GIS solutions for dredging and subsurface mapping

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Abstract:
A geographic information system with specialized applications was developed to provide baseline information for regions including hydrographic, topographic, subsurface information, shoreline position, dredging records and other regional utilities, infrastructure, and land use information. Customized GIS applications were developed for planning and estimation of cost and time required for a project. The GIS also incorporated existing technology with regards to numerical models and tools. It works as a decision making tool for dredging planners.

Dredging planning is based on the behavior and type of subsurface soil. Borelog survey plays an important role in dredging planning. Borelog information helps to decide the type of dredger, rock cutters required, depth of cut and so many other factors. Depth of cut of material is dependent upon N value or SPT value of soil.

In the port planning, dredging is used for reclamation of land. Ground survey and bathymetry survey is important after certain time interval for sedimentation analysis. GIS is used as tool for 3D modeling, spatial database management, Visualization of temporal data, Production, Cost and time estimation and for dredging planning.

GIS provides an interface to hydrographic, topographic, historic dredge material data for a region and as well as custom application designed to facilitate engineering analysis. To date, development of Dredging Planning and Estimation tool has included: input of spatial data for dredging database management through DPRs(daily progress reports), Borelog and bathymetry data from survey, use of a Arc Info and built-in tools for data management and better visualization and display, creation of custom application to extend the utility of Arc GIS for required goals. This paper will give you an overview of how one can use GIS in dredging application for data management, dredging planning production analysis, time and cost estimation.

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Introduction

Dredging is a method of excavation in which the soil is removed from the sea bottom and is transported over water. For dredging activity, the subsurface information of ground to be dredged and the selection of the correct equipment play a vital role. The selection of appropriate dredger depends upon various factors viz. the type of soil to be dredged, the depth of dredging, the quantity of dredged material, relocation of the dredged material at the needful place, etc. In accessing the dredging costs, it is important that appropriate dredger is used for each type of soil to provide better productivity at optimised cost. Borelog information is used to generate subsurface strata through the interpolation methods using TIN. GIS helps in 2D and 3D visualization of the subsurface which helps in analysing and providing better and detailed idea about the location.

Dredging information and management system (DIMS) provides dredger details, daily work progress, production information and fuel consumption of every dredger that is working onsite. It works as a decision making tool for dredging planners. On the basis of past records, they can estimate the cost and time of upcoming future dredging projects at the same location and under same conditions.

For the development of DIMS, ArcGIS desktop has been used. ArcGIS provides various in-built tools like 3D analyst, tracking analyst, data management tool which are used for DIMS. For production analysis and dredging planning we have customised tools in ArcGIS application.

Spatial Data Input

Spatial data that are currently included in the DIMS includes:

1) **Borehole data**- Borelog survey records are required as input for the DIMS. The mapping of Borelog requires Borelog database. A dataset must be interpolated on the basis of borelog information using TIN (triangular irregular network) surface.

2) **Hydrographic and Topographic survey data**- Hydrographic and bathymetry data is required at regular time intervals to analyse changes in sea before and after dredging. Single beam and multi-beam hydrographic instruments are used for it. Differential Global Positioning System (DGPS) data is used for topographic and ground level survey.

3) **Satellite images**- Geo-eye high resolution satellite images are used for mapping. These images are geo-referenced and projected.

4) **Dredging Records**- Daily dredging reports are collected from site that includes the dredger activity, production report, fuel consumption and information about location.

5) **IHC Reports**- IHC Merwede provides solutions for optimum use of dredging equipment against minimum costs. It provides standard charts for certain conditions for different type of dredgers like IHC 6518, IHC 6525 and so on.

6) **Landuse**- With the help of high resolution satellite images and ground survey, land use features are captured. It helps to project the area that should be cut and filled. It also helps in laying path of floating and shore pipeline and so on.

**Database Creation, Mapping and Display Using ArcGIS:**

This section outlines the use of built in ArcGIS functionality for subsurface and dredging mapping. ArcGIS and its extension is used in geo-database creation and data manipulation.
Subsurface Mapping—Subsurface mapping is based on borelog data and borelog mapping. The borelog mapping is performed in two steps. The first step is the database creation and second is the display of data in desired form. Thereafter, Borelog data captured from ground survey and uploaded on geo-database. For better visualisation and to provide a better sense of understanding, borelog 3D mapping is done with the help of ArcScene.

Using interpolation method and borelog data, virtual soil surface is generated, which provides a real 3D view of the surface present beneath the sea and provides valuable underground information. It works as an input for DIMS and helps decision makers to decide which area to be dredged and thereby helping in optimising the project cost.

Dredging Mapