TECHNICAL INPUTS TO DREDGING COST ESTIMATES

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ABSTRACT

Tendering a price for a dredging project involves producing an estimate that answers three questions; how much work is there, how much time will it take, and how much will it cost? At Great Lakes Dredge & Dock Company (GLD&D), the question about time is answered by a Production Engineer, who develops a technical estimate that takes into account the geotechnical information, layout of the dredging location, layout of the disposal area, and the capabilities of the chosen dredge. The engineer does this by estimating the productivity of the dredge in the expected conditions of the project, and comparing it to the performance of the dredge on the same or similar projects in previous years. In addition the engineer looks at other factors that might affect the execution of the project, such as weather, access restrictions or environmental conditions. This paper discusses the factors that GLD&D takes into account when preparing such estimates, presents some common pitfalls, and presents a case study of an estimate for a project that GLD&D bid, was awarded and performed successfully.

Keywords: Production, pump, layout, limit theory, dredge cycle, tender

INTRODUCTION

When tendering a project, any dredging contractor must first prepare an estimate of the cost of the project. While different contractors approach estimating from different perspectives, all must produce some sort of estimate in order to determine if they wish to tender the project and at what price. In order to produce an estimate, they must understand the scope of the project, the cost of operating the equipment, and how productive the equipment will be on the project. These three tasks in estimating can be characterized in terms of three questions to be answered:

1. How much work is there to do?
2. How much time will it take to do?
3. How much will it cost?

At GLD&D, each of these questions is answered by a different member of the estimating team. In addition, a larger group provides advice, insight or oversees the process. In all, a team of 10 or more people may be involved in the estimating process in one way or another, but the engineers answering these three questions are the most closely involved in the process.

Production Engineers at GLD&D have the job of answering the question of how much time it will take, by estimating the productivity of dredging equipment on the project. They do this using both technical models of dredge production and empirical evidence from similar projects.

THE ESTIMATING TEAM

As mentioned in the introduction, the estimating team consists primarily of a Cost Estimator, a CAD Engineer, and a Production Engineer. A larger team of experts and managers assists with training, advice and supervision.

Cost Estimator

The Cost Estimator is responsible for estimating how much the project will cost. Dredging itself is usually paid for on a volume basis, but all dredging projects have some additional components of cost. These can include mobilizing and demobilizing the dredge, environmental monitoring, ancillary construction activities (such as dike construction, walkways or planting on the beach, etc.), or even works to enable the dredging process, such as fabrication of specialized equipment. The Cost Estimator will determine the prices of such ancillary activities, using prices from similar projects, quotes from subcontractors or from specialists within GLD&D. In addition this engineer will determine a daily or weekly cost of the dredge. This cost, multiplied by the time that the Production Engineer estimates, will be the estimated cost of the project.

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CAD Engineer

At GLD&D a CAD Engineer does a takeoff to determine the scope of the project. The first part of this takeoff is a volume calculation of the dredge area and fill area based on survey information provided by the owner. Then the engineer will determine the size of the area to be dredged, and the distance to transport the spoil. This engineer is also responsible for preparing plan view drawings, cross-sections (Figure 1) and profiles of the dredge area, including specialized drawings such as rock contour maps (Figure 2). These drawings can be crucial in helping the rest of the team understand any details of the project that the overall numbers hide.

![Figure 1](image1.png)

**Figure 1.** An example of two cross-sections with similar areas and volumes, but very different layouts, which will require different digging methods.

![Figure 2](image2.png)

**Figure 2.** A rock-contour map helps the engineering team visualize where the most difficult work might be. The Geotechnical Specialist will help the CAD Engineer lay out this drawing for the benefit of the estimating team.

Other Team Members

The three primary team members have a large cast of others to call upon for advice and assistance. These include more senior members of their respective departments or specialists such as geotechnical engineers and cost accountants.

In addition the estimators have access to current or former field personnel who provide guidance to the intricacies and pitfalls of a dredging project. Lastly, the estimate will be reviewed by the senior personnel who make the pricing decisions.
THE ROLE OF THE PRODUCTION ENGINEER

The Production Engineer has the primary duty of determining how long the project will take. She does this by estimating the productivity of the dredge and applying that to the quantities determined by the CAD Engineer. The Production Engineer estimates dredge production using three methods:

- A theoretical method that uses production models to compare the capability of the dredge to the conditions of the project
- A method based on historical performance on similar projects in the past
- A method that combines the two by calibrating production models on past projects, then extends the model to the current project, based on its unique parameters

Project Characteristics and Site Conditions

In preparing to look at a project the Production Engineer will gather information of a number of key characteristics of the project.

Figure 3. A ladder-depth layout to determine CSD ladder angles and clearances.
These include:

- The layout of the dredging area – depth and width of cut as well as thickness (face) to be dredged
- The disposal location, upland or offshore, and transport distances and any processing that is required
- Any access restrictions due to shallow existing depths, that may restrict the equipment that may be used or require flotation digging
- Deep required depths that may affect the productivity or suitability of the dredge (Figure 3)
- Soil parameters of the material to be dredged:
  - Soil type: sand/clay/rock or other
  - Density, stiffness or hardness of the material, how difficult will it be to cut
  - Grain size and pumpability, how will it behave in a slurry
- Expected weather conditions (including tide ranges) that may affect working time or impact production
- Environmental restrictions such as specialized equipment or monitoring that may impact production or working hours

Information Quality

In preparing the estimate, the Production Engineer must be on the lookout for inaccurate or contradictory material that may increase the risk of the project. A good example of this was on a project that GLD&D performed in 1997 (see Figures 4 and 5). In this project, the owner provided borings that showed mostly sand to be dredged, with a layer of rock occurring just below the required depth. The estimate, based on this information was for a production of 1440 m³/WH (mostly pump limited) and 5 teeth/day. The lowest production and greatest tooth usage was expected in the deepest portion of the project where the dredge would need to cut some rock to leave grade.

Once the project started, the dredge encountered much more rock than was expected and GLD&D initiated a boring campaign to better understand the project. In the original campaign the owner’s representatives had performed Standard Penetration Tests (SPTs) in all borings regardless of the material type. SPTs involve driving a 50 mm O.D. (2 inch), 35mm I.D. (1 3/8 inch) split spoon sampler into the ground with a 63.5 kg (140 lb) weight dropped 760 mm (30 inch). The number of blows of the hammer required to drive the sampler 0.3 meter (1 foot) is called the
‘blow count’, and is a common method of determining the relative density of soil. However SPTs can give erroneous results in certain types of weak to moderately strong conglomerate rock underlain by softer sediments.

In this case the split spoon broke through and fractured the rock layers, sometimes giving blow counts lower than in the surrounding sand layers, and retrieving broken rock samples as gravel and sand. GLD&D’s more careful investigation included drilled cores when rock was suspected, revealing the much more extensive rock layers shown in Figure 5. In the end the dredge achieved an average of 605 m³/WH and used 105 teeth/day, resulting in much higher costs.

Figure 5. Borings taken by GLD&D showed much more extensive rock layers throughout the dredge area.

Theoretical Estimates – Cutter Suction Dredge

The theoretical estimates the Production Engineer produces are based on a cycle analysis of the dredging process, with the digging portion of the cycle determined using limit theory. A typical simple cycle for a Cutter Suction Dredge (CSD) working on wires is shown in Figure 6 below. The cycle consists of the dredge swinging from point A to point B, stopping and stepping ahead from B to C, swinging back to A’, stepping ahead and starting the cycle again. More complicated patterns and cycles are possible, but the basic outlines are the same.
The production for the dredge is calculated as follows:

\[ P_{dig} = \frac{Q_{cycle}}{t_{step} + t_{misc} + t_{swing}} \]  

(1)

Where:

- \( P_{dig} \) is the overall production
- \( Q_{cycle} \) is the quantity removed in the course of a cycle and is equal to:
  \[ Q_{cycle} = f_{dig} \times s \times w \]  
  (2)

- \( f_{dig} \) is the face, or thickness of material removed
- \( s \) is the step length
- \( w \) is the width of cut
- \( t_{step} \) is the time the dredge takes to step ahead
- \( t_{misc} \) is any miscellaneous time in the cycle, used to account for acceleration/deceleration or operator inefficiency
- \( t_{swing} \) is the time the dredge spends swinging

The first two elements of the cycle time, \( t_{step} \) and \( t_{misc} \) are generally empirical estimates, based on observations of the dredge in question. These can account for up to 30% of the cycle time.

**Limit Theory**

The last element of the cycle, \( t_{swing} \), is the subject of limit theory. Limit theory is the observation that at any given moment there is some limitation to the instantaneous production (as opposed to the overall production \( P_{dig} \)) of the dredge. At GLD&D we distinguish a number of different limits at which a dredge can operate:

- **Pump Limit** – The maximum pumping capacity of the dredge
- **Cutter Limit** – The maximum cutting capacity of the dredge
Swing Limit – The maximum swing speed at which the dredge still removes material


Pump Limit

The pump limit of the dredge is a function of the pipeline length and diameter, the suction and discharge elevations, the material to be pumped, and of course the power of the pump(s) in line. On short pipelines this limit has a maximum defined by the suction performance (NPSH) of the pump, or by the power of the pumping installation. As the line gets ever longer, the pump limit approaches 0 asymptotically. However, at some low production the process becomes difficult to control and it becomes economically beneficial to add a booster pump.

Cutter Limit

The cutter limit is the maximum quantity of material the dredge can disturb given the power of the dredging installation and strength of material. This is complicated by the fact that a CSD generally ‘spills’ some of the material cut, so the cutting production must be applied to a larger quantity than the removed or ‘dig’ quantity.

Swing Limit

The swing limit is generally encountered in low face, when the dredge is able to swing as fast as the swing winches allow, thus maximizing coverage (area covered per unit time), without hitting another production limit.

Swing Time

The swing time in equation 1 is calculated as follows:

\[
t_{\text{swing}} = \frac{W}{v_{\text{swing}}}
\]

Where:

\[v_{\text{swing}}\] is the swing speed of the dredge, calculated as:

\[
v_{\text{swing}} = \frac{P_{\text{inst}}}{Q}
\]

Where:

\[P_{\text{inst}}\] is the pump or cutter limited production

\[Q\] is the quantity either removed (in the pump limited case) or cut (in the cutter limited case)

In general we take the lowest of the swing speeds calculated from the pump and cutter, or the maximum swing speed of the winch installation.

CASE STUDY – A SOUTH CAROLINA BEACH PROJECT

In December 2006, GLD&D won a tender for a beach project in South Carolina. GLD&D executed the project the following summer. The layout of the project is shown in Figure 7, showing the borrow area, fill, and pipeline routes.
The project layout shown in Figure 7 reveals some details about the project. The borrow site is offshore in 6.1 – 9.1 m (20 – 30 ft) of water, with no protection against weather, incurring a risk of downtime. The pipeline length will be between 6,400 and 7,900 m (21,000 and 26,000 ft), with the bulk of the pipeline, 5,940 m (19,500 ft), as submerged pipe. The beach to be filled is 3,320 m (10,900 ft) long, with GLD&D’s planned landing in the middle to minimize shore pipe. The borrow area is broken into 4 sections, with over 760,000 m$^3$ (1M CY) of material available. The required quantity on the beach was 371,000 m$^3$ (485,000 CY) (versus an advertised quantity of 382,000 m$^3$ (500,000 CY)).

The project was estimated for the Dredge Alaska:

- 67.1x17.1x3.8 m (220x56x12.5 ft) Hull, 2.6 m (8.5 ft) draft
- 8,430 KW (11,300 HP) installed power
- 1040 KW (1400 HP) cutter power
- 5370 KW (7200 HP) main pump
- 1120 KW (1500 HP) underwater pump
- Digging on wires, to reduce the risk of breaking a spud in high seas

Ultimately the project was performed by the Dredge Illinois, a sister ship to the Alaska with essentially the same specifications.
Material Information

Plenty of material information was provided by the owner. A total of 60 vibracores were taken in and around the area to be dredged. Vibracores involve vibrating a hollow tube into the seabed to obtain a sample. They provide little information about the strength or density of the material, but are a relatively quick and cheap way to sample the sea bottom. The material descriptions in the vibracore logs indicated three types of material present:

- “Coarse, poorly graded sand” - According to ASTM this would be 2.0 – 4.75mm sand which is very difficult to pump.
- “Fine silty sand” – According to ASTM and the USCS, 0.75 – 0.435 mm sand with >12% fines, which would be relatively easy to pump
- “Elastic Silt” – Which would be easy to pump but unsuitable for fill

The main concern at the bid stage was the “coarse sand”, due to the potential pumping problems on the long pipeline length. However, the actual grain size distribution tests provided with the borings indicated that the majority of the material fell into the second two categories. In particular, the grain size tests performed on material from the “coarse” layer indicated fine or fine-medium material. This is a common error in the visual classification of sand, where the field estimation of sand size distribution is coarser than later tests indicate. The overall median grain size D50 (size at which 50% of the material by weight is finer) was 0.24 mm, comfortably in the fine sand range.

Pumping Capacity

Figure 8 illustrates the pumping capacity of the Dredge Illinois, and the risk attendant in the coarse material. If a significant fraction of the sand fell in the medium-coarse range the dredge would have difficulty pumping the material at economically sustainable rates. However, the material analysis described above indicated that we could expect the higher pumping capacity to hold.
Figure 8. Dredge Illinois pump capacity
Dig Production

Face in the borrow area varied from 0.91 m to 3.0 m (3 ft to 10 ft), as indicated in Figure 7, where the contour colors in the borrow site indicate available face, with red indicating > 3.0 m (10 ft) and black indicating <=0.91 m (3 ft). The bulk of the material was in areas between 0.91m and 1.8 m (3ft and 6 ft) of face. Figure 9 shows the sensitivity of the Dredge Illinois production to the available bank height. Given the available cutter power, we expected the dredge to be able to cut the material with no problems. Depending on the line length, the dredge would likely be swing limited in low face (indicated by the upward sloping production curve), and pump limited in high face (indicated by the flattening of the pump curve). The notch in the curve is due to an assumption that the dredge would only be able to take 2.4 m (8 ft) of face before taking a second swing between steps.

Figure 9. Dredge Illinois dig production.
References

As indicated on the layout in Figure 7, we had information on an adjacent project performed by a competitor in 2005, plus we gathered references from projects performed by GLD&D in similar materials using similar equipment. Figure 10 shows a summary of these references. The competitor project was performed on slightly shorter lines than expected for this project, but dredged in higher face. The relevant GLD&D references, by contrast, are for work on longer lines and higher face. The competitor references validate our decision to discount the possibility of medium or coarse sand in our estimate. The GLD&D references give us confidence that the dredge could make our estimate given the capability of our equipment.

Outcome

Table 1 summarizes the outcome of the project, while Figure 11 illustrates the outcome versus the estimated production curves. The actual performance of the dredge on the project largely fell within the estimated envelope of productions.
Table 1. Project outcome.

<table>
<thead>
<tr>
<th>Estimated</th>
<th>Actual</th>
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<tbody>
<tr>
<td>• 371,000 m³ (485,000 CY)</td>
<td>• 372,000 m³ (486,000 CY)</td>
</tr>
<tr>
<td>• 6,400 – 7,900 m (21,000 – 26,000 ft) Pipe</td>
<td>• 6100 – 9100 m (20,000 – 30,000 ft) Pipe</td>
</tr>
<tr>
<td>• 0.94 – 1.4 m (3.1 – 4.5 ft) Face average</td>
<td>• 1.3 m (4.4 ft) Face average</td>
</tr>
<tr>
<td>• 920 – 1300 m³/WH (1200 – 1700 CY/WH) average</td>
<td>• 1200 CM/WH (1600 CY/WH) average</td>
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<td>• 2 weeks weather delays</td>
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**Figure 10: Dredge Illinois Actual vs. Estimated Productions**

**CONCLUSION**

This project was in part successful due to the initial layout by our estimating team in the bidding stage. In particular, the combination of theoretical and empirical (experience-based) production estimates allows GLD&D to approach bidding and operations with confidence. Although this obviously does not ensure success, without this or a similar process the contractor is taking much greater risk when they tender a project.
REFERENCES
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CITATION