	21	21	degree/s
average depth	12	12	
lift velocity	1	0,3	m
grab time	1	1	s
fall velocity	1	1	m/s
time to empty clamsh	2,6	2,6	s
hight of freeboard	2	2	m
cycle time	43,03		s

capital cost		
Iold	203,892	2015
Inew	231,975	2022
inflation	0,13773	
capital	1,8E+07	Euros
	Bureau of Labor Statistics Data (bls.gov)	

Fuel calculation			
Fuel consumption	2790	L/day	
Fuel price	0,8635	dollars/L	5% fee
Fuel cost per d	2409,17	dollars/day	

cost summary		
Production summary		
production rate	33701	
production volume	12,00	
esrimated daily run time	10,32	
required dredging hours	#####	
required days	211,9	
Fuet cost	2409	
lubricants (10% of fuel cost)	240,9	
Repairs and maintenance	6731,91	
Depreciation	2413	
Mob/Demob	1330652	
Insurance	2089,1	
Crew	11972	
Rentals	25000	
10% overhead and bonding	5085,61	
Total job cost	9856613	euros
Price per m3	6,90041	euros/m3

parameters	Value		Defaults	Units	
Sediment type	4	4	4		
A	10000	30000		m^2	average area dredged
z	2	2	2	m	thickness of material dredged
H	1000	2300		m^3	Hopper capacity
C	9,6	21,7		m^3	Capacity of the bucket
V	1428410,00	1428410,00		m^3	volume to be dreged
d	12	12		m	depth
h	2	2	2	m	offborad hight
ta	0,33	0,33	0,33	Hrs	time to advance the barge
sa	120	120	120	deg	average swing angle
th	1	1	0,25	Hrs	time to change the hopper
B	1,25	1,25	1,25		Bulking factor
fa	0,9907824	0,993039004			delay factor for advancing the dredger
fh	0,6415849	0,645046263			delay factor for changing the hopper
fm	0,78	0,78	0,78		fill factor
fc	0,72	0,72	0,72		Capacity factor
C adjusted	6,912	15,624			modifcation factor
Volume dredged	402950	602150		m^3	volume of sediments actually dregded
CT	43,028571	43,02857143		second	Cycle time
Pnom	451,06996	1019,6061		m^3/hr	Nominal production
Pmax	286,7321	653,1148766		m^3/hr	Max production
	14795,3765	33700,72763		m^3/week	
Total dredging	4981,69	2187,07		Hrs	
	443,60538	211,92569		days	
	444	212			

Daily cost	$	
Fuel	2409,17	
Lubricants	240,917	
Minor repairs	2303,02	
Major repairs	4428,89	
Insurance	2089,1	
Depreciation	2413	25 years
Crew and Labor	11972	14 workers on the 3 dredges
Equipements Rental	25000	
Total	50856,1	
Overhead and bonding rate	0,1	
Overhead and bonding	5085,61	
Total cost with overhead and	55941,7	
Profit	5594,17	
Total daily cost	61535,9	
Total Production cost	1,3E+07	
Mob/ Demob rate	0,102	
Mob/Demob	1330652	
Total Project cost	1,4E+07	
Year factor	1,13769	
Year adj Cost	1,6E+07	Dollars
Location factor	0,60264	2022
Location Adj Cost	9856613	Euros
Additional Costs		
Rock/Debris removal	0	
Government-directed standb	0	
Enviromental Monitoring	0	
Other project-specific costs	0	
Total Adjusted Cost	9856613	Euros

Appendix A-2: calculation spreadsheet for zone 4. Like the previous Appendix, with different input values related to the zone, such as, the volume to be dredged.

