COST ESTIMATING PROJECTS FOR LARGE CUTTER AND HOPPER DREDGES

A Thesis

by

FRANCESCO JOHN BELESIMO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2000

Major Subject: Ocean Engineering

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Approved as to style and content by:

Robert E. Randall
Robert E. Randall
(Chair of Committee)

Andrew Vastano
(Member)

Daniel Cox
Daniel T. Cox
(Member)

John Niedzwecki
(Department Head)

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ABSTRACT

Cost Estimating Projects for Large Cutter and Hopper Dredges. (May 2000)

Francesco John Belesimo, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Robert E. Randall

Estimating the cost of a dredging project is the most important part of a project's life cycle. A precise account of the costs associated with performing dredging work begins with the production estimate and ends with the cost estimate. The production estimate is based on a clear understanding of some fundamental laws governing hydraulic transport including variations of the Bernoulli Equation. Newer theories concerning friction loss in a pipeline aid in the development of the production estimate phase of the program. Practical experience aids in the transition from production estimate to cost estimate.

This thesis reviews the process of creating a program that for the first time provides users not associated with the government or dredging companies a method to determine the cost of a dredging project employing a hopper dredge. The program consists of two Microsoft Excel spreadsheets and provides a means to estimate either large cutter (27" and larger) or hopper dredge projects. The program allows for a high degree of customization to account for either a particular dredge or project. In a series of comparisons, the program output had an average difference of 17.3% between the estimated price and the price awarded to the winning bidder. For the same projects the government estimate varied an average of 16.2%. Using the accuracy of the government estimate as a measure of accomplishment, the program can be considered a success.

ACKNOWLEDGEMENTS

The author would like to express his gratefulness to Dr. Robert Randall for his support and motivation on this thesis and during the years spent in graduate school in general. The author would also like to express his gratitude to Dr. Daniel Cox for his technical writing advice and Dr. Andrew Vastano for serving on his thesis committee.

The author would like to thank Mr. James W. Bean Sr., Mr. Ancil S. Taylor Jr., and Mr. Walter Lee of C.F. Bean Corporation for their support during the two years spent in graduate school. Their trust, confidence, and support made graduate school possible.

And last but certainly not least the author would like to thank his wife, Christa W. Belesimo for putting up with the late hours, too much talk about classes, and for spending two years waiting for me to finish this thesis.

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INTRODUCTION

Between the years of 1995 and 1999 the United States spent an average of 514 million dollars per year on federal navigation and shore protection dredging projects (USACE, 2000). This figure is representative of contracts completed by independent contractors. An average of over 200 million cubic yards of material per year was removed during channel maintenance and deepening, harbor maintenance and deepening, and beach renourishment. Independent dredging contractors bid on all of the work contracted by the federal government though a sealed bidding process. In order for contractors to win a sealed bid they must be deemed the lowest responsible bidder for a particular project. The objective of the contractor is to bid the project according to a cost estimate and a desired profit margin. The profit margin for a given project is a matter for each individual contractor to decide but an understanding of the actual costs of a project is a matter that is of concern industry wide.

A cost estimate is based on an understanding of site conditions, planned equipment usage, and contract considerations. Every dredging contractor in the U.S. relies on accurate cost *estimating in order to* sustain business through the procurement of dredging contracts. The estimate of the costs that will be incurred to complete a particular dredging project is the most important part of a bid. Contractors rely on their estimating departments to calculate the expected costs of desired projects, and in turn,

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The citations on the following pages follow the style and format of the Journal of Dredging Engineering.

estimating departments rely on experience and proprietary estimating programs. There are several programs designed to estimate the cost of cutter suction dredges. This report outlines the creation of a new program that estimates the cost of cutter-suction and hopper dredge projects.

Objective

The objective of this thesis is to explain the reasoning behind and the steps involved in creating a comprehensive program to estimate the costs of dredging projects for cutter and hopper dredges. The results of the program are tested by comparing the output of the program to the winning bid price and the government estimate for 10 dredging projects that have been awarded between 1998 and early 2000. The program is based on a number of worksheets created in a Microsoft Excel spreadsheet. There are separate spreadsheets for both cutter and hopper dredges with hyperlinks that connect the sheets to an opening page. The utility of the program is enhanced by virtue of the fact that users with a basic understanding of Excel can tailor the sheets to reflect a specific dredge and project location.

CUTTER AND HOPPER DREDGES

Almost seventy five percent of dredging contracts in the U.S. are performed by either cutter or hopper dredges. Cutter dredges mechanically agitate material from the seafloor and transport a slurry of seawater and sediment to either a confined disposal area, an open water disposal area, or on shore to be used as beach fill. Hopper dredges drag devices on the seafloor that "scrape" sediment from the seafloor and pump the material to an on-board hopper for storage. The hopper dredge then sails to either an offshore disposal site to dispose of the material or pumps out the material though a pipeline to a shore placement area. The following sections describe cutter and hopper dredges in more detail.

Cutter Dredges

The cutter dredge market in the U.S. accounted for 58% of the material removed and 47% of the total dollars spent on dredging projects during the period between 1995 and 1999 (USACE, 2000). Cutter dredges were used for channel and harbor maintenance and deepening and for beach renourishment. There were over 500 contracts performed by cutter dredges for the U.S. Army Corps of Engineers during the period (USACE, 2000). A cutter dredge is most effective in areas where the bank height of the required material is greater than the cutterhead diameter. With a high bank a cutter dredge can sustain productivity rates near the maximum for extended periods of time. Cutter dredges are suited to dredging in areas with materials that include silt, clay (soft to medium stiff), sand, gravel, and loose rock. Figures 1 and 2 illustrate a schematic diagram and a photograph of a cutter dredge respectively.

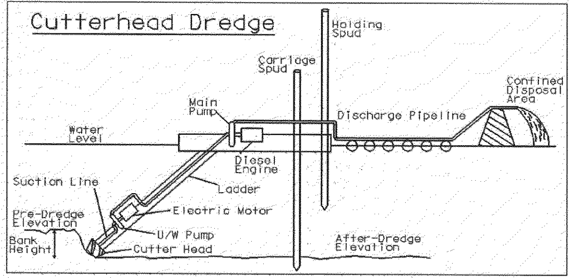


Figure 1. Schematic Diagram of a Cutter Dredge

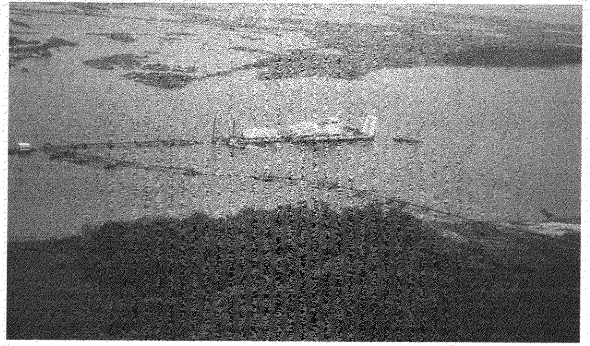


Figure 2. Photograph of Bean Horizons' Cutter Dredge Meridian

The underwater portion of a cutter dredge is comprised of a ladder that supports the cutter and in some cases an underwater pump. The ladder is supported by means of trunions mounted on the deck of the dredge and is lowered and raised using a winch and a multi-part block. The cutter is lowered to the seafloor and rotates in order to cut and loosen the material in the vicinity of the suction mouth. The cutter can be driven either by electric motors or hydraulic motors. In many cases, cutter dredges utilize an underwater pump mounted on the ladder as close to the suction mouth as possible. The use of an underwater pump decreases the likelihood of cavitation in the dredge system and increases the maximum production of a dredge by allowing the transport of higher concentrations of slurry. The underwater pump can also be driven by either an electric motor or hydraulic motor. The material is drawn into the suction mouth and is transported though the suction pipe to the underwater pump. The material passes through the centrifugal pump and energy is imparted to the fluid causing a rise in pressure on the discharge side of the pump. The slurry moves up the ladder to the main dredge pump(s). The main dredge pump(s) are driven by diesel engines or in the case of electric dredges by electric motors. The main pump(s) add more energy to the system by increasing the pressure on the discharge side of the pump. After passing through the main pump(s) the material is transported through a floating or submerged pipeline to the disposal area.

The cutterhead is continually moved from side to side of the dredging area through the use of swing winches. There are two swing winches on a cutter dredge located on either side of the ladder. The winches alternately haul-in or pay-out wire to swing the dredge. As seen in Figure 3, swing wires originate at winches and travel down the ladder, though swing sheaves, and out to swing anchors located away and in front of the bow. The swing anchors are moved forward as the dredge moves forward into the project area. Spuds are used to advance the dredge forward into the cut and to provide a pivot point at the stern around which the dredge rotates. Spuds can be used for projects in inland and protected waters. Using spuds in severe or even modest wave climates can cause bending, damage, or possible breakage of spuds. On a dredge that utilizes a carriage spud, the carriage is advanced aft in its tracks in order to move the dredge forward. At the end of a full carriage set the holding spud is dropped in order to hold the dredge in a fixed position as the carriage spud is raised and the carriage is reset. When the carriage is reset the carriage spud is dropped and the holding spud is raised. Using this technique the dredge is moved forward into the bank in order to continually position the cutterhead in the path of material that is to be removed.

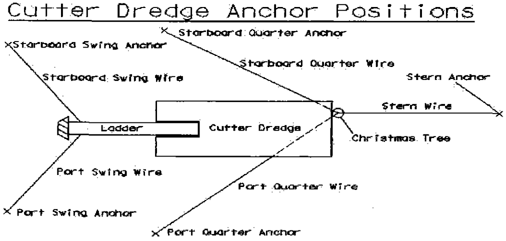
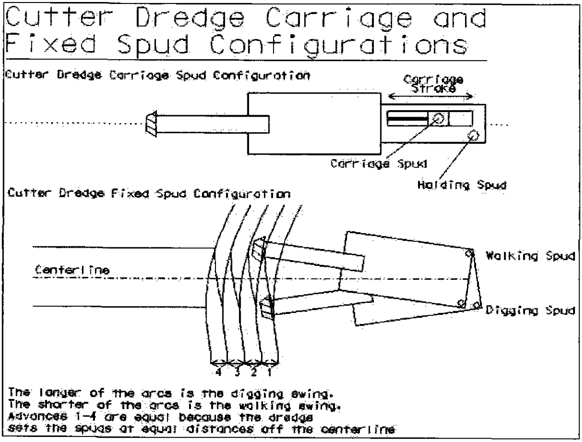


Figure 3. Position of Swing and Christmas Tree Wires and Anchors

Fixed spud dredges have two fixed spuds located at the stern of the dredge at both quarters. A fixed spud dredge is advanced by alternately dropping and raising the spuds while on different sides of the cut. By this means the dredge "walks" forward into the cut as illustrated in Figure 4. Another form of fixing the stern of the dredge and advancing is though the use of a christmas tree as shown in Figure 3 . This arrangement is used in unprotected or offshore environments. It allows the dredge to respond to the seas without the possible loss of a spud. A christmas tree is a device located at the stern of a dredge that allows three wire ropes to pass from the deck, down to the water, and out to the anchors. This is achieved by having two sets of three sheaves, one set at the top and one set at the bottom. Wire ropes from three winches pass through the top set of sheaves, down the middle of the tree, through the lower set of sheaves and then to three separate anchors. The anchors are positioned to the stern (stern anchor), off the port quarter (port quarter anchor), and off the starboard quarter (starboard quarter anchor). This three point mooring allows the stern to be fixed about the christmas tree. The dredge advances by paying out wire on the stern winch and hauling in wire on the winches that lead to the quarter anchors. Constant tension is kept on the wires to prevent transient shock forces causing damage to the dredge. These shock forces are caused by slack in the wires being suddenly hauled in by the winches or by passing waves. If the movement of the dredge causes tension in the wires that approaches the tension settings, then the winches automatically pay-out small amounts of wire and then haul-in to re-tension after the wave has passed.



The longer of the arcs is the digging swing.
The shorter of the arcs is the walking swing.
Advances 1-4 are equal because the dredge
sets the spuds at equal distances off the centerline

Figure 4. Cutter Dredge Carriage and Fixed Spud Configurations

Hopper Dredges

The hopper dredge market accounted for 20% of the material removed and 21% of the total dollars spent on dredging projects during the period between 1995 and 1999 (USACE, 2000). Hopper dredges were used for channel and harbor maintenance and deepening and for beach renourishment. A hopper dredge is essentially a ship that stores dredged material in an onboard hopper that it removes from the sea floor by dragging a mechanism called a draghead to scrape the material and draw it into a suction inlet. These dredges are most effective in areas where there is a minimal bank height and the disposal area is located a distance greater than would be economical to use a cutter dredge. They are well suited for projects that require the removal of silt, loosely packed sand, and soft clays. Hopper dredges have the built in ability to mobilize and demobilize without the rental or use of additional equipment. Figures 5 and 6 illustrate a schematic diagram and a photograph of a hopper dredge.

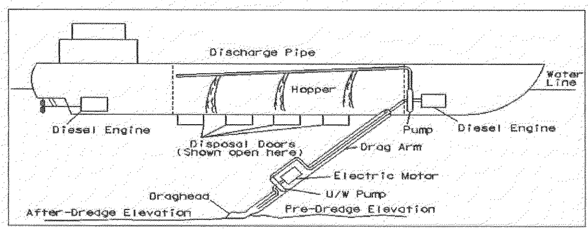


Figure 5. Schematic Diagram of a Hopper Dredge

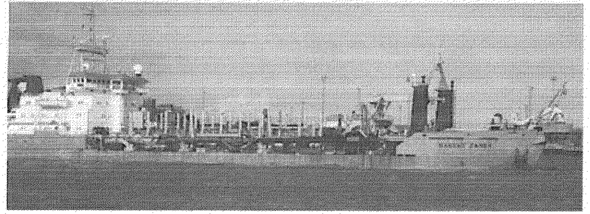


Figure 6. Photograph of Boskalis' Hopper Dredge Barent Zanen

The dredging process begins when the draghead passes over the seafloor and scrapes material up towards the suction mouth located inside the draghead. The material then passes through the suction pipe to the underwater pump located on the drag arm. The underwater pump is driven by either an electric motor or hydraulic motor. The underwater pump adds energy to the system by raising the pressure on the discharge side of the pump. The material then passes through a pipeline in the dragarm to the hull. The pipeline passes though the ships hull and to a main pump located in the pump room. This pump increases the pressure on the discharge side and sends the slurry through the discharge pipeline and into the hopper. The hopper can have a capacity of from 400 cubic meters to over 23,000 cubic meters (500 to 30,000 cubic yards). Most hopper dredges in the U.S. and around the world range from 750 to 7,600 cubic meters (1,000 to 10,000 cubic yards) of hopper capacity. There are "Jumbo-Dredges" owned by European dredging companies that have hopper capacities of over 25,000 cubic meters (32,700 cubic yards).

While material is pumped into the hopper, excess water is discharged overboard except in the case of silt, mud, or when the specifications of a project dictate zero overflow. In the case of silt or mud slurries, the sediment in the mixture settles out of suspension very slowly. This means that the slurry in the hopper is approximately uniform in concentration and that any further flow into the hopper will result in a discharge containing approximately the same volume of dredged material. Under these circumstances, when the hopper is full, the dredge pumps are shut down, the drag arms are raised, and the dredge sails to the disposal area. The settling time for sand is much less than that of silt or mud and consequently excess water discharged from the hopper will contain substantially less material than the inflow slurry. In this case the excess water is discharged until the hopper is full or the maximum allowable draft is achieved. Since clay has a tendency to ball-up, the same procedure is followed to fill the hopper as with sand.

When the hopper is filled to the desired capacity, the dredge sails to either an offshore disposal area or a pump-out station. At the offshore disposal area the dredge discharges the material in the hopper by opening large doors located at the bottom of the hopper. The material in the hopper drops though the doors and falls to the seafloor. When materials such as clay are dredged, water jets are sprayed inside the hopper during discharge to aid in the removal of sediment. Another type of disposal system used on hopper dredges is the split hull hopper. Instead of having bottom doors the dredge splits down the centerline in order to drop material out of the hopper. The split hull hopper uses large hydraulic rams located fore and aft to open the hopper. If a pump-out station is used, the dredge connects to a shore line and pumps a mixture of seawater and the contents of its hopper through the main dredge pump(s).

FUNDAMENTALS OF HYDRAULIC TRANSPORT

Centrifugal pumps introduce energy into a hydraulic transport system by increasing the velocity of the slurry inside the pump shell. According to continuity, the volume of an incompressible fluid into a centrifugal pump must be equal to the volume exiting the pump. Therefore as the fluid flows out of the pump into a pipeline of equal diameter as the inlet pipeline the discharge velocity must approach the inlet velocity. According to Bernoulli's Law, as the velocity decreases while the elevation and cross section remain the same, the pressure must increase. In this fashion the pressure or head of the system is increased. The units of pressure are newtons per meter squared (or psi) and the units of head are m-N/N or meters (or ft-lb/lb = feet). The output of a centrifugal pump is known as the pump head (H_p) and is the difference between the head at the suction side (H_s) and the discharge side (H_d).

$$H_p = H_d - H_s \tag{1}$$

and

$$H_d = \frac{P_d}{\gamma} + \frac{V_d^2}{2g} + z_d \tag{2}$$

$$H_s = \frac{P_s}{\gamma} + \frac{V_s^2}{2g} + z_s \tag{3}$$

where γ is the specific weight of the transported fluid, P_d and P_s are the discharge side and suction side pressures respectively, V_d and V_s are the discharge side and suction side average velocities, g is the acceleration due to gravity, and z_d and z_s are the discharge side and suction side elevations measured relative to the centerline of the pump. The combination of Equations 2 and 3 yields the Bernoulli equation. The energy equation is a modified version of Bernoulli's equation that includes the pump head, the loss attributed to friction in the pipeline, and minor losses

$$\frac{P_s}{\gamma}+\frac{V_s^2}{2g}+z_s+H_p=\frac{P_d}{\gamma}+\frac{V_d^2}{2g}+z_d+H_f+H_m \tag{4}$$

where H_f are the losses due to friction and H_m are minor losses.

Friction loss in a dredge system is caused by interaction between the fluid and the walls of the pipeline that are not completely smooth. The friction loss in a hydraulic transport system can be calculated for horizontal flow using the Wilson et al.(1997) equation. Friction loss using the Wilson equation is explained later in the thesis. Minor losses are incurred at turns in the pipeline, valves, ball joints, flanged connections, nozzles, at the suction mouth, and at the discharge. Minor losses are determined using the following relationship called the minor loss equation (Herbich, 1992)

$$H_m=K\frac{V^2}{2g} \tag{5}$$

where K is a coefficient that represents particular causes of minor loss in a transport system. In practice, all of these K values are summed and utilized as an equivalent K value for use in the minor loss equation. Table 1 lists some values for items common to dredge systems.

Table 1. Minor Loss Coefficients (Randall, 1999)

Pipe System Component	Minor Loss Coefficient - K
Suction Entrance	
Plain End Suction	1.0
Rounded Suction	0.1
Oval	1.0
Elbows	
Long Radius 90 Degree (flanged)	0.2
Long Radius 45 Degree (flanged)	0.2
Regular 90 Degree (flanged)	0.3
Stern Swivel	1.0
Ball Joints	
Straight	0.1
Fully cocked (17 Degree)	0.9
End Section	1.0

An assumption made when calculating the friction loss is that the flow is horizontal. In most dredging applications horizontal flow is common. When the flow of the slurry encounters a positive or negative incline there is a change in the friction loss. The change in friction loss is calculated using the following equation developed by Wilson et al (1997)

$$\Delta i(\theta) = \Delta i(0)\cos\theta + (S_s - 1)C_V \sin\theta \qquad (6)$$

and

$$\Delta i(0) = i_m - i_w \tag{7}$$

where i_w is the head loss in meters (feet) of water per meter (foot) of pipe for water, i_m is the head loss in meters (feet) of water per meter (foot) of pipe for the mixture, C_V is the concentration by volume, S_s is the specific gravity of the solids, and θ is the angle of inclination measured to the horizontal. The result of this equation allows for the friction loss on an incline to be calculated for the inclined segment of the pipe. The length of horizontal pipe and its corresponding friction loss is added to the friction loss incurred through the inclined portion of the pipeline and results in the total loss due to friction in the pipeline.

Flow of slurry in a pipeline varies according to the composition of the solids in the slurry and the transport velocity. Figure 7 represents this relationship.

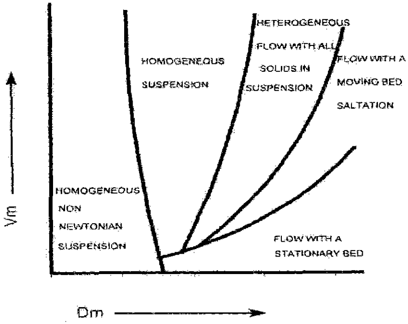


Figure 7. Flow Regimes (TID, 1999)

The first area in the chart shows that very small grain size materials are transported in homogeneous non-newtonian suspensions. The materials in this range have very slow or no settling velocities. The materials that fall into this range are low plasticity clays and silt. This type of flow has an even distribution of particles throughout the cross section of flow. The second area represents homogeneous suspension. In this type of flow the material particles travel at the same velocity as the carrier fluid. There is little or no change in the concentration of solids across the flow cross section. Materials that can fall into this range are silt, low plasticity clay, and when in low enough concentrations medium to high plasticity clays. The third area in the graph represents heterogeneous flow with no deposits. In heterogeneous flow all of the particles remain in suspension but there is a difference in concentration across the section from top to bottom with the concentration of solids at the bottom of the flow greater than at the top. The fourth region of the graph shows heterogeneous flow with heavier particles settling to the bottom but continuing to move along the pipe. The materials that move along the bottom of the pipeline are known as a bed load. The velocity of the grains is less than the velocity of the carrier fluid and the concentration by transport is smaller that the concentration by volume. In this area, pipeline resistance is minimized and for most hydraulic transport situations this is commonly the design velocity (TID, 1999). The fifth flow regime represents flow with a stationary bed. In this case, the bed load no longer moves in the direction of flow but remains stationary. In this flow regime, the possibility of "plugging" or clogging the pipeline exists and should be avoided.

Review of Past Work

Work in estimating the cost of cutter and hopper dredge projects takes place every day in the offices of dredging companies around the world. The details of their work are not available outside of the company, and rightly so, for contracts are awarded in the U.S. on the basis of lowest bid. Fortunately there has been a substantial amount of research conducted at higher learning institutions around the world that can be utilized in order to create a viable method for estimating the cost of hydraulic dredging projects.

There has been extensive research in the area of estimating production of a hydraulic transport system employing centrifugal pumps. Research by Wilson et al. (1997) into the friction loss resulting from the transport of slurries produced an accurate equation to calculate friction loss in horizontal and inclined pipelines. In a paper by Van Den Berg et al. (1999), the results of Wilson's equation are compared to the results of four commonly used friction loss equations. For slurry specific gravities of 1.15 - 1.75 the Wilson equation was matched by only Jufin & Lopatin in accuracy. The data show that the Wilson equation like the Jufin & Lopatin equation produce results with accuracies that fall between ±15% of field data.

The paper by Van Den Berg et al. (1999) describes the effects of solids in a transport system as determined through field testing on board the hopper dredge "Pearl River". In the paper it is concluded that in large diameter (greater than 750mm or 30" inside diameter) systems the effects of solids concentration on head and efficiency are negligible up to a concentration by volume of 48%. This is greater than the previously regarded concentration value of 25% by Wilson et al. (1997) who used smaller pumps and pipelines in developing the Wilson equation.

In addition there are over 40 other equations by a variety of engineers around the world to describe friction loss. A list of commonly used equations along with their developers and ranges of applicability is located in the Appendix (Table A-23).

The production estimate is developed using an equation to calculate the friction loss in the pipeline and consequently the required horsepower. This leads to the development of a cost estimate. The area of cost estimating has been approached by Bray et al. (1997). Their work provides a detailed analysis of the components of a cost estimate, and it was a useful reference when developing the cost estimating portion of the spreadsheets described in this thesis.

Henshaw et al. (1999) outlined a unique method of cost estimating. The authors gathered data on the cost and magnitude of 18 dredging projects performed on the Great Lakes. The data were sorted according to project volume, and mobilization and demobilization costs. By removing the mobilization and demobilization costs the cost per cubic yard of removed material was plotted and an algorithm was developed to estimate the cost based on the required volume of the project. This method produced accurate cost estimate results for projects on the Great Lakes.

Miertschin and Randall (1998) describe a method of estimating the cost of cutter dredge projects. They utilized non-dimensional pump curves in order to cover a wide range of dredge sizes. The paper shows that their method of estimating production correlated well with the Army Corps of Engineers "Cutpro" software (Scott, 1997).

Comparisons of the program output versus the actual costs of four projects for the Texas Gulf Intracostal Waterway showed an average difference of forty seven percent.

The U.S. Army Corps of Engineers (1997) present a set of engineering instructions that describe the preparation of dredge cost estimates. These instructions outline the government's approach to cost estimating but do not include information on production estimates or assigning cost to individual items.

PRODUCTION ESTIMATES FOR CUTTER AND HOPPER DREDGES

Production estimates for both cutter and hopper dredges can be determined for a dredging project if the character of the material and disposal distance remains fairly constant. If there are significant changes in the character of required material or the disposal distance, the production estimating portion of the program can be used to determine productions on a reach-by-reach basis. The productions for each reach can be combined using a weighted average and entered as the final production estimate.

Cutter Dredge Production

The production rate for cutter dredges is based on the maximum production rate possible for a given equipment configuration. This production rate is then adjusted to reflect the level of expected on-site production. The production rate is limited by the efficiency of the dredge cycle, bank height considerations, advance limitations, and swing limitations. The first step in calculating the production is calculating the terminal velocity of a grain representative of the required material.

Using information about the median grain size and specific gravity from the data input portion of the program, the terminal velocity of a grain in the dredged material slurry is calculated using a relationship developed by Schiller (1992)

$$V_t = 134.14 * (d_{50} - 0.039)^{0.972} \qquad (8)$$

where V_t is the terminal velocity in mm/s, and d_{50} is the median grain size in mm. Schiller's terminal velocity was chosen because of its ease of use and accuracy. A grain achieves terminal velocity when the drag forces on the grain are in equilibrium with the gravitational forces on the grain and the acceleration of the grain is zero. For grain sizes smaller than medium-grained sand, as the terminal velocity increases (larger grain size), the velocity in the pipeline must also increase in order to prevent the grain from falling out of suspension. Conversely, as the terminal velocity decreases (smaller grain size), the velocity in the pipeline can be safely reduced without deposition of material in the pipeline.

The friction factor is determined using an equation developed by Swamee and Jain (1976). The equation expresses the friction factor from the Moody chart originally developed in 1944 (Moody, 1944). The Swamee and Jain expression (Equation 10) is an explicit expression and is similar to the indeterminate Colebrook-White expression (Equation 9) for the friction factor.

$$\frac{1}{f} = -2\log\left(\frac{2.51}{R\sqrt{f}} + \frac{\varepsilon}{3.71D}\right) \tag{9}$$

$$f = \frac{0.25}{\left[\log\left(\frac{\varepsilon}{3.7D} + \frac{5.74}{R^{0.9}}\right)\right]^2} \tag{10}$$

where *f* is the dimensionless friction factor, ε is the pipe roughness, D is the pipe diameter, and R is the Reynolds number for the flow. When the inner wall of the pipeline becomes polished after dredging begins ε approaches zero and the friction factor becomes dependent on the Reynolds number only. When the terminal velocity and the friction factor are determined, the friction loss in the pipeline is calculated using Equation 11.

Equation 11 is used to determine the friction loss in the pipeline because of its accuracy. Confirmed by Van Den Berg et al. (1999) the results of Equation 11 compare well with field data, and it was chosen over other equations in order to achieve the highest degree of accuracy in calculating dredge production. The friction loss in the discharge and suction lines is calculated using Equations 8, 10, and 11

$$i_m = \frac{f\,V^2}{2gD} + 0.22(SG_s - 1)V_{50}^{M} C_V V^{-M} \tag{11}$$

$$V_{50} = w\sqrt{\frac{8}{f}}\cosh\left(\frac{60d_{50}}{D}\right) \tag{12}$$

$$w = 0.9V_t + 2.7\left[\frac{(\rho_s - \rho_f)g\mu}{\rho_f^2}\right]^{\frac{1}{3}} \tag{13}$$

where i_m is the friction loss in terms of meters of water per meter of pipe (also feet of water per foot of pipe), f is the friction factor, V is the fluid velocity in meters (feet) per second, g is the gravitational constant in meters (feet) per second squared, D is the inside diameter of the pipe in meters (feet), SG_s is the specific gravity of the solids, M is a function of the grain size distribution and is normally equal to 1.7, μ is the dynamic viscosity of the carrier fluid, and ρ_s and ρ_f are the density of the solids and carrier fluid respectively. The minor losses in the system are calculated using Equation 5. The friction losses are combined with minor losses in the system in order to calculate the total system head loss.

Critical velocity is the velocity at which individual grains begin to fall out of suspension and create deposits in the pipeline. The critical velocity is the minimum velocity at which the system should operate. The following expression (Wilson et al., 1997) is used to determine the critical velocity.

$$V_c = \frac{8.8\left[\frac{\mu_s\left(S_s - S_f\right)}{0.66}\right]^{0.55} D^{0.7} d_{50}^{1.75}}{d_{50}^2 + 0.11D^{0.7}} \tag{14}$$

where V_c is the critical velocity in meters per second, μ_s is a dimensionless coefficient that varies from 0.4 - 0.55, D is the inside diameter of the pipeline in meters, d_{50} is the median grain size in millimeters, S_s is the specific gravity of the solids, and S_f is the specific gravity of the carrier fluid.

The total head curve is determined using data input from the pump selection portion of the spreadsheet. This information is used to create a total head curve from the pump information selected. The head curves for each pump are added together in order to create a curve representative of all of the pumps used. Figure 8 shows the combination of the system loss curve, the total head curve, and the critical velocity. On the plot the critical velocity has been converted to a flowrate in gallons per minute using the diameter of the discharge pipe. The intersection of the system loss and the system head curves occurs at 47,300 gallons per minute (GPM) or 2.98 cubic meters per second. The critical flowrate occurs at 31,200 GPM (1.97 m^3/s) so the system can operate safely at 47,300 GPM (2.98 m^3/s). The intersection of the curves denotes the *maximum* production capabilities of the system at maximum horsepower output and the pump speed that corresponds to the maximum horsepower.

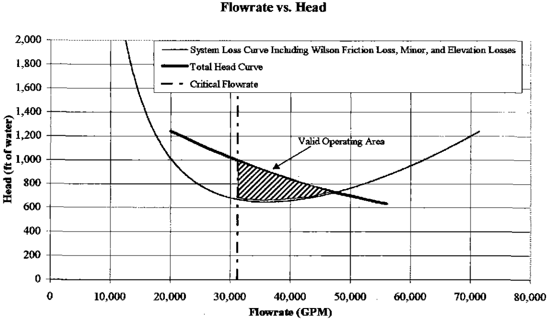


Figure 8. Plot of System Loss and Total Head Curves

The system can operate at any point in the region bounded by the critical flowrate, the friction loss curve, and the system head curve assuming that cavitation does not occur.

If the estimator desires a lower flowrate, a flowrate in this region can be used or the specific gravity of the slurry can be increased. An increase in slurry specific gravity shifts the critical flowrate line to the right, raises the friction loss curve, and in effect lowers the operating flowrate. As a consequence of raising the slurry specific gravity the area in which the dredge can operate in is reduced. If cavitation occurs at this flowrate either the slurry velocity or specific gravity must be reduced.

Cavitation is the formation and collapse of low pressure regions in the pipeline or inside the pump. The occurrence of cavitation can cause damage to the dredge plant or pipeline. It is caused when the pressure in the pipeline or pump is lowered to a level equal to the vapor pressure of the carrier fluid. When the pressure reaches the vapor pressure regions of vapor form in the dredge slurry. When these regions collapse severe damage to the pipeline walls, pump shell, or impeller may occur. Net positive suction head (NPSH) is the head available to the pump above the vapor pressure (Herbich, 1992).

If the required net positive suction head (NPSH) is greater than the available NPSH cavitation occurs. The required NPSH is taken from the pump curve for the first pump in the system. The required NPSH is a function of flowrate and impeller speed. As the flowrate and impeller speed increase so does the required NPSH. The available NPSH is determined using an equation that is a result of the manipulation of the Bernoulli equation,

$$Available\ NPSH = \frac{P_a}{\gamma_m} - \frac{P_v}{\gamma_m} + \frac{d}{S_m} - z_2 - h_l \qquad (15)$$

where P_a is atmospheric pressure, γ_m is the specific weight of the slurry, P_v is the vapor pressure of the carrier fluid, d is the digging depth, S_m is the specific gravity of the dredge slurry, z_2 is the digging depth minus the pump depth measured at the centerline, and h_l is the head loss on the suction side of the pump. The head loss on the suction side of the pump is determined by adding the suction side minor losses to the suction side friction losses.

When the system is configured such that the intersection of the system loss curve and the total head curves occurs at a flowrate greater than the critical flowrate and no cavitation occurs, the production is calculated. The flowrate taken from the plot coincides with the maximum production rate the system can support. This flowrate along with the concentration is used in the following equation to compute the production rate

$$P = Q * AC_V * 0.297 \qquad (16)$$

where P is the production rate in cubic yards per hour, Q is the flowrate in GPM, AC_V is the average concentration by volume of solids, and 0.297 is a conversion factor. However, this production rate must be adjusted in order to more closely reflect rates that can be attained on site. The production rate is adjusted downward for the following reasons.

In most cases cutter dredges are unable to constantly keep the cutterhead in a location that will make sufficient material available to sustain the maximum production rate. During these times, the concentration of solids in the slurry decreases lowering the production. In order to adjust the production rate for losses due to swinging and advancing, a dredge cycle efficiency is multiplied against the maximum production rate. Typical values for the dredge cycle efficiency can range from 75-80% for carriage spud configurations, 50-60% for fixed spuds, and 70-80% when a christmas tree is used. These values can be used as a guideline for selecting the cycle efficiency but there is no substitution for actual field data regarding cycle efficiency.

The production rate is used in conjunction with the daily running time of the equipment to calculate the daily production rate. The daily run time is sum of the down time delays subtracted from the total number of hours in the daily work cycle (24 except for the beginning and end of a project). Common delays encountered by cutter dredges are shifting anchors, adding/removing pipeline, advancing/resetting the carriage, cleaning trash from the pumps, repairs, traffic, and weather delays. The expected delays are entered by the user and are used to develop the daily run time. The calculation of the daily production rate (1150 to 2700 m^3/hr, 1500 to 3500 yd^3/hr) concludes the production rate estimate for the cutter dredge.

Hopper Dredge *Production*

Minor losses and the losses due to friction are calculated for hopper dredges in the same fashion as for cutter dredges. Production calculations are different for hopper dredges than for cutter dredges from the production rate forward. When the production rate for the hopper dredge is calculated the character of the material is considered when estimating the amount of time it takes to fill the hopper to capacity. If the material is silt or mud, or the contract specifies zero overflow, the time to fill the hopper is calculated by dividing the volumetric flowrate by the hopper capacity. The reason for not overflowing the hopper when pumping silt or mud was previously discussed. If the character of the material is sand, gravel, or clay, a different approach is taken when calculating the time to fill the hopper. Once the hopper is initially filled, excess water may overflow allowing an additional amount of slurry into the hopper. The hopper is continually filled until the maximum load is attained. The time to fill the hopper also depends on the turning time at the dredging site. When the hopper dredge moves along the entire length of the project it must turn around in order to continue dredging or travel to the disposal area. Time is also expended turning at the disposal site. The turning time at the disposal site and the dredging area is determined by the user and entered into the program. The sail time is the time it takes for the dredge to travel to the disposal site after the last amount of material has been deposited in the hopper. This time is calculated using the average distance to the disposal area divided by the sailing speed of the dredge. The time to fill the hopper, turning time, and sailing time are used in order to find the number of dredging cycles per day the hopper dredge can perform. When the number of cycles per day is multiplied with the average load in the hopper, the daily production rate is known. The average load in the hopper is determined based on the type of material pumped into the hopper. If the material is silt or mud the volume of material in the hopper for each cycle is determined by multiplying the total capacity of the hopper by the average concentration of the slurry. If the material is not silt or mud, the volume of material in the hopper for each cycle is determined by multiplying the capacity of the hopper by a factor determined by the user (85% is a common value). This factor is based on the fact that if material with high specific gravity is being removed, the dredge may reach its maximum allowable draft before the hopper is completely full. The daily production of the hopper dredge is determined by multiplying the number of dredging cycles per day by the volume per cycle.

DEVELOPMENT OF THE COST ESTIMATE

The development of a cost estimate is based on the production capabilities of either a cutter or hopper dredge. The hourly production rate for cutter dredges and the cycle capacity for hopper dredges is the basis for the daily production capability. The required volume for a particular project is adjusted by an overdredging factor to reflect the gross volume that is to be removed to complete the project. The gross volume estimate is divided by the daily production rate in order to describe the total number of days for completion of the project. For the cutter dredge the daily production rate is the hourly production times the estimated daily run time. The daily production rate for a hopper dredge is the cycle volume times the number of cycles per day. Lost time for hopper dredges is summed and added to the total number of days to complete the job. Lost hours are included in the cutter project duration. When the length of time to complete the job in days is known the cost of the job begins to take form. The total cost is comprised of fuel and lubricant, repair and maintenance, pipeline wear, capital depreciation, insurance, labor, equipment rental, mobilization and demobilization, special items, and bonding costs.

Fuel and Lubricants

The cost of fuel can approach 30% of the total cost of a dredging project. Fuel usage is directly tied to the pipeline length of the job for cutter dredges and the sailing distance for hopper dredges. Fuel costs cover all of the costs associated with the dredge engines, house power on the dredge (lighting, outlets, etc.), attendant plant fuel, and lubricants associated with their use. The daily usage of fuel for house power and attendant plant are entered directly in gallons and multiplied by the cost per gallon for the fuel. The dredge engine fuel costs are calculated on a cost per unit horsepower per hour of use basis. According to Bray et al. (1997) a reasonable assumption for fuel usage is 0.05 gallons per horsepower per hour. The total horsepower for the installed dredge engines is taken from the pump selection sheet in the program and multiplied by the production hours for the cutter dredge. For hopper dredges the horsepower is multiplied by the dredge time per cycle times the cycles per day times the production days. For both cutter and hopper dredges the number of horsepower-hours is multiplied by the fuel usage value. Additionally the fuel used for the propulsion plant for hopper dredges is included. The daily fuel usage for the propulsion engines is listed as a variable for the user to enter. The fuel usage per horsepower per hour is fully adjustable to reflect variances in fuel costs. Lubricant costs are assumed to cost ten percent of the fuel costs (Bray et al., 1997)

Repairs and Maintenance

The cost of repairs and maintenance generally accounts for 20% of the total job costs. Regular maintenance includes painting, cleaning, oiling and greasing, and routine upkeep of the dredge plant. Repair costs cover the costs associated with replacing worn or damaged equipment on the dredge. According to Bray et al. (1997) the costs associated with repair and maintenance can be approximated by multiplying the capital cost of the dredge plant by 0.00044 for cutter dredges and 0.00041 for hopper dredges. The capital cost of a cutter dredge can be approximated by multiplying the pipeline diameter (in millimeters) by 26,500 and subtracting $9,000,000 (if using inches multiply by 673,100 and subtract $9 million). The capital cost of a hopper dredge can be approximated by multiplying the hopper capacity (in metric tons) by 2,500 and adding $5,000,000 (if using short tons multiply by 5,512.5 and subtract $5 million).

Pipeline Wear

Wear is a natural consequence of transporting a slurry though a pipeline. The cost of wear is associated to the loss of wall thickness due to slurry transport. Because of wear, the pipeline cost must be depreciated over its useful life. The units for wear are commonly expressed as millimeters (inches) of wear per million cubic yards (meters) pumped. A common value for maintenance work is 0.8 mm (0.03 inches) per million cubic yards dredged. In order to attach a cost to pipeline wear the user enters the cost of new pipe per foot and the available wall thickness. The available wall thickness is generally 6 millimeters (0.23 inches) for schedule 20 pipe. The relationship between slurry transport and pipeline wear costs is as follows,

$$\frac{\text{expected wear}}{\text{available wall thickness}} * \frac{\text{cost (dollars)}}{\text{unit length of pipe}} = \text{pipeline wear cost} \qquad (17)$$

By dividing the expected wear by the available wall thickness and multiplying by the cost per foot times the length of pipe used, a pipeline wear cost is developed.

Depreciation

The dredge plant is depreciated on the basis of straight line depreciation over a period specified by the user. The depreciation realized during the project is based on the expected yearly occupancy time for the dredge and not on 365 days. The depreciation is calculated by dividing the capital cost of the dredge by the multiplication of the depreciation period by the expected days of occupancy per year. This figure is then multiplied by the days on the job for the dredge and results in the total cost of depreciation for the project duration.

Insurance

Insurance costs are entered by the user as a cost per year for the dredge and attendant plant. This cost is divided by the expected occupancy for the dredge and multiplied by the expected project duration. Typical values for insurance costs can vary from 2% - 4% of the capital cost of the dredge depending on work and safety records.

Labor

Due to the highly variable cost of labor around the country, the labor costs are determined from user input. There is a sheet for labor costs for both the cutter and hopper dredge spreadsheets. The sheet contains a breakdown of the most common positions that are required for a dredging project. The user can enter the daily rate and number of employees at each position. A fringe rate of 30% is the default value in the spreadsheet to cover the employer social security contribution, and health care. Included in the labor sheet is the weekly cost for food for the dredge crew.

Rentals

In the dredging community, some equipment is best left to other companies to supply. These types of equipment include marsh buggies, bulldozers, and crew boats. Other common rental items are field office space, portable self-contained lighting units, barges, and tugboats. There is room to enter day rates for all of these items. The cost for earthmoving equipment and crewboats are entered as the cost of rental plus operators and fuel.

Mobilization and Demobilization

In the dredging industry mobilization and demobilization costs are a highly variable cost from job to job. The cost to move equipment to a new location varies with distance, time of year, type of contract, and whether or not the route includes traveling on the open ocean. The issue is made more difficult by the practice of rolling the demobilization costs into the mobilization cost of a subsequent contract. In light of the complexity of the issue, this cost is left to the user to enter based on knowledge gained in practice. There is an entry for the mobilization and demobilization costs in the input portion of both the cutter and hopper programs.

Special Items

Special items refer to extra costs as a result of contract specifications. In certain cases a contract may specify that the contractor provide the client with items such as an office, office equipment, dedicated transportation to and from the dredge in the form of an extra crewboat, and in some cases ground transportation. In addition to items provided to the client the specifications may mandate certain environmental testing or remediation. Environmental costs that are commonly incurred during dredging projects include turbidity monitoring, sea turtle monitoring (for both cutter and hopper projects), whale monitoring, sea grass monitoring, and bird monitoring. These types of monitoring and testing can be quite costly and require the user to request cost estimates from licensed and insured environmental monitoring or testing companies.

Bonding

Bonding is an assurance made to the client that the work will be completed. If a contractor defaults on the project, the value of the performance bond is guaranteed to the client. The total value of the performance bond must be equal to the total price bid on the project. Bonding costs usually vary from 1.0% to 1.5% of the bid price. The bonding costs are associated with the contractors bond rating and project completion history. In the cutter and hopper programs the bonding costs are entered as a percentage and are the final calculation leading to the total job cost.

Final Project Cost

The final cost of the project is assembled using all of the previously listed items. The final cost is what the contractor expects to spend in order to complete the project. This cost does not reflect any profit that may be realized as a result of the project. The margin, or the income that the contractor wishes to achieve on the contract is based on many factors. These factors include the competitors equipment utilization, the contractors pending and current work, upcoming contracts, and the state of the dredging market at the time of the project.

USING THE COST ESTIMATING PROGRAM

The cost estimating program is comprised of a set of Microsoft Excel spreadsheets. The sheets that control the cutter and hopper dredge estimates are connected via local hyperlinks to an opening page that allows the user to choose the type of dredge that will be used for a specific project. The links automatically adjust when the program is transferred from the installation floppy disk to the users hard drive. The structure of both the cutter and hopper dredge cost estimating pages have been created to be similar in structure. Table 2 shows the navigation box from the cost estimating spreadsheet for cutter dredges.

Table 2. Structure of Cost Estimating Program

DATA ENTRY	**Cutter Dredge Cost Estimator**
Pump Selection	
Cutter Calculations	
Delay Entry	Return to Opening Sheet
Rentals	
Crew	
Cost Summary	

Navigating through each of the spreadsheets is accomplished by clicking on the name of the desired sheet in the navigation box. Links to the opening sheet exist only in the data entry sheets. To begin the cost estimating process the user begins at the data entry page.

Data Entry

The data entry sheet for cutter dredges (Table 3) is where the user specifies the conditions of the project. For cutter dredges the user begins with entering the type of advancing mechanism the dredge will employs, whether it has a carriage spud, fixed spuds, or a christmas tree. Other questions particular to a cutter dredge such as average pipeline length, number of ball joints, and number of scope connections are listed in the sheet for the users attention. The data entry page for the hopper dredge program (Table 4) is similar to the corresponding sheet in the cutter estimating program. The hopper data entry sheet begins with an entry for the hopper capacity. Entries for the number of drag arms used, average sailing distance to the disposal area, and fuel usage for propulsion and house power are also listed for the user to define. After the data entry sheet is completed the user moves to the pump selection page.

Table 3. Data Entry Sheet for Cutter Dredge Program

Input	Description
1	Carriage Spud (1), Fixed Spud (2), Christmas Tree (3)
42	Dredging Depth (ft)
28	Depth of U/W Pump Centerline (If U/W Pump not used enter 0)
1	Elevation of First Pump if no U/W pump used (ft)
15	Suction Pipe Length (ft)
10000	Average Length of Discharge Pipeline (ft)
10	Elevation of Discharge (ft)
B	Would you like to enter Equivalent Loss (E) or a Breakdown of Minor Losses (B)?
4	Number of 90 Degree Elbows
2	Number of Swivel Elbows
22	Ball joints
50	Scope connections
0	Unused Pumps (Used only if a pump is intentionally left unpowered)
1	Entrance Loss value
0	Equivalent System Loss (Enter only if a Breakdown is not used)
30	Suction Pipeline ID (Inches)
30	Discharge Pipeline ID (Inches)
0.00015	Roughness of Pipeline(ft) (Common Value 0.00015)
0.4	d50 of material (mm)
1.3	Average Specific Gravity of Slurry
2.65	Specific Gravity of Solids
s	Fresh or Seawater ("f" , "s")
0.050	Hourly Fuel usage per Utilized Horsepower for Dredge Engines (Gallons)
150	Daily fuel usage for House Power (Gallons)
$ 0.60	Cost per Gallon for Fuel (Dollars)
210	Attendant Plant Fuel Usage (Gallons)
$ 1,364,000	Annual Cost of Repairs and Maintenance (Dollars)
310	Yearly Dredge Utilization (Days)
6,000,000	Required Dredging Volume (yd^3)
4.0	Expected Overdredging (Percent)
$ 10,000,000	Capital Cost of Dredge (Dollars)
30	Depreciation Period (Years)
$ 750,000	Mobilization and Demobilization Costs (Dollars)
$ 500,000	Yearly Insurance Costs (Dollars)
1.5	Bonding Rate (Percent)
$ -	Special Contract Costs (Dollars)

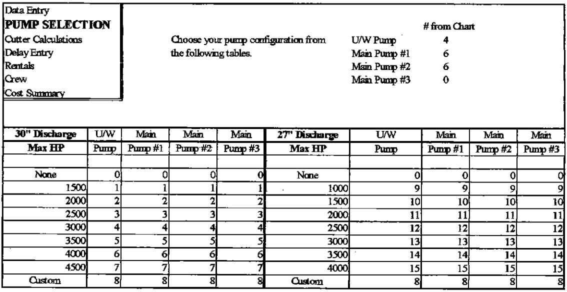
Table 4. Data Entry Sheet for Hopper Dredge Program

Input	Description
6000	Hopper Capacity (yd^3)
2	Enter 1 for material that will settle in the Hopper 2 for materials that will not
2	Number of Drag Arms Used
6.5	Sailing Speed (Knots)
15	Average Sailing Distance to Disposal Area (Nautical Miles)
42	Dredging Depth (ft)
27	Depth of U/W Pump Centerline (If U/W Pump not used enter 0)
0	Elevation of First Pump if no U/W pump used
15	Suction Pipe Length (ft)
110	Length of Discharge Pipeline (ft)
10	Elevation of Discharge (ft)
8	Suction Side Losses
20	Discharge Side Losses
30	Suction Pipeline ID (Inches)
30	Discharge Pipeline ID (Inches)
0.00015	Roughness of Pipeline(ft) (Common Value .00015)
0.065	d50 of material (mm)
1.6	Average Specific Gravity of Slurry
2.65	Specific Gravity of Solids
s	Fresh or Seawater ("f" , "s")
0.050	Hourly Fuel usage per Utilized Horsepower for Dredge Engines (Gallons)
6,000	Daily fuel usage for Propulsion and House Power (Gallons)
$ 0.62	Cost per Gallon for Fuel (Dollars)
210	Attendant Plant Fuel Usage (Gallons)
$ 1,332,500	Annual Cost of Repairs and Maintenance (Dollars)
325	Yearly Dredge Utilization (Days)
1,000,000	Required Dredging Volume (yd^3)
5.0	Expected Overdredging (Percent)
$10,000,000	Capital Cost of Dredge (Dollars)
30	Depreciation Period (Years)
$ 300,000	Mobilization and Demobilization Costs (Dollars)
$ 500,000	Yearly Insurance Costs (Dollars)
1.5	Bonding Rate (Percent) (Common Value 1.0-1.5)
$ -	Special Contract Costs (Dollars)

Pump Selection

On the pump selection page the user completes a few lines pertaining to pump selection. The choices allow the user to enter the installed horsepower for an underwater pump and three main pumps. There are tables for both 30 inch and 27 inch dredges. For cutter dredges the three main pumps could signify two hull pumps and one booster pump. Table 5 illustrates the pump selection sheet. If the pumping system does not contain a booster, a second main pump, or an underwater pump, then zeros are entered in the appropriate areas to signify that the pump does not exist. If the user finds that the configuration for their application is not listed then a space for a custom entry is provided to enter the horsepower and head at given flowrates. With the initial data entry

Table 5. Dredge Pump Configuration Selection Sheet



Data Entry
PUMP SELECTION
Cutter Calculations
Delay Entry
Rentals
Crew
Cost Summary

Choose your pump configuration from the following tables.

	# from Chart
U/W Pump	4
Main Pump #1	6
Main Pump #2	6
Main Pump #3	0

30" Discharge	U/W	Main	Main	Main	**27" Discharge**	U/W	Main	Main	Main
Max HP	Pump	Pump #1	Pump #2	Pump #3	**Max HP**	Pump	Pump #1	Pump #2	Pump #3
None	0	0	0	0	None	0	0	0	0
1500	1	1	1	1	1000	9	9	9	9
2000	2	2	2	2	1500	10	10	10	10
2500	3	3	3	3	2000	11	11	11	11
3000	4	4	4	4	2500	12	12	12	12
3500	5	5	5	5	3000	13	13	13	13
4000	6	6	6	6	3500	14	14	14	14
4500	7	7	7	7	4000	15	15	15	15
Custom	8	8	8	8	Custom	8	8	8	8

and pump selection completed the user proceeds to the calculations section of the program.

Cutter and Hopper Calculations

All of the production calculations for the cutter and hopper sheets are performed on the calculations sheet. The information from the data entry and pump selection pages are brought together to calculate the maximum flowrate at a user specified slurry specific gravity. The user must view the loss plot (Figure 9) in order to determine where the operating point for their configuration falls. The operating point is read from the plot and entered into

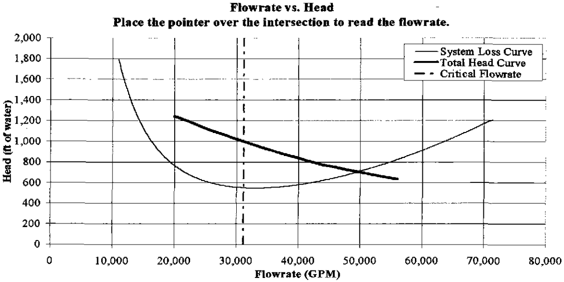
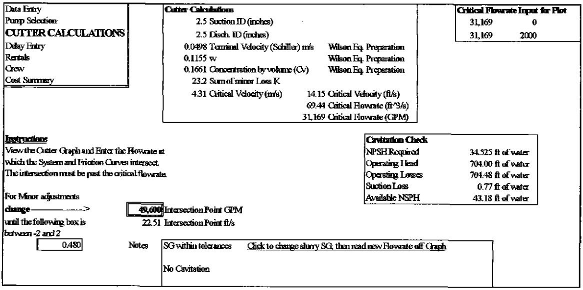


Figure 9. Using System Loss and Total Head Curves for Production Estimate

the cutter calculations page as a flowrate. When the pointer is placed over the intersection of the system loss curve and the total head curve, the program automatically reveals the coordinates of that point. The user reads the flowrate from the intersection and enters it on the calculations page. There is a specific place on the calculations page for the operating flowrate. When the flowrate is entered the user may fine tune the flowrate until the sheet indicates that the value is close enough to actual to begin cost estimating. Table 6 shows the calculations page with the operating flowrate entry.

Table 6. Production Calculation and Cavitation Check



Data Entry
Pump Selection
CUTTER CALCULATIONS
Delay Entry
Rentals
Crew
Cost Summary

Cutter Calculations

2.5	Suction ID (inches)		
2.5	Disch. ID (inches)		
0.0498	Terminal Velocity (Schiller) m/s		Wilson Eq. Preparation
0.1155	w		Wilson Eq. Preparation
0.1661	Concentration by volume (Cv)		Wilson Eq. Preperation
23.2	Sum of minor Loss K		
4.31	Critical Velocity (m/s)	14.15	Critical Velocity (ft/s)
		69.44	Critical Flowrate (ft^S/s)
		31,169	Critical Flowrate (GPM)

Critical Flowrate Input for Plot

31,169	0
31,169	2000

Instructions
View the Cutter Graph and Enter the Flowrate at which the System and Friction Curves intersect.
The intersection must be past the critical flowrate.

For Minor adjustments
change ——————>
until the following box is
between -2 and 2

49,600	Intersection Point GPM
22.51	Intersection Point ft/s

0.480

Cavitation Check

NPSH Required	34.525 ft of water
Operating Head	704.00 ft of water
Operating Losses	704.48 ft of water
Suction Loss	0.77 ft of water
Available NSPH	43.18 ft of water

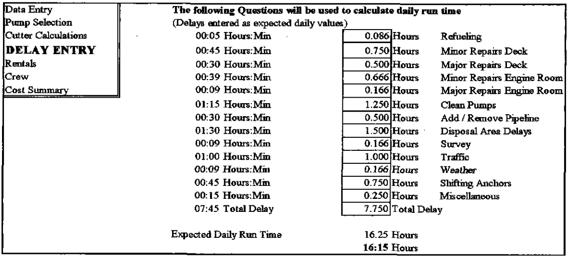
Notes
SG within tolerances
Click to change slurry SG, then read new Flowrate off Graph
No Cavitation

To the left of the entry for the operating flowrate is a set of instructions that allow the user to fine tune the flowrate. At the bottom center of the page is a box that alerts the user if cavitation occurs. If cavitation does occur the user must either decrease the flowrate or the slurry specific gravity. The operating point on the loss plot shows the maximum operating point. If the user decides that it would be in the best interest to operate at a lower flowrate, a value less than the maximum but greater then the critical flowrate may be chosen. The next step in the process is to enter the expected delays into the program.

Delay Entry

The delays entered for the cutter and hopper sections of the program are differentiated by the types of delays that are represented in the sheet. For the cutter program the daily *run time calculated* using the delays is applied directly to the production rate to find the daily production rate. For the hopper program the delays are summed and used to determine the total amount of delays for the entire job. These delays are added to the number of days required to complete the job. Table 7 shows the delay entry page for the cutter sheet.

Table 7. Delay Entry and Summary Sheet



Data Entry	**The following Questions will be used to calculate daily run time**		
Pump Selection	(Delays entered as expected daily values)		
Cutter Calculations	00:05 Hours:Min	0.086 Hours	Refueling
DELAY ENTRY	00:45 Hours:Min	0.750 Hours	Minor Repairs Deck
Rentals	00:30 Hours:Min	0.500 Hours	Major Repairs Deck
Crew	00:39 Hours:Min	0.666 Hours	Minor Repairs Engine Room
Cost Summary	00:09 Hours:Min	0.166 Hours	Major Repairs Engine Room
	01:15 Hours:Min	1.250 Hours	Clean Pumps
	00:30 Hours:Min	0.500 Hours	Add / Remove Pipeline
	01:30 Hours:Min	1.500 Hours	Disposal Area Delays
	00:09 Hours:Min	0.166 Hours	Survey
	01:00 Hours:Min	1.000 Hours	Traffic
	00:09 Hours:Min	*0.166 Hours*	Weather
	00:45 Hours:Min	0.750 Hours	Shifting Anchors
	00:15 Hours:Min	0.250 Hours	Miscellaneous
	07:45 Total Delay	7.750 Total Delay	
	Expected Daily Run Time	16.25 Hours **16:15** Hours	

The delays are entered in the center column of the list as time in decimal hours. There is a column to the left of center that allows the user to check the entered times as hours and minutes. The total delays are shown on the last line of the list and the expected daily run time is shown at the bottom of the page in both decimal and hours and minutes.

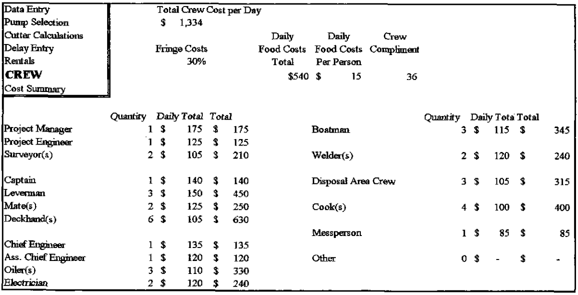
Rentals

The rentals section of the program lists common rental items for both cutter and hopper dredging projects. The rental rates are entered as day rates and should include the cost for operators for earthwork machinery or crewboats. The typical cost for renting a crewboat with an operator and including fuel is $750 to $1,100 per day.

Crew

Crew costs are entered on the basis of daily rate. The sheets for cutter and hopper dredges list the positions common to either type of operation and have space for the user to enter a custom position. The user can adjust the number of positions used and the day rate for each position. The sheet also contains entries for the fringe costs as a percentage of salary and the daily food costs per person of the crew. The daily food cost per person is multiplied by the crew compliment to determine the daily food cost for the entire operation. Table 8 shows the crew wages sheet for the cutter program.

Table 8. Crew Wages, Fringe Rates, and Food Rates



Data Entry
Pump Selection
Cutter Calculations
Delay Entry
Rentals
CREW
Cost Summary

Total Crew Cost per Day
$ 1,334

Fringe Costs
30%

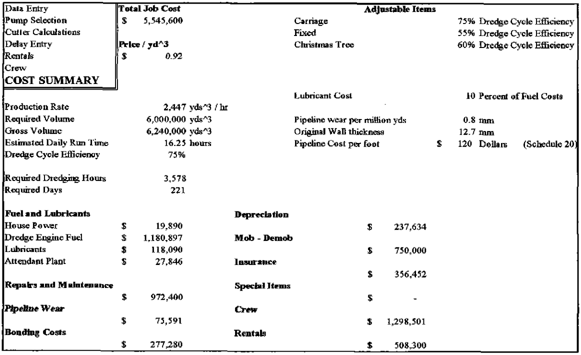
Daily Food Costs Total	Daily Food Costs Per Person	Crew Compliment
$540	$ 15	36

	Quantity	Daily Total	Total		Quantity	Daily Tota	Total
Project Manager	1	$ 175	$ 175	Boatman	3	$ 115	$ 345
Project Engineer	1	$ 125	$ 125				
Surveyor(s)	2	$ 105	$ 210	Welder(s)	2	$ 120	$ 240
Captain	1	$ 140	$ 140	Disposal Area Crew	3	$ 105	$ 315
Leverman	3	$ 150	$ 450				
Mate(s)	2	$ 125	$ 250	Cook(s)	4	$ 100	$ 400
Deckhand(s)	6	$ 105	$ 630				
				Messperson	1	$ 85	$ 85
Chief Engineer	1	$ 135	$ 135				
Ass. Chief Engineer	1	$ 120	$ 120	Other	0	$ -	$ -
Oiler(s)	3	$ 110	$ 330				
Electrician	2	$ 120	$ 240				

Cost Summary

The cutter and hopper dredge estimating programs both contain cost summary sheets. This sheet is where all of the costs associated with the job are listed together and totaled into a job cost estimate. All of the costs are tabulated on this page for review and a unit cost per yard is listed. Adjustments for the dredge cycle efficiency and pipeline wear are available for the user to make final adjustment to the estimating process. Information on the wear rate, the available wall thickness, and the cost per foot for the pipeline are located on this page and can be adjusted by the user. At this point the user should review all of the cost categories and input parameters before finalization of the estimating process. Table 9 represents a sample of the final cost estimate sheet.

Table 9. Final Cost Estimate Summary



Data Entry	**Total Job Cost**						**Adjustable Items**				
Pump Selection	$	5,545,600			Carriage				75%	Dredge Cycle Efficiency	
Cutter Calculations					Fixed				55%	Dredge Cycle Efficiency	
Delay Entry	**Price / yd^3**				Christmas Tree				60%	Dredge Cycle Efficiency	
Rentals	$	0.92									
Crew											
COST SUMMARY											
					Lubricant Cost				10	Percent of Fuel Costs	
Production Rate		2,447	yds^3 / hr								
Required Volume		6,000,000	yds^3		Pipeline wear per million yds				0.8	mm	
Gross Volume		6,240,000	yds^3		Original Wall thickness				12.7	mm	
Estimated Daily Run Time		16.25	hours		Pipeline Cost per foot			$	120	Dollars	(Schedule 20)
Dredge Cycle Efficiency		75%									
Required Dredging Hours		3,578									
Required Days		221									
Fuel and Lubricants				**Depreciation**							
House Power	$	19,890				$	237,634				
Dredge Engine Fuel	$	1,180,897		**Mob - Demob**							
Lubricants	$	118,090				$	750,000				
Attendant Plant	$	27,846		**Insurance**							
						$	356,452				
Repairs and Maintenance				**Special Items**							
	$	972,400				$	-				
Pipeline Wear				**Crew**							
	$	75,591				$	1,298,501				
Bonding Costs				**Rentals**							
	$	277,280				$	508,300				

PROGRAM TESTING

In order to test the accuracy of the cutter and hopper dredge cost estimating programs a number of comparisons were made with actual dredging projects. Two hopper dredging projects and eight cutter dredge projects, completed between 1998 and early 2000 were used to put the results the programs to the test. The results were compared to both the government estimate and the winning bid for each project. The cost data were collected from the U.S. Army Corps of Engineers Navigation Data Center webpage (www.wrsc.usace.army.mil/ndc). The Dredging Statistics program collects data pertaining to dredging costs and provides contract award summaries and yearly dredging cost information.

Comparison of Actual Costs with Government and Program Estimates

The comparison between the output of the program, the winning bids and the government estimates for the projects provided exciting insight into the utility of the program. The objective of the comparison was to provide information concerning the performance of the program using real world data. Table 10 describes the costs, magnitude, and type of equipment utilized on the jobs that were used to perform the comparison. A listing of all the input parameters for all of the test cases is available in the Appendix. The output from the program was increased by ten percent to reflect the margin that the bidding companies would have included in their bids. The comparison shows that the estimating program produces costs that average within twenty percent of the government estimate and the winning bids for the ten projects selected.

Table 10. Projects Used to Compare Cost Estimates from Program

Project Number	Name	Dredge Type	Total Volume (million yd^3 / million m^3)	Government Estimate (U.S. Dollars)	Winning Bid (U.S. Dollars)	Program Output (Including 10% Margin) (U.S. Dollars)
1	Mobile Harbor	Hopper	1.00 / 0.76	2,633,971	2,784,351	2,853,234
2	Savannah & Brunswick	Hopper	2.00 / 1.53	4,198,960	4,732,000	2,972,075
3	MRGO 8-12	Cutter	1.60 / 1.22	2,082,000	1,635,000	1,662,672
4	Port Mansfield	Cutter	0.30 / 0.23	1,046,496	1,279,200	921,766
5	Tiger Pass	Cutter	1.00 / 0.76	3,536,200	2,753,000	2,020,244
6	Baptiste Collette	Cutter	0.90 / 0.69	1,604,700	1,332,850	1,610,868
7	Calcasieu River	Cutter	3.50 / 2.68	4,592,100	4,490,000	4,081,438
8	MRGO 4-8	Cutter	1.50 / 1.15	1,690,000	1,382,500	1,377,489
9	Theodore Ship Channel	Cutter	1.00 / 0.76	1,446,303	1,346,050	1,249,232
10	MRGO 23-27	Cutter	1.40 / 1.07	1,628,200	1,084,000	1,516,086

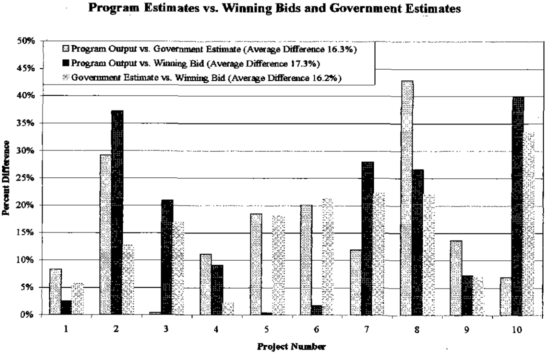


Figure 10. Comparison of Estimated Cost, Government Estimate, and Actual Costs

The program output differed from the government estimate an average of 16.3% while the difference to the winning bids was 17.3%. The average difference between the government estimates and the winning bids for the same data set was 16.2%. The estimating program detailed in this report showed an average difference of only 1.1% from the government estimate for the test projects. Figure 10 shows a plot that compares the program results versus the government estimates and the winning bids.

The individual estimates calculated using the program varied between 0.4% to 42.9% from the government estimate and 0.4% to 39.9% from the winning bids. The government estimate varied between 2.2% and 33.4% when compared to the winning bids. The estimates calculated using the program were less than 10% from the winning bid for jobs 1,4,5,6 and 9. Table 11 lists the differences in the estimates for all of the projects tested.

Table 11. Percent Difference Between Estimated and Actual Costs

Project Number	Name	Percent Difference Gov. to Program	Percent Difference Winner to Program	Percent Difference Gov. to Winner
1	Mobile Harbor	8.3%	2.5%	5.7%
2	Savannah & Brunswick	29.2%	37.2%	12.7%
3	MRGO 8-12	0.4%	20.9%	16.9%
4	Port Mansfield	11.1%	9.1%	2.2%
5	Tiger Pass	18.5%	0.4%	18.2%
6	Baptiste Collette	20.1%	1.7%	21.5%
7	Calcasieau River	11.9%	27.9%	22.2%
8	MRGO 4-8	42.9%	26.6%	22.1%
9	Theodore Ship Channel	13.6%	7.2%	6.9%
10	MRGO 23-27	6.9%	39.9%	33.4%

The cause of the differences between the program output and the winning bids is most likely attributable to mobilization and demobilization costs. All efforts were made to calculate reasonable figures for these costs that would be applicable to most major dredging companies. Differences between the estimated and actual costs could also be a factor of special conditions particular to the projects, particularly numbers two and eight. Differences between the estimated cost and actual cost for project number two can be attributed to the fact that it was comprised of two separate channels located seventy five miles apart. The dredge and all of its support equipment would have been moved between the channels increasing the length and cost of the project . Project number eight was performed by a contractor that performed subsequent work in the same channel. The contractor may have planned on the occurrence of this situation and spread the mobilization and demobilization costs across the two projects.

Sensitivity Analysis

In order to determine which factors in the estimating process contribute to the greatest changes in the cost of a project, a sensitivity analysis was performed for both the cutter and hopper programs. In order to determine the variables that have the greatest influence on the output, a test case for both the hopper and cutter programs was developed. The inputs that were held constant for the cutter sensitivity analysis were the volume at 764,439 cubic meters (1,000,000 cubic yards), the pipeline length at 1,524 meters (5,000 feet), the grain size at 0.4 millimeters, the specific gravity of the slurry at 1.4, the digging depth at 12.8 meters (42 feet), and the engine configuration was 2,000 horsepower on the underwater pump and 3,000 horsepower on the number one and two main pumps. For the hopper dredge sensitivity analysis the hopper capacity was 4,587 cubic meters (6,000 cubic yards), the digging depth was 12.8 meters (42 feet), and the engine configuration was 1,500 horsepower on the underwater pump and 3,000 horsepower on the main pump. Table 12 shows the data that were held constant and the inputs that were varied.

In order to present the data from the sensitivity analysis, Figures 11 and 12 show the results as percent difference from the baseline on the abscissa and percent change in cost on the ordinate. For the cutter program the baseline for cycle efficiency, fuel costs, and mobilization and demobilization are 50%, $0.50, and $200,000 respectively. For the hopper program the baseline for sailing distance, sailing speed, fuel costs, and mobilization and demobilization are 2 nautical miles, 4 knots, $0.50, and $200,000 respectively. Figure 11 shows that the changes in the cycle efficiency change the total cost of the cutter project the most. It seems that the strongest influence on the price of a cutter job falls into the area that the contractor can control. The cycle efficiency can be increased by thoroughly planning the cutter dredge's digging pattern and by operator education. Changes to the cost of mobilization and demobilization have the least effect on the cutter project costs because any change in this cost affects the total cost on a one to one basis. The fuel costs of the cutter project increase linearly with an increase in the unit cost of fuel but aside from hedging the cost of fuel little can be done to effect this aspect of project costs.

The sensitivity analysis of the hopper dredge program (Figure 12) shows that the sailing distance has the greatest effect on the cost of a project. As with fuel there is not much the contractor can do to control this aspect of the project cost. As with the fuel costs in the cutter dredge analysis this cost cannot be controlled by the contractor for hopper dredges either. The mobilization and demobilization costs follow the same trend for the hopper dredge as with the cutter dredge. The sailing speed of the hopper dredge is the only parameter taken into account that can be affected by the contractor. Unfortunately the sailing speed is more a function of decisions made when designing the hopper dredge then what the contractor does during a project. The sailing speed of a hopper dredge should be maximized at all times by proper maintenance and repair of the hull and propulsion plant. As a result of the sensitivity analysis it is clear that the dredging contractor has some degree of control of the costs of a project utilizing a hopper dredge and a high level of control when using a cutter dredge. All efforts should be made to educate the cutter dredge operator in the area of dredge cycle efficiency and its effect on project cost.

Table 12. Sensitivity Analysis Parameters

Cutter Dredge		**Hopper Dredge**	
Constant	**Variable**	**Constant**	**Variable**
Project Volume	Cycle Efficiency	Project Volume	Sailing Distance
Pipeline Length	Fuel Costs	Hopper Capacity	Sailing Speed
Grain Size	Mob. & Demob.	Grain Size	Fuel Costs
Specific Gravity of Slurry		Specific Gravity of Slurry	Mob. & Demob.
Digging Depth		Digging Depth	
Pump Configuration		Pump Configuration	

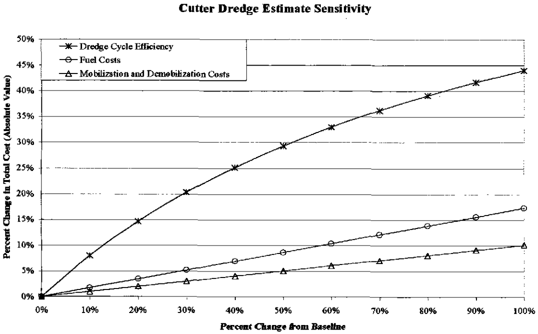


Figure 11. Cutter Dredge Estimate Sensitivity

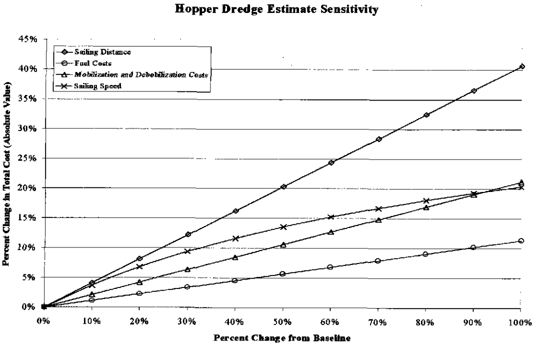


Figure 12. Hopper Dredge Estimate Sensitivity

CONCLUSIONS

The objective of this thesis was to develop and test a program to estimate the costs of both cutter and hopper dredge projects. Two programs were developed in order to accomplish this objective, one for both cutter and hopper dredges. The programs are essentially based on a maximum production rate estimate that is determined using input data. The Wilson et al. (1997) equation is used to determine the system friction losses in the dredge pipeline. System losses are compared to the total available head curve to determine the production rate. With the exception of the mobilization and demobilization costs, all other factors that contribute to the cost of the project are based on the production estimate.

When the output costs from the program were compared to actual cost data for real world projects the results were found to be quite acceptable. The programs estimated the costs of ten dredging projects within an average of 17.3% while the government estimate averaged 16.3%. Using the accuracy of the government estimate as a measure of accomplishment, the program can be considered a success.

As a result of working on this thesis one point becomes clear about cutter dredges. The cost of a cutter dredge project is greatly affected by the dredge cycle efficiency. The most effective way to decrease the cost of the cutter dredge project is to increase the efficiency of the dredging cycle. Increasing the efficiency of the dredging cycle is a worthwhile endeavor and more research in this area could prove to be very rewarding.

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APPENDIX

TEST CASES AND EQUATION LIST

TEST CASE (CUTTER PROGRAM) - BAPTIST COLLETTE

Table A-1. Input Data Used to Estimate Baptiste Collette

Input	Description
1	Carriage Spud (1), Fixed Spud (2), Christmas Tree (3)
42	Dredging Depth (ft)
28	Depth of U/W Pump Centerline (If U/W Pump not used enter 0)
1	Elevation of First Pump if no U/W pump used (ft)
15	Suction Pipe Length (ft)
10000	Average Length of Discharge Pipeline (ft)
10	Elevation of Discharge (ft)
B	Would you like to enter Equivalent Loss (E) or a Breakdown of Minor Losses (B)?
4	Number of 90 Degree Elbows
2	Number of Swivel Elbows
22	Ball joints
50	Scope connections
0	Unused Pumps (Used only if a pump is intentionally left unpowered)
1	Entrance Loss value
0	Equivalent System Loss (Enter only if a Breakdown is not used)
30	Suction Pipeline ID (Inches)
30	Discharge Pipeline ID (Inches)
0.00015	Roughness of Pipeline(ft) (Common Value 0.00015)
0.4	d50 of material (mm)
1.3	Average Specific Gravity of Slurry
2.65	Specific Gravity of Solids
s	Fresh or Seawater ("f" , "s")
0.050	Hourly Fuel usage per Utilized Horsepower for Dredge Engines (Gallons)
150	Daily fuel usage for House Power (Gallons)
$ 0.60	Cost per Gallon for Fuel (Dollars)
210	Attendant Plant Fuel Usage (Gallons)
$ 1,364,000	Annual Cost of Repairs and Maintenance (Dollars)
310	Yearly Dredge Utilization (Days)
6,000,000	Required Dredging Volume (yd^3)
4.0	Expected Overdredging (Percent)
$ 10,000,000	Capital Cost of Dredge (Dollars)
30	Depreciation Period (Years)
$ 750,000	Mobilization and Demobilization Costs (Dollars)
$ 500,000	Yearly Insurance Costs (Dollars)
5.0	Bonding Rate (Percent)
$ -	Special Contract Costs (Dollars)

Table A-2. Pump Selection Used to Estimate Baptist Collette

Data Entry
PUMP SELECTION
Cutter Calculations
Delay Entry
Rentals
Crew
Cost Summary

Choose your pump configuration from the following tables.

	# from Chart
U/W Pump	2
Main Pump	4
Main Pump	4
Main Pump	0

30" Discharge	U/W Pump	Main Pump #1	Main Pump #2	Main Pump #3	**27" Discharge**	U/W Pump	Main Pump #1	Main Pump #2	Main Pump #3
Max HP					**Max HP**				
None	0	0	0	0	None	0	0	0	0
1500	1	1	1	1	1000	9	9	9	9
2000	2	2	2	2	1500	10	10	10	10
2500	3	3	3	3	2000	11	11	11	11
3000	4	4	4	4	2500	12	12	12	12
3500	5	5	5	5	3000	13	13	13	13
4000	6	6	6	6	3500	14	14	14	14
4500	7	7	7	7	4000	15	15	15	15
Custom	8	8	8	8	Custom	8	8	8	8

Table A-3. Calculations Page For Estimating Baptist Collette

Data Entry
Pump Selection
CUTTER CALCULATIONS
Delay Entry
Rentals
Crew
Cost Summary

Cutter Calculations

Value	Item	Note
2.5	Suction ID	
2.5	Disch ID	
0.0765	Terminal Velocity (Schiller) m/s	Wilson Eq. Preparation
0.1395	w	Wilson Eq. Preparation
0.2279	Concentration	Wilson Eq. Preperation
21.8	Minor Loss K	
5.68	Critical Velocity (m/s)	18.65 Critical Velocity (ft/s)
		91.55 Critical Flowrate (ft^3/s)
		41,092 Critical Flowrate (GPM)

Critical Flowrate Input for Plot	
41,092	0
41,092	2000

Instructions
View the Cutter Graph and Enter the Flowrate at which the System and Friction Curves intersect.
The intersection must be past the critical flowrate.

For Minor adjustments change ———————> 34,740 Intersection Point GPM
15.77 Intersection Point ft/s
until the box is between -2 and 2
-189.001

Cavitation Check	
NPSH Required	24.3 ft of water
Operating Head	697.30 ft of water
Operating Losses	508.30 ft of water
Suction Loss	1.03
Available NSPH	24.49

Notes
SG within tolerances   Click to change slurry SG, then read new Flowrate off Graph
Please Enter a flowrate greater than the Critical Flowrate
No Cavitation
Please Check Entered Flowrate

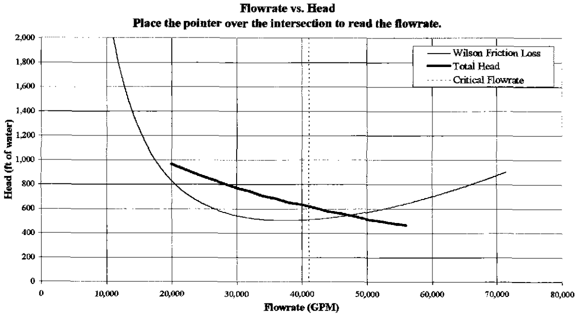

Figure A-1. Loss Plot Created While Estimating Baptist Collette

Table A-4. Delays Used to Estimate Baptist Collette

The following Questions will be used to calculate daily run time
(Delays entered as expected daily values)

00:05 Hours:Min	0.083 Hours	Refueling
00:45 Hours:Min	0.750 Hours	Minor Repairs Deck
00:30 Hours:Min	0.500 Hours	Major Repairs Deck
00:45 Hours:Min	0.750 Hours	Minor Repairs Engine Roon
00:30 Hours:Min	0.500 Hours	Major Repairs Engine Roon
01:30 Hours:Min	1.500 Hours	Clean Pumps
00:45 Hours:Min	0.750 Hours	Add / Remove Pipeline
00:30 Hours:Min	0.500 Hours	Disposal Area Delays
00:10 Hours:Min	0.167 Hours	Survey
00:45 Hours:Min	0.750 Hours	Traffic
00:15 Hours:Min	0.250 Hours	Weather
01:00 Hours:Min	1.000 Hours	Shifting Anchors
00:00 Hours:Min	0.000 Hours	Miscellaneous
07:30 Total Delay	7.500 Total Delay	

Expected Daily Run Time	16.50 Hours **16:29**

Table A-5. Rentals Used to Estimate Baptist Collette

Total Rental Price per Day
$2,800.00

All Daily Rental Prices should include fuel, and operator co

Marsh Buggy(s)	$1,300.00
CrewBoat	$1,500.00
Bulldozer(s)	$ -
Tug Boat(s)	$ -
Barge(s)	$ -
Office Space	$ -
Light Plant(s)	$ -
Other	

Table A-6. Crew, Fringe, and Food Costs Used to Estimate Baptist Collette

Data Entry
Pump Selection
Cutter Calculations
Delay Entry
Rentals
CREW
Cost Summary

Total Crew Cost per Day
$5,875.57

Fringe Costs	Weekly Food Costs
30%	$3,000.00

	Quantity	Daily Total	Total
Project Manager	1	$ 175.00	$ 175.00
Project Engineer	1	$ 125.00	$ 125.00
Surveyor(s)	2	$ 105.00	$ 210.00
Captain	1	$ 140.00	$ 140.00
Leverman	3	$ 150.00	$ 450.00
Mate(s)	2	$ 125.00	$ 250.00
Deckhand(s)	6	$ 105.00	$ 630.00
Chief Engineer	1	$ 135.00	$ 135.00
Ass. Chief Engineer	1	$ 120.00	$ 120.00
Oiler(s)	3	$ 110.00	$ 330.00
Electrician	2	$ 120.00	$ 240.00
Boatman	3	$ 115.00	$ 345.00
Welder(s)	2	$ 120.00	$ 240.00
Disposal Area Crew	3	$ 105.00	$ 315.00
Cook(s)	4	$ 100.00	$ 400.00
Messperson	1	$ 85.00	$ 85.00
Other	0	$ -	$ -

Table A-7. Cost Summary For Baptist Collette

Data Entry
Pump Selection
Cutter Calculations
Delay Entry
Rentals
Crew
COST SUMMARY

Total Job Cost
$1,464,474.02

Price / yd^3
$ 1.63

Adjustable Items	
Carriage	75% Dredge Cycle Efficiency
Fixed	55% Dredge Cycle Efficiency
Christmas Tree	60% Dredge Cycle Efficiency
Lubricant Cost	10 Percent of Fuel Costs
Pipeline wear per million yds	0.8 mm
Original Wall thickness	12.7 mm
Pipeline Cost per foot	$ 120.00 Dollars (Schedule 20)

Production Rate	2,351 yds^3 / hr
Required Volume	900,000 yds^3
Gross Volume	945,000 yds^3
Estimated Daily Run Time	16.50 hours
Dredge Cycle Efficiency	75%
Required Dredging Hours	564
Required Days	34.18

Fuel and Lubricants	
House Power	$ 2,563.85
Dredge Engine Fuel	$ 112,807.86
Lubricants	$ 11,280.79
Attendant Plant	$ 3,589.39
Repairs and Maintenance	$ 150,412.39
Pipeline Wear	$ 45,354.33
Bonding Costs	$ 73,223.70