Based on the data of April 2023	
Angelo B	
(yellow)	default input
(blue)	Project input
(green)	automated calculation
(light green)	Final resulst

Dredger type	bucket size	Hopper capacity	Volume dredged	daily wor	Horse pc	Fuel L/day
Angelo B	9,6	1000	402950	11,23	3202	1290
Cavour	5	500	92750	9,438	850	450
Giochino Bacheto	7,1	800	106450	10,3	2400	1050
total	21,7	2300	602150	10,323	6452	2790

Soil type		Bulking factor (B)	Fill Factor (Fm)	capacity factor
Mud	1	1,15	0,86	1
Loose Sand	2	1,1	0,84	0,72
Compact Sand	3	1,3	0,82	0,72
Sand and Clay	4	1,25	0,78	0,72
Stones	5	1,3	0,67	0,36
Broken Rock	6	1,5	0,52	0,36

cycle time			
Factors	time	default	
average swing angle	120	120	degree
swing speed	21	21	degree/s
average depth	12	12	
lift velocity	1	0,3	m
grab time	1	1	s
fall velocity	1	1	m/s
time to empty clamsh	2,6	2,6	s
hight of freeboard	2	2	m
cycle time	43,03		s

capital cost		
Iold	203,892	2015
Inew	231,975	2022
inflation	0,137735	
capital	15255062	Euros
	Bureau of Labor Statistics Data (bls.gov)	

Fuel calculation			
Fuel consumption	2790	L/day	
Fuel price	0,8635	dollars/L	5% fee
Fuel cost per da	2409,165		

cost summary		
Production summary		
production rate	33701	
production volume	12,00	
esrimated daily run time	10,32	
required dredging hours	####	
required days	103	
Fuet cost	2409	
lubricants (10% of fuel cost)	240,9	
Repairs and maintenance	5797	
Depreciation	2413	
Mob/Demob	7E+05	
Insurance	3703	
Crew	11972	
Rentals	25000	
10% overhead and bonding	5153	
Total job cost	5E+06	euros
Price per m3	6,992	euros/m3

parameters	Value		Defaults	Units	
Sediment type	4	4	4		
R					
A	10000	30000		m^2	average area dredged
z	2	2	2	m	thickness of material dredged
H	1000	2300		m^3	Hopper capacity
C	9,6	21,7		m^3	Capacity of the bucket
V	694000,00	694000,00		m^3	volume to be dreged
d	12	12		m	depth
h	2	2	2	m	offborad hight
ta	0,33	0,33	0,33	Hrs	time to advance the barge
sa	120	120	120	deg	average swing angle
th	1	1	0,25	Hrs	time to change the hopper
B	1,25	1,25	1,25		Bulking factor
fa	0,9907824	0,993039			delay factor for advancing the dredger
fh	0,6415849	0,6450463			delay factor for changing the hopper
fm	0,78	0,78	0,78		fill factor
fc	0,72	0,72	0,72		Capacity factor
C adjusted	6,912	15,624			modifcation factor
Volume dredged		602150		m^3	volume of sediments actually dregded
CT	43,028571	43,028571		seconds	Cycle time
Pnom	451,06996	1019,6061		m^3/hr	Nominal production
Pmax	286,7321	653,11488		m^3/hr	Max production
	14795,376	33700,728		m^3/week	
Total dredging	2420,38	1062,60		Hrs	
	215,52785	102,96514		days	
		103			

Daily cost	$	
Fuel	2409,165	
Lubricants	240,9165	
Minor repairs	1983,15801	
Major repairs	3813,765404	
Insurance	3702,684858	
Depreciation	2413	
Crew and Labor	11972	14 workers on the 3 dredges
Equipements Rental	25000	
Total	51534,68977	
Overhead and bonding rate	0,1	
Overhead and bonding	5153,468977	
Total cost with overhead and b	56688,15875	
Profit	5668,815875	
Total daily cost	62356,97462	
Total Production cost	6422768,386	
Mob/ Demob rate	0,102	
Mob/Demob	655122,3754	
Total Project cost	7077890,762	
Year factor	1,137690044	
Year adj Cost	8052445,853	Dollars
Location factor	0,60264	2022
Location Adj Cost	4852725,969	Euros
Additional Costs		
Rock/Debris removal	0	
Government-directed standby	0	
Enviromental Monitoring	0	
Other project-specific costs	0	
Total Adjusted Cost	4852725,969	Euros

Appendix A-3: calculation spreadsheet for zone 5

Based on the data of April 2023			default input
			Project input
			automated calculation
			Final resulst
Angelo B			

Dredger type	bucket size	Hopper capacity	Volume dredged	daily worl	Horse p	Fuel L/day
Angelo B	9,6	1000	402950	11,23	3202	1290
Cavour	5	500	92750	9,438	850	450
Giochino Bachet	7,1	800	106450	10,3	2400	1050
total	21,7	2300	602150	10,3227	6452	2790

Soil type		Bulking factor (B)	Fill Factor (Fm)	capacity factor
Mud	1	1,15	0,86	1
Loose Sand	2	1,1	0,84	0,72
Compact Sand	3	1,3	0,82	0,72
Sand and Clay	4	1,25	0,78	0,72
Stones	5	1,3	0,67	0,36
Broken Rock	6	1,5	0,52	0,36

parameters	Value		Defaults	Units	
Sediment type	4	4	4		
R					
A	10000	30000		m^2	average area dredged
z	2	2	2	m	thickness of material dredged
H	1000	2300		m^3	Hopper capacity
C	9,6	21,7		m^3	Capacity of the bucket
V	748000	748000		m^3	volume to be dreged
d	12	12		m	depth
h	2	2	2	m	offborad hight
ta	0,33	0,33	0,33	Hrs	time to advance the barge
sa	120	120	120	deg	average swing angle
th	1	1	0,25	Hrs	time to change the hopper
B	1,25	1,25	1,25		Bulking factor
fa	0,99078244	0,990039			delay factor for advancing the dredger
fh	0,64158487	0,64504626			delay factor for changing the hopper
fm	0,78	0,78	0,78		fill factor
fc	0,72	0,72	0,72		Capacity factor
C adjusted	6,912	15,624			modifcation factor
Volume dredged		602150		m^3	volume of sediments actually dredged
CT	43,0285714	43,0285714		seconds	Cycle time
Pnom	451,06996	1019,60606		m^3/hr	Nominal production
Pmax	286,732103	653,114877		m^3/hr	Max production
	14795,3765	33700,7276		m^3/week	
Total dredging	2608,71	1145,28		Hrs	
	232,298028	110,976832		days	
		111			

cycle time			
Factors	time	default	
average swing angle	120	120	degree
swing speed	21	21	degree/s
average depth	12	12	
lift velocity	1	0,3	m
grab time	1	1	s
fall velocity	1	1	m/s
time to empty clams	2,6	2,6	s
hight of freeboard	2	2	m
cycle time	43,029		s

Daily cost	$	
Fuel	2409,165	
Lubricants	240,9165	
Minor repairs	1983,15801	
Major repairs	3813,765404	
Insurance	3435,824688	
Depreciation	2413	
Crew and Labor	11972	14 workers on the 3 dredges
Equipements Rental	25000	
Total	51267,8296	
Overhead and bonding rate	0,1	
Overhead and bonding	5126,78296	
Total cost with overhead and	56394,61256	
Profit	5639,461256	
Total daily cost	62034,07382	
Total Production cost	6885782,194	
Mob/ Demob rate	0,102	
Mob/Demob	702349,7838	
Total Project cost	7588131,978	
Year factor	1,137690044	
Year adj Cost	8632942,204	Dollars
Location factor	0,60264	2022
Location Adj Cost	5202556,29	Euros
Additional Costs		
Rock/Debris removal	0	
Government-directed standby	0	
Enviromental Monitoring	0	
Other project-specific costs	0	
Total Adjusted Cost	5202556,29	Euros

capital cost		
Iold	203,892	2015
Inew	231,975	2022
inflation	0,137735	
capital	15255062	Euros
	Bureau of Labor Statistics Data (bls.gov)	

Fuel calculation			
Fuel consumption	2790	L/day	
Fuel price	0,8635	dollars/L	5% fee
Fuel cost per da	2409,165		

cost summary		
Production summary		
production rate	33701	
production volume	12,00	
esrimated daily run time	10,323	
required dredging hours	1145,28	
required days	110,98	
Fuel cost	2409,2	
lubricants (10% of fuel cost)	240,92	
Repairs and maintenance	5796,9	
Depreciation	2413	
Mob/Demob	702350	
Insurance	3435,8	
Crew	11972	
Rentals	25000	
10% overhead and bonding	5126,8	
Total job cost	5E+06	euros
Price per m3	6,9553	euros/m3

Appendix A-4: calculation spreadsheet for the comparison of the total cost estimation of different projects. This spreadsheet has an extra table and figure representing the difference between the thesis spreadsheet, Pararis (2017), the winning bid and the government estimation.

default input
Project input
automated calculation

Soil type		Bulking factor (B)	Fill Factor (Fm)	capacity factor
Mud	1	1,15	0,86	1
Loose Sand	2	1,1	0,84	0,72
Compact Sand	3	1,3	0,82	0,72
Sand and Clay	4	1,25	0,78	0,72
Stones	5	1,3	0,67	0,36
Broken Rock	6	1,5	0,52	0,36

parameters	Value		Defaults	Units	
Sediment type	4	4			
A	1142,7	1142,7		m^2	average area dredged
z	2	2	2	m	thickness of material dredged
H	3440	3440		m^3	Hopper capacity
C	7,65	7,65		m^3	Capacity of the bucket
V	133797,00	133797,00		m^3	volume to be dreged
d	10,7	10,7		m	depth
h	2	2	2	m	offborad hight
ta	0,33	0,33	0,33	Hrs	time to advance the barge
sa	120	120	120	deg	average swing angle
th	0,25	0,25	0,25	Hrs	time to change the hopper
B	1,25	1,25	1,25		Bulking factor
fa	0,93540985	0,935409848			delay factor for advancing the dredger
fh	0,96851508	0,968515084			delay factor for changing the hopper
fm	0,78	0,78	0,78		fill factor
fc	0,72	0,72	0,72		Capacity factor
C adjusted	5,508	5,508			modifcation factor
Volume dredged	0	0		m^3	volume of sediments actually dredged
CT	40,4285714	40,42857143		seconds	Cycle time
Pnom	382,562714	382,5627138		m^3/hr	Nominal production
Pmax	346,58596	346,5859603		m^3/hr	Max production
Total dredging time	386,04	386,04		Hrs	
	28,5957599	28,59575985		days	
		29			

Project	WB	Gov	Thesis	Pararis	GE vs W	Thesis v	Thesis v	Pararis vsWB
Barcelor	602200	552050	506439,35	647861	-8,3278	-8,2621	-15,902	7,6
Erie Harl	868980	1330700	1064419	1123416	53,134	-20,011	22,491	29,3
Fariport	1640000	1846500	1018107,4	1231146	12,591	-44,863	-37,92	-24,9
Huron H	1165150	1231800	983000,27	1192673	5,7203	-20,198	-15,633	2,4
Lorain H	773200	1310050	842571,66	1041344	69,432	-35,684	8,972	34,7
Toledo I	436700	736600	526607,29	632245	68,674	-28,508	20,588	44,8
Coos B	2862160	3824852	1774489,7	1761572	33,635	-53,606	-38,002	-38,5
Suisun b	1769330	2158825	1344514,3	1456005	22,014	-37,72	-24,01	-17,7
Total	10117720	12991377	8060148,97	9086262	28,402	-37,958	-20,336	-10,195
					34,191	31,1065	22,94	24,988

cycle time			
Factors	time	default	
average swing angle	120	120	degree
swing speed	21	21	degree/s
average depth	10,7	12	
lift velocity	1	0,3	m
grab time	1	1	s
fall velocity	1	1	m/s
time to empty clamsh	2,6	2,6	s
hight of freeboard	2	2	m
cycle time	40,429		s

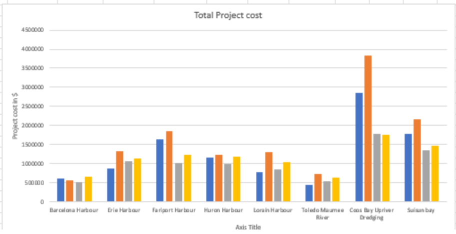
city	location fa	year	volume	depth	yearly factor	Bucket size
New Yor	1,13	2014	54283	3	0,9989	4,5
Pennsylv	1,14	2014	191139	7,6	0,9989	11,5
Ohio	0,94	2014	229366	7,3	0,9989	11,5
Ohio 2	0,94	2014	210253	8,5	0,9989	11,5
Ohio 3	0,94	2014	126151	8,5	0,9989	7,65
Ohio 4	0,94	2014	76455	8,5	0,9989	7,65
Oregon	1,13	2015	198784	10,7	1	7,65
Californi	1,24	2015	133797	10,7	1	7,65

Daily cost	$	
Fuel	4297,5388	
Lubricants	429,75388	
Minor repairs	1882,5221	
Major repairs	3620,2348	
Insurance	1207	
Depreciation	2413	
Crew and Labor	8878	
Equipements Rental	5312	
Total	28040,049	
Overhead and bonding rate	0,1	
Overhead and bonding	2804,0049	
Total cost with overhead and b	30844,054	
Profit	3084,4054	
Total daily cost	33928,46	
Total Production cost	983925,34	
Mob/ Demob rate	0,102	
Mob/Demob	100360,38	
Total Project cost	1084285,7	
Year factor	1	0,9989
Year adj Cost	1084285,7	
Location factor	1,24	California
Location Adj Cost	1344514,3	
Additional Costs		
Rock/Debris removal	0	
Government-directed standby	0	
Enviromental Monitoring	0	
Other project-specific costs	0	
Total Adjusted Cost	1344514,3	

capital cost		
Iold	101,5	
Inew	134,5	
inflation	0,3251232	
capital cost	14480939	Euros

Fuel calculation		
Consumption rate	0,0481	gal/HP-Hr
Average HP	2038	
Fuel consumption	98,0278	gal/hr
	1568,4448	gal/day
Fuel price	2,74	Dollar
Fuel cost per day	4297,5388	

cost summary		
Production summary		
production rate	346,58596	
production volume	133797,00	
esrimated daily run time	2014	
required dredging hours	386,04	
required days	28,59576	
Fuel cost	4297,5388	
lubricants (10% of fuel cost)	429,75388	
Repairs and maintenance	5502,7568	
Depreciation	2413	
Mob/Demob	100360,38	
Insurance	1207	
Crew	8878	
Rentals	5312	
10% overhead and bonding	30844,054	
Total job cost	1344514,3	Dollars
Price per m3	10,048912	Dollars/m3



Appendix A-4: calculation spreadsheet for the comparison of the production cost estimation of different projects. In this spreadsheet and as mentioned in previous sections, the cost of mob/demob was not accounted for. Nevertheless, it is the same projects and procedure.

(yellow)	default input
(blue)	Project input
(green)	automated calculation

Soil type		Bulking factor (B)	Fill Factor (Fm)	capacity factor
Mud	1	1,15	0,86	1
Loose Sand	2	1,1	0,84	0,72
Compact Sand	3	1,3	0,82	0,72
Sand and Clay	4	1,25	0,78	0,72
Stones	5	1,3	0,67	0,36
Broken Rock	6	1,5	0,52	0,36

parameters	Value		Defaults	Units	
Sediment type	4	4	4		
R	4	4	4		
A	1142,7	1142,7		m^2	average area dredged
z	2	2	2	m	thickness of material dredged
H	3440	3440		m^3	Hopper capacity
C	11,5	11,5		m^3	Capacity of the bucket
V	210253,00	210253,00		m^3	volume to be dreged
d	8,5	8,5		m	depth
h	2	2	2	m	offborad hight
ta	0,33	0,33	0,33	Hrs	time to advance the barge
sa	120	120	120	deg	average swing angle
th	0,25	0,25	0,25	Hrs	time to change the hopper
B	1,25	1,25	1,25		Bulking factor
fa	0,8956741	0,8956741			delay factor for advancing the dredger
fh	0,9501119	0,9501119			delay factor for changing the hopper
fm	0,78	0,78	0,78		fill factor
fc	0,72	0,72	0,72		Capacity factor
C adjusted	8,28	8,28			modifcation factor
Volume dredged	0	0		m^3	volume of sediments actually dregded
CT	36,028571	36,028571		second:	Cycle time
Pnom	645,32784	645,32784		m^3/hr	Nominal production
Pmax	549,16795	549,16795		m^3/hr	Max production
Total dredging tir	382,86	382,86		Hrs	
	28,359806	28,359806		days	
		28			

Project	WB	Gov	Thesis	Paparis	GE vs W	Thesis v	Thesis v	Paparis vs WB
Barcelo	5E+05	465450	459563,84	587896	-8,466	-1,265	-9,624	15,6
Erie Harl	8E+05	1186000	965897,45	1E+06	42,55	-18,56	16,09	22,5
Fariport	2E+06	1739000	923872,44	1E+06	11,55	-46,87	-40,74	-28,3
Huron H	1E+06	1141000	892014,77	1E+06	0,529	-21,82	-21,41	-4,6
Lorain H	7E+05	1208750	764584,09	944959	72,31	-36,75	8,993	34,7
Toledo M	4E+05	679500	477865,05	573725	70,73	-29,67	20,07	44,2
Coos Ba	2E+06	3115100	1610244,7	2E+06	47,32	-48,31	-23,85	-24,4
Suisun b	1E+06	1258825	1220067,4	1E+06	28,6	-3,079	24,64	35
Total	8E+06	10793625	7314109,7	8E+06	31,19	-32,24	-11,1	0,2169
MAE					35,26	25,791	20,68	26,163

cycle time			
Factors	time	default	
average swing angle	120	120	degree
swing speed	21	21	degree/s
average depth	8,5	12	
lift velocity	1	0,3	m
grab time	1	1	s
fall velocity	1	1	m/s
time to empty clamsh	2,6	2,6	s
hight of freeboard	2	2	m
cycle time	36,03		s

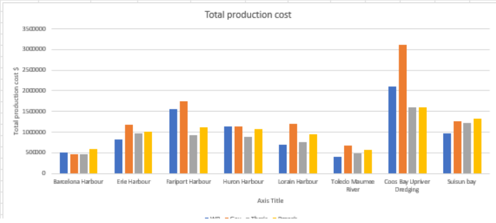
city	location fa	year	volume	depth	yearly factor	Bucket size
New Yor	1,13	2014	54283	3	0,9989	4,5
Pennsyl	1,14	2014	191139	7,6	0,9989	11,5
Ohio	0,94	2014	229366	7,3	0,9989	11,5
Ohio 2	0,94	2014	210253	8,5	0,9989	11,5
Ohio 3	0,94	2014	126151	8,5	0,9989	7,65
Ohio 4	0,94	2014	76455	8,5	0,9989	7,65
Oregon	1,13	2015	198784	10,7	1	7,65
Californi	1,24	2015	133797	10,7	1	7,65

Daily cost	$	
Fuel	4297,53875	
Lubricants	429,753875	
Minor repairs	1882,52207	
Major repairs	3620,23475	
Insurance	1207	
Depreciation	2413	
Crew and Labor	8878	
Equipements Rental	5312	
Total	28040,0494	
Overhead and bonding rate	0,1	
Overhead and bonding	2804,00494	
Total cost with overhead and	30844,0544	
Profit	3084,40544	
Total daily cost	33928,4598	
Total Production cost	949996,875	
Mob/ Demob rate	0	
Mob/Demob	0	
Total Project cost	949996,875	
Year factor	0,9989	0,9989
Year adj Cost	948951,879	
Location factor	0,94	Ohio 2
Location Adj Cost	892014,766	
Additional Costs		
Rock/Debris removal	0	
Government-directed standb	0	
Enviromental Monitoring	0	
Other project-specific costs	0	
Total Adjusted Cost	892014,766	

capital cost		
Iold	101,5	
Inew	134,5	
inflation	0,325123153	
capital c	14480939	Euros

Fuel calculation		
Consumption rate	0,0481	gal/HP-Hr
Average HP	2038	
Fuel consumption	98,0278	gal/hr
	1568,4448	gal/day
Fuel price	2,74	Dollar
Fuel cost per da	4297,538752	

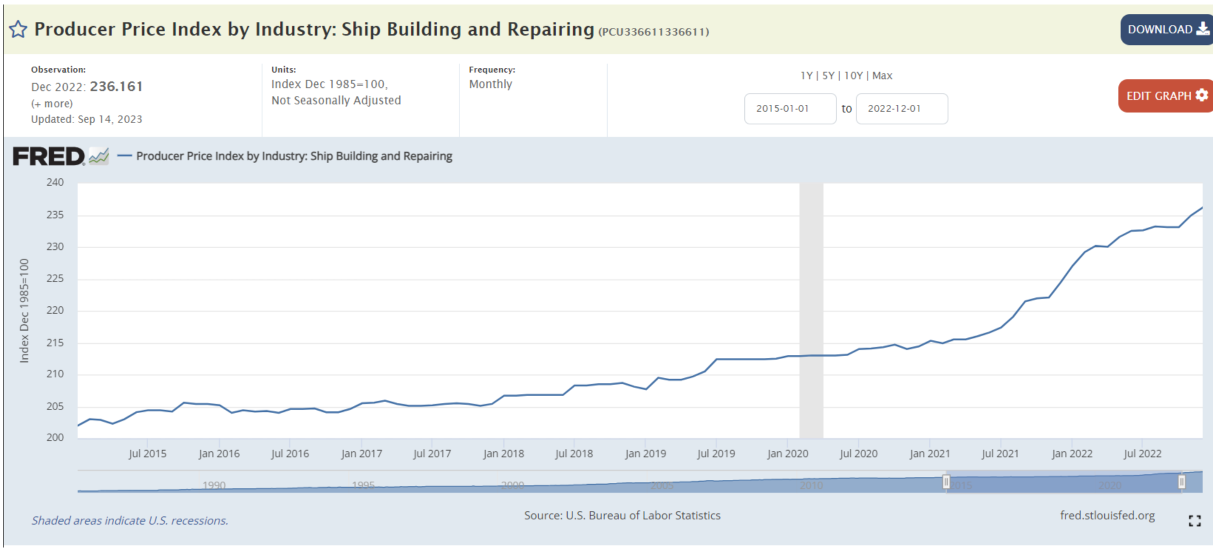
cost summary		
Production summary		
production rate	549,168	
production volume	#######	
esrimated daily run time	2014	
required dredging hours	382,86	
required days	28,3598	
Fuet cost	4297,54	
lubricants (10% of fuel cost)	429,754	
Repairs and maintenance	5502,757	
Depreciation	2413	
Mob/Demob	0	
Insurance	1207	
Crew	8878	
Rentals	5312	
10% overhead and bonding	30844,05	
Total job cost	892014,8	Dollars
Price per m3	4,242578	Dollars/m3



Appendix B: Producer price index by industry: Ship Building and Repairing.

The average values for the year 2022 and 2015 were obtained from the graph below.

203,892 and 231,975 respectively, to account for the inflation.



Appendix C: Department of Labor and Industrial Relations, State of Hawaii. “Wage Rate Schedule Bulletin No. [488.” 2016,](#) For water front construction(dredging).