Depreciation	$ 36,757.67
Mob - Demob	$ 750,000
Insurance	$ 55,136.51
Special Items	$ -
Crew	$ 200,854.26
Rentals	$ 95,716.98

TEST CASE (HOPPER PROGRAM) - Mobile Harbor

Table A-8. Input Data Used to Estimate Mobile Harbor

Input	Description
6000	Hopper Capacity (yd^3)
2	Enter 1 for material that will settle in the Hopper 2 for materials that will not
2	Number of Drag Arms Used
6.5	Sailing Speed (Knots)
15	Average Sailing Distance to Disposal Area (Nautical Miles)
42	Dredging Depth (ft)
27	*Depth of U/W Pump Centerline* (If U/W Pump not used enter 0)
0	Elevation of First Pump if no U/W pump used
15	Suction Pipe Length (ft)
110	Length of Discharge Pipeline (ft)
10	Elevation of Discharge (ft)
8	Suction Side Losses
20	Discharge Side Losses
30	Suction Pipeline ID (Inches)
30	Discharge Pipeline ID (Inches)
0.00015	Roughness of Pipeline(ft) (Common Value .00015)
0.065	d50 of material (mm)
1.6	Average Specific Gravity of Slurry
2.65	Specific Gravity of Solids
s	Fresh or Seawater ("f" , "s")
0.050	Hourly Fuel usage per Utilized Horsepower for Dredge Engines (Gallons)
6,000	Daily fuel usage for Propulsion and House Power (Gallons)
$ 0.62	Cost per Gallon for Fuel (Dollars)
210	Attendant Plant Fuel Usage (Gallons)
$ 1,332,500	Annual Cost of Repairs and Maintenance (Dollars)
325	Yearly Dredge Utilization (Days)
1,000,000	Required Dredging Volume (yd^3)
5.0	Expected Overdredging (Percent)
$10,000,000	Capital Cost of Dredge (Dollars)
30	Depreciation Period (Years)
$ 300,000	Mobilization and Demobilization Costs (Dollars)
$ 500,000	Yearly Insurance Costs (Dollars)
1.5	Bonding Rate (Percent) (Common Value 1.0-1.5)
$ -	Special Contract Costs (Dollars)

Table A-9. Pump Selection Used to Estimate Mobile Harbor

Data Entry
PUMP SELECTION
Hopper Calculations
Delay Entry
Rentals
Crew
Cost Summary

Choose your pumps from the following tables

	# from Chart
U/W Pump	1
Main Pump	4
Main Pump	0
Main Pump	0

30" Discharge	U/W Pump	Main Pump #1	Main Pump #2	Main Pump #3	**27" Discharge**	U/W Pump	Main Pump #1	Main Pump #2	Main Pump #3
Max HP					**Max HP**				
None	0	0	0	0	None	0	0	0	0
1500	1	1	1	1	1000	9	9	9	9
2000	2	2	2	2	1500	10	10	10	10
2500	3	3	3	3	2000	11	11	11	11
3000	4	4	4	4	2500	12	12	12	12
3500	5	5	5	5	3000	13	13	13	13
4000	6	6	6	6	*3500*	*14*	*14*	*14*	*14*
4500	7	7	7	7	4000	15	15	15	15
Custom	8	8	8	8	Custom	8	8	8	8

Table A-10. Calculations Page For Estimating Mobile Harbor

Data Entry
Pump Selection
HOPPER CALCULATIONS
Delay Entry
Rentals
Crew
Cost Summary

Hopper Calculations

2.50	Suction ID (inches)		
2.50	Disch. ID (inches)		
0.0039	Terminal Velocity (Schiller) m/s		Wilson Eq. Preparation
0.0741	w		Wilson Eq. Preparation
0.3514	Concentration		Wilson Eq. Preparation
30	Sum of minor Loss K		
0.31	Critical Velocity (m/s)	1.02	Critical Velocity (ft/s)
		5.00	Critical Flowrate (ft^3/s)
		2,244	Critical Flowrate (GPM)

Critical Flowrate Input for Plot

2,244	0
2,244	2000

Instructions

View the Cutter Graph and Enter the Flowrate at which the System and Friction Curves intersect. The intersection must be past the critical flowrate.

For Minor adjustments
change ——————>
until the box is between -2 and 2
-186.369

40,000	Intersection Point GPM
18.15	Intersection Point ft/s

Cavitation Check

NPSH Required	27.8 ft of water
Operating Head	356.30 ft of water
Operating Losses	169.93 ft of water
Suction Loss	0.68
Available NSPH	31.41

Notes

SG within tolerances   Click to change slurry SG, then read new Flowrate off Graph

No Cavitation

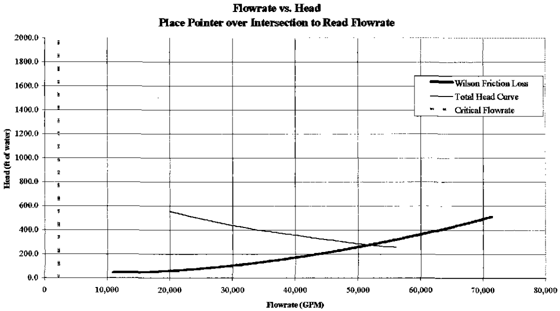

Figure A-2. Loss Plot Created While Estimating Mobile Harbor

Table A-11. Delays Used to Estimate Mobile Harbor

The following Questions will be used to calculate daily run time

12.00 Hours	Refueling	10.34%
8.00 Hours	Minor Repairs Deck	6.90%
8.00 Hours	Major Repairs Deck	6.90%
15.00 Hours	Minor Repairs Engine Room	12.93%
15.00 Hours	Major Repairs Engine Room	12.93%
10.00 Hours	Clean Pumps / Drag Heads	8.62%
1.00 Hours	Survey	0.86%
20.00 Hours	Traffic	17.24%
25.00 Hours	Weather	21.55%
2.00 Hours	Miscellaneous	1.72%
116.00 Total Delay		100.00%
4.83 Days for Delays		4.35%
		22.96

Table A-12. Rentals Used to Estimate Mobile Harbor

Total Rental Price per Day
$4,575.00

All Daily Rental Prices should include fuel, and operator costs

Marsh Buggy(s)	$ -
CrewBoat	$1,600.00
Bulldozer(s)	$ -
Tug Boat(s)	$ -
Barge(s)	$ 325.00
Plough	$2,500.00
Office Space	$ 150.00
Light Plant(s)	$ -

Table A-13. Crew, Fringe, and Food Costs Used to Estimate Mobile Harbor

Data Entry
Pump Selection
Hopper Calculations
Delay Entry
Rentals
CREW
Cost Summary

Total Crew Cost per Day (including fringe)
$ 4,335.00

Fringe cost
30%

Daily Food Costs Total	Daily Food Costs Per Person	Crew Compliment
$ 435.00	$ 15.00	29

	Quantity	Daily Total	Total
Project Manager	1	$ 262.50	$ 262.50
Project Engineer	1	$ 187.50	$ 187.50
Surveyor(s)	2	$ 157.50	$ 315.00
		$ -	
Master	2	$ 210.00	$ 420.00
Dragtender	2	$ 225.00	$ 450.00
Chief Mate	1	$ 187.50	$ 187.50
Third Mate	1	$ 165.00	$ 165.00
Deck AB	2	$ 142.50	$ 285.00
Ordinary Seaman	2	$ 127.50	$ 255.00
Other	0	$ -	$ -
Chief Engineer	1	$ 202.50	$ 202.50
Ass. Chief Engineer	1	$ 180.00	$ 180.00
Oiler(s)	3	$ 165.00	$ 495.00
Electrician	2	$ 180.00	$ 360.00
		$ -	
Welder(s)	2	$ 180.00	$ 360.00
		$ -	
Cook(s)	4	$ 150.00	$ 600.00
		0	
Messperson	1	$ 127.50	$ 127.50
		$ -	
Clerk	1	$ 150.00	$ 150.00

Table A-14. Cost Summary For Mobile Harbor

Data Entry	**Total Job Cost**	
Pump Selection	$	2,620,407
Hopper Calculations		
Delay Entry	**Price / yd^3**	
Rentals	$	2.62
Crew		
COST SUMMARY		

Adjustable Items			
Hopper capacity used with Sand	80%		
Hopper capacity used with non-settling mud,s	100%		
Turning	15%	Percent of Dredge Time	
Lubricant Cost	10%	Percent of Fuel Costs	
Pipeline wear per million yds	0.8	mm	
Available Wall thickness	6.0	mm	
Pipeline Cost per foot	$ 120.00	Dollars	(Schedule 20)
Required Dredging Hours	263		
Required Days	116		

Production Rate	8,350	yds^3 / hr
Required Volume	1,000,000	yds^3
Gross Volume	1,050,000	yds^3
Hopper Capacity	6,000	yds^3
Estimated Dredge Time/Cycle	0.505	hours
Estimated Turn Time/Cycle	0.076	hours
Estimated Disposal Time/Cycl	0.170	hours
Estimated Sail Time/Cycle	4.766	hours
Estimated Volume/Cycle	2,109	yds^3
Estimated Cycles/Day	4.5	
Estimated yd^3/Day	9,465	yds^3

Fuel and Lubricants			**Depreciation**		
Propulsion and Power	$	413,540		$	118,974
Dredge Engine Fuel	$	3,026	**Mob - Demob**		
Lubricants	$	41,657		$	300,000
Attendant Plant	$	15,103	**Insurance**		
				$	178,462
Repairs and Maintenance			**Special Items**		
	$	475,600		$	-
Pipeline Wear			**Crew**		
	$	1,760		$	502,860
Bonding Costs			**Rentals**		
	$	38,725		$	530,700

Table A-15. Job Summary for Savannah and Brunswick

Cost Comparison		
Job:		Equipment Type
Savannah & Brunswick Entrance		Hopper Dredge
		6000 yds^3 Capacity
Location:		
Georgia		
Mobilization and Demobilization	$ 1,600,000	
Overflow Allowed	YES	
Digging Depth	42	feet
Sailing Distance (Sail @ 6.5 Knot	6	Nautical Miles
150% of Gulf Wages		
Government Estimate	$ 4,198,960	
Winning Bid	$ 4,732,000	
Program +10%	$ 2,972,075	
Program	$ 2,701,886	
% Differences		
Winning Bid vs. Government Estimate		12.7%
Program +10% vs. Government Estimate		-29.2%
Program +10% vs. Winning Bid		-37.2%

Table A-16. Job Summary for Calcasieau River

Cost Comparison		
Job:		Equipment Type
Calcasieau River		Cutter Dredge
		Spud Type Carriage
Location:		75% Cycle Efficiency
Louisiana		
Average Discharge Line	7000	feet
Mobilization and Demobilization	$1,000,000	
Digging Depth	44	feet
Run Time	16.25	hours
Production Rate	2684	yds^3/hour
Gulf Wages		
Government Estimate	$4,592,100	
Winning Bid	$4,490,000	
Program +10%	$4,081,438	
Program	$3,710,398	
% Differences		
Winning Bid vs. Government Estimate		-2.2%
Program +10% vs. Government Estimate		-11.1%
Program +10% vs. Winning Bid		-9.1%

Notes: 3 Marsh Buggies @ $1200/day required instead of 1

Table A-17. Job Summary for Mississippi River Gulf Outlet Miles 4-8

Cost Comparison		
Job:		Equipment Type
Mississippi River Gulf Outlet Miles 4-8		Cutter Dredge
		Spud Type Carriage
Location:		75% Cycle Efficiency
Louisiana		
Average Discharge Line	4000	feet
Mobilization and Demobilization	$ 300,000	
Digging Depth	43	feet
Run Time	16.45	hours
Production Rate	2982	yds^3/hour
Gulf Wages		
Government Estimate	$1,690,000	
Winning Bid	$1,382,500	
Program +10%	$1,377,489	
Program	$1,252,263	
% Differences		
Winning Bid vs. Government Estimate		-18.2%
Program +10% vs. Government Estimate		-18.5%
Program +10% vs. Winning Bid		-0.4%

Table A-18. Job Summary for Mississippi River Gulf Outlet Miles 8-12

Cost Comparison		
Job:		Equipment Type
Mississippi River Gulf Outlet Miles 8-12		Cutter Dredge
		Spud Type Carriage
Location:		75% Cycle Efficiency
Louisiana		
Average Discharge Line	6000	feet
Mobilization and Demobilization	$ 500,000	
Digging Depth	43	feet
Run Time	16.5	hours
Production Rate	2982	yds^3/hour
Gulf Wages		
Government Estimate	$2,082,000	
Winning Bid	$1,635,000	
Program +10%	$1,662,672	
Program	$1,511,520	
% Differences		
Winning Bid vs. Government Estimate		-21.5%
Program +10% vs. Government Estimate		-20.1%
Program +10% vs. Winning Bid		1.7%

Table A-19. Job Summary for Port Mansfield Entrance Channel

Cost Comparison		
Job:		Equipment Type
Port Mansfield Entrance Channel		Cutter Dredge
		Spud Type Christmas Tree
Location:		60% Cycle Efficiency
Texas		
Average Discharge Line	1500	feet
Mobilization and Demobilization	$ 450,000	
Digging Depth	22	feet
Run Time	12.25	hours
Production Rate	2385	yds^3/hour
Gulf Wages		
Government Estimate	$1,046,496	
Winning Bid	$1,279,200	
Program +10%	$ 921,766	
Program	$ 837,969	
% Differences		
Winning Bid vs. Government Estimate		22.2%
Program +10% vs. Government Estimate		-11.9%
Program +10% vs. Winning Bid		-27.9%

Note: Run time is low because job is between jetties. Breaking waves inside jettie severely hinder the dredging operation.

Table A-20. Job Summary for Tiger Pass

Cost Comparison		
Job:		Equipment Type
Tiger Pass		Cutter Dredge
		Spud Type Carriage
Location:		60% Cycle Efficiency
Louisiana		
Average Discharge Line	3600	feet
Mobilization and Demobilization	$ 650,000	
Digging Depth	20	feet
Run Time	14.5	hours
Production Rate	2247	yds^3/hour
Gulf Wages		
Government Estimate	$3,536,200	
Winning Bid	$2,753,000	
Program +10%	$2,020,244	
Program	$1,836,585	
% Differences		
Winning Bid vs. Government Estimate		-22.1%
Program +10% vs. Government Estimate		-42.9%
Program +10% vs. Winning Bid		-26.6%

Note: 11 pipelines crossing on this job lead excess delays and lower the daily run
Narrow cut and low bank height lead to lower dredge cycle efficiency

Table A-21. Job Summary for Theodore Ship Channel #2

Cost Comparison		
Job:		Equipment Type
Theodore Ship Channel #2		Cutter Dredge
		Spud Type Carriage
Location:		75% Cycle Efficiency
Alabama		
Average Discharge Line	5500	feet
Mobilization and Demobilization	$ 500,000	
Digging Depth	42	feet
Run Time	16.75	hours
Production Rate	2992	yds^3/hour
Gulf Wages		
Government Estimate	$1,446,303	
Winning Bid	$1,346,050	
Program +10%	$1,249,232	
Program	$1,135,665	
% Differences		
Winning Bid vs. Government Estimate		-6.9%
Program +10% vs. Government Estimate		-13.6%
Program +10% vs. Winning Bid		-7.2%

Table A-22. Job Summary for Mississippi River Gulf Outlet Miles 23-27

Cost Comparison		
Job:		Equipment Type
Mississippi River Gulf Outlet Miles 23-27		Cutter Dredge
		Spud Type Carriage
Location:		75% Cycle Efficiency
Louisiana		
Average Discharge Line	4500	feet
Mobilization and Demobilization	$ 500,000	
Digging Depth	43	feet
Run Time	16.5	hours
Production Rate	2982	yds^3/hour
Gulf Wages		
Government Estimate	$1,628,200	
Winning Bid	$1,084,000	
Program +10%	$1,516,086	
Program	$1,378,260	
% Differences		
Winning Bid vs. Government Estimate		-33.4%
Program +10% vs. Government Estimate		-6.9%
Program +10% vs. Winning Bid		39.9%

Table A-23. List of Friction Loss Equations (TID, 1999)

Gl.-Nr.	Jahr	Verfasser	Lit.	Gleichung	Experiment. Basis und Gültigkeit	Bewegungsart	Bemerkung
1	1954	Durand Condolios	14	$\phi = 81\,\psi^{-1,5}$	Sand, Kohle; $40 < D < 580$ mm $0.2 < d < 25$ mm $C_T \leq 20$ %;	$v > v_{kr}$ heterogen und springend	grobes Fördergut nur für $D \leq 200$ mm gemessen
2	1963	Condolios Chapus	9	$\phi = 85\,\psi^{-1,5}$	dto.	dto.	dto.
3	1961	Bonnington	2	$\phi = 71\,\psi^{-1,5}$	-	dto.	-
4	1962	Chaskelberg Karlin	8	$\phi = 78\,\psi^{-1,4}$	Sand, Kies; $0,5 < d < 2$ mm; $400 < D < 700$ mm	$v > v_{kr}$	-
5	1963	Ellis und andere	15	$\phi = 385\,\psi^{-1,5}$	Nickel-Wasser-Gemisch	-	-
6	1967	Kazanskij	22	$\phi = 134\,\psi^{-1,4}$	11 Sandsorten $0,23 < d < 1,48$ mm $D = 100$ mm	heterogen, springend	
7	1962	Zandi und Govatos	46	$\phi = 6,3\,\psi^{-0,354}$ für $\psi > 10$ $\phi = 280\,\psi^{-1,93}$ für $\psi < 10$	Vergleich verschied. Messungen $D < 610$ mm	dto.	
8	1970	Babcock	1	$\phi = 6,3\,\psi^{-0,254}$	Sand, $0,15 < d < 0,2$ mm $D = 1''$, glatt (Kunststoff) $C_V \leq 20$ %	homogen	
9	1971	Walte	47	$\phi = 36\,\psi^{-1,37}$	Vergleich verschied. Daten; gültig für Sand	-	
10	1955	Newitt u. and.	34	$\phi = 1100\,Fr^{-2}\,\frac{w}{v}\,\rho^+$	Sand; G:1800g Dr>v>17w	-	
11	1950	Jufin und Lopatin	19	$\phi = 33000\,Fr^{-3}\,\frac{d}{D}$	Sand; $d < 1$ mm für $D < 400$ mm $d < 2$ mm für $D > 400$ mm	heterogen, springend	
12	1966	Jufin und Lopatin	19	$\phi = 2000\,Fr^{-3}\sqrt{\frac{d}{D}\,\frac{d_{10}}{d_{90}}}$	Kies; $d > 1$ mm f. $D < 400$ mm $d > 2$ mm f. $D > 400$ mm	gleitend, springend	
13	1962	Sillu und Kobernik	38	$\phi = Fr^{-3} + 0,5$	Sand $0,1 < d < 0,5$ mm $410 < D < 900$ mm	heterogen, springend	
14	1971	Hayden und and.	45	$\phi = 100\,\psi^{-1,3}(\rho^+)^{-0,5}$	Sand, Kies $D = 1''; 2''$	heterogen, springend	
15	1970	Charles	6	$\phi = 120\,\psi^{-1,5} + \rho^+$	Sand, Nickel, $D = 1''$, $C_{Tmax} = 20$ %	heterogen	
16	1955	Newitt und and.	34	$\phi = 66\,Fr^{-2}\,\rho^+$	Sand	gleitend, springend	
17	1970	Babcock	1	$\phi = 60,6\,Fr^{-2}\,\rho^+$	Grobsand, Stahlteilchen $D = 1''$	gleitend, springend	$\phi \neq f\,(C_T)$
18	1952	Worster	46	$\phi = 120\,Fr^{-3}(\rho^+)^{1,5}$	grobes Fördergut, u.a. Kohle	gleitend, springend	$\phi \neq f\,(C_T)$
19	1955	Newitt und and.	34	$\phi = \rho^+$	Vergleich mehrerer Messungen $d < 0,15$ mm	pseudohomogen (NEWTON)	

Table A-24. List of Friction Loss Equations (TID, 1999)

Gl. Nr.	Jahr	Verfasser	Lit.	Gleichung	Experiment. Basis und Gültigkeit	Bewegungsart	Bemerkung
20	1977	Kazanskij	–	$\phi = 1{,}55 \cdot 10^5\, k^{2/3} D^{1/3} v^{-2} (\rho^*)^{-1}\, Fr_{xD}$	Fein- bis Grobsand 50<D<300 mm Kunststoff 60 µm<d<2 mm	v > vv_{kr}, heterogen, springend	Messungen SBC und eigene, k = 0,04 mm; k* = k/D
21	1961	Führböter	16	$i = i_w + \frac{S_{kt}}{v} \cdot c_T$; $S_{kt} = 2{,}59\, d_a - 0{,}37$	Sand, Kies, D = 300 mm 0,15<d<4,8 mm	$v > v_{kr}$ heterogen, springend	
22	1959	Korsajev	32	$i = i_w + K(\rho - \rho_w)$	Sand: 15 < D < 200 mm Kies: D = 500, 700 mm	$v > v_{kr}$ heterogen springend	K = emp. Konstante
23	1972	Duckworth Argyros	10	$i = i_w + 1{,}72\, v^2 \frac{C}{C-1}\, c_s\, Fr^{-2,48}\, \phi(\frac{\rho_s}{\rho_w})$	$0{,}028<\rho_s/\rho_w<11{,}1$ $0{,}02<d/D<0{,}66$	–	$\phi(\rho_s/\rho_w)$ graphisch abzulesen
24	1972	Vočadlo	40	$i = i_w + i_2 + i_3$	Vergleich verschied. Messungen, kleine D	–	–
25	1965	Jufin	18	$i = i_w + (i_e - i_w)(3\,\frac{d_{10}}{d_{90}})^{0,22}$	Mehrkornsand	–	i_e = i f. Einkornsand
26	1967	Wiedenroth	42	$i = i_w + c_R\, \rho^+ \frac{w}{v}$	Vergleich verschied. Messungen	schlupffreie Föm.	
27	1971	Brauer	3	$i = i_w + 14{,}1\, c_T\, v\rho^+ D^{1/3} v^{-2/3} \nu^{-1/3}$	dto.	–	–
28	1973	Karasik	21	$i = i_w + (i_{kr} - i_{wkr})\frac{v_{kr}}{v}$	Feinsand, Eisenerz, D=200,300 mm ρ<1250 t/m³	–	Voraussetzung: v_{kr}, i_{kr} bekannt
29	1973	Karasik	21	$i = i_w\, \rho/\rho_w + (i_{kr} - i_{wkr}\, \rho/\rho_w)\frac{v_{kr}}{v}$	Feinsand, Eisenerz, D=200,300 mm, ρ>1250 t/m³	–	Voraussetzung: v_{kr}, i_{kr} ist bekannt
30	1970	Smoldyrev	39	$i = i_w(1+\rho^+ C) + K\rho^+ C (\frac{w}{v})^2 \frac{D}{d}$	Eisen- und Kupfererz, Kupferkonzentrat 0,05<d<0,123 mm 78<D<250 mm	pseudohomogen (NEWTON), heterogen	K = 0,30 bis 0,32
31	1970	Smoldyrev	39	$i = i_w + K\rho^+ C\, \frac{w}{v} \sqrt{\frac{D}{d}}$	Grobkörniges Fördergut 25<D<900 mm	gleitend, springend	K — D (mm) 3,0 — 25 ÷ 50 2,5 — 50 ÷ 60 0,45 — 150 ÷ 300 0,30 — 700 ÷ 900
32	1970	Smoldyrev	39	$i = i_w + f\rho^+ C$	Mittelkörniges Fördergut	heterogen	f — Fördergut 0,7 ÷ 0,56 Felsensplitt 0,55÷0,47 mittelhart. Gestein 0,45÷0,36 {Kies (rund) weiches Gestein 0,35÷0,30 harte Kohle 0,2 ÷ 0,1 weiche Kohle
33	1954	Worster	44	$\frac{\sqrt{i} - \sqrt{i_w}}{\sqrt{i}} = 4 w^{0,173} \left(\frac{C_T g D \rho^+}{v}\right)^{0,143} - \frac{2q\sqrt{2 i_w}}{v}$		–	–
34	1970	Krivenko	33	$i = \frac{i_w}{1-C_T} + \rho^+ \frac{C_R}{1-C_T}\left[f_1 (2\frac{d}{D})^{1/3} + f_2 (0{,}18 + C_R \cdot Fr^{-1/3})\right]$	Grobkörniges Fördergut 1,8<d<50 mm 50<D<700 mm	gleitend, springend	vorausgesetzt $\frac{C_T}{C_R}$ bekannt, f_1, f_2 = f (d)
35	1966	Jufin Lopatin	19	$i = i_w \left[1 + 2(\frac{v_o}{v})^3\right]$; $v_o = 5{,}5 (D C_T)^{1/6} Fr_x^{1/4}$	Feinsand bis Kies 103<D<900 mm umfangreiche exp. Basis	heterogen springend gleitend	geeignet vor allem für hohe C_T und große D
36	1976	Kazanskij	28	$i = i_w \left[1 + 2(N\frac{v_o}{v})^3\right]$; $v_o = 0{,}721 D^{1/6} Fr_x^{1/4} \cdot 5{,}12^{k_T}$ $N = 0{,}826\, v + 1{,}49 - 2{,}38\, D$	Sand 60-100 mesh 50<D<300 mm Kunststoffwandung	heterogen	Modifikation der Gl.36 für Kunststoffwandung
37	1976	Kazanskij Brühl	28 5	dto. mit: $v_o = 0{,}721\, D^{1/6} (Fr_{xtr})^{1/4}\, 5{,}12^{k_T}$ $Fr_{xtr} = Fr_x \left(\frac{\rho_s/\rho_{tr} - 1}{\rho_s - \rho_w} \cdot \frac{w_{tr}}{w_w}\right)^{1,5}$	Sand mit 30 bis 40 % Feinststoff mit d<60 µm D = 4"; 2" (Kunststoff)	heterogen	Modifikation der Gl.37 für Feinststoffanteil über 2-3%.

Table A-25. Explanation of Variables for Equation List (TID, 1999)

$$\phi = \frac{i_m - i_w}{i_w * C} = A * \Psi^{-1.5} \Rightarrow i_m = i_w\left(1 + C * A * \Psi^{-1.5}\right) \qquad \text{(A-1)}$$

$$\Psi = \frac{V^2}{gD_p} * \frac{\sqrt{g * d_{50}}}{w} \qquad \text{(A-2)}$$

$$F_r^2 = \frac{V^2}{gD_p} \qquad \text{(A-3)}$$

These explanations were found in the TID course material. The variables are defined as follows,

C - Concentration by volume

A - Area of pipeline

D_p - Diameter of pipeline

i_w - Hydraulic gradient for water (meters (feet) of water per meter (foot) of pipe)

V - Velocity of Slurry

g - Gravitational constant

VITA

Francesco (Frank) John Belesimo

Mr. Belesimo was born February 10, 1973 in New York City, NY. He grew up in the town of North Babylon on Long Island. Mr. Belesimo attended Texas A&M University and graduated in May of 1996 with a Bachelor of Science in Ocean Engineering. Upon graduation, Mr. Belesimo took a job with C.F. Bean Corporation, a dredging company located in New Orleans, Louisiana.

Mr. Belesimo worked at C.F. Bean as a Field Engineer (Surveyor) and Production Engineer. While in this position he gained valuable experience in the fields of dredge production and operation, hydrographic and land surveying, and the business of dredging in general. In July of 1997 he was promoted to Project Engineer. As Project Engineer he learned the details of managing projects, motivating employees, and dealing with clients.

After getting married in August of 1998, Frank began classes at Texas A&M University in pursuit of a Master of Science. During the two years of graduate school Mr. Belesimo worked as a consultant to C.F. Bean. Mr. Belesimo expects to graduate with a Master of Science in Ocean Engineering in May of 2000.

Francesco John Belesimo
217 August Road
North Babylon, NY 11703