From the table below, the average salaries of a dredging vessel workers were obtained.

WAGE RATE SCHEDULE BULLETIN NO. 488

Classification	Current			2016			2017			2018			Remarks
	Prevailing Wage Total	Basic Hourly Rate	Fringe Hourly Rate	Prevailing Wage Total	Basic Hourly Rate	Fringe Hourly Rate	Prevailing Wage Total	Basic Hourly Rate	Fringe Hourly Rate	Prevailing Wage Total	Basic Hourly Rate	Fringe Hourly Rate	See Pg 7-9
* **WATER FRONT CONSTRUCTION (DREDGING):**	**9/19/16**												
CLAMSHELL OR DIPPER DREDGES:													
Clamshell or Dipper Operator	$72.60	$42.69	$29.91	-	-	-	-	-	-	-	-	-	11,13
Mechanic; Welder; Watch Engineer	$71.94	$42.03	$29.91	-	-	-	-	-	-	-	-	-	13
Deckmate; Bargemate	$71.54	$41.63	$29.91	-	-	-	-	-	-	-	-	-	13
Fire Person; Oiler; Deckhand; Barge Worker	$69.88	$39.97	$29.91	-	-	-	-	-	-	-	-	-	13
HYDRAULIC SUCTION DREDGES:													
Lever Operator	$72.24	$42.33	$29.91	-	-	-	-	-	-	-	-	-	13
Mechanic; Welder	$71.94	$42.03	$29.91	-	-	-	-	-	-	-	-	-	13
Watch Engineer (steam or electric)	$72.09	$42.18	$29.91	-	-	-	-	-	-	-	-	-	13
Dozer Operator	$71.88	$41.97	$29.91	-	-	-	-	-	-	-	-	-	13
Deckmate	$71.54	$41.63	$29.91	-	-	-	-	-	-	-	-	-	13
Winch Operator (stern winch on dredge)	$71.43	$41.52	$29.91	-	-	-	-	-	-	-	-	-	13
Fire Person; Oiler; Deckhand (can operate anchor scow under direction of deckmate); Levee Operator	$69.88	$39.97	$29.91	-	-	-	-	-	-	-	-	-	13
DERRICKS:													
Operator: Derrick, Piledriver, Crane	$72.60	$42.69	$29.91	-	-	-	-	-	-	-	-	-	13
Deckmate; Saurman Type Dragline (up to & including 5 yds.)	$71.54	$41.63	$29.91	-	-	-	-	-	-	-	-	-	13
Saurman Type Dragline (over 5 cu. yds.)	$71.94	$42.03	$29.91	-	-	-	-	-	-	-	-	-	13
Fire Person; Oiler; Deckhand	$69.88	$39.97	$29.91	-	-	-	-	-	-	-	-	-	13
BOAT OPERATORS:													
Master Boat Operator	$72.24	$42.33	$29.91	-	-	-	-	-	-	-	-	-	13
Boat Operator	$72.09	$42.18	$29.91	-	-	-	-	-	-	-	-	-	13
Boat Deckhand	$69.88	$39.97	$29.91	-	-	-	-	-	-	-	-	-	13
* **WATER WELL DRILLER:**	**9/19/16**												
Water Well Driller	$39.68	$31.00	$8.68	-	-	-	-	-	-	-	-	-	
Water Well Driller Helper	$25.58	$18.00	$7.58	-	-	-	-	-	-	-	-	-	
WELDER:													
Use wages of craft to which welding is incidental, except for Chain-Link Fence Erector. See remark.													10

Comments: Overtime must be paid at one and one-half times the basic hourly rate plus the hourly cost of required fringe benefits.
*** Indicates a wage, fringe benefit, remark, or title change from the previous bulletin.**

Appendix D: OECD. (2023). Price level indices

the location factor, we need to change from the United States of America to Italy, and for that OECD price level indices were used. Italy (Red) 82 and United States of America (Blue) 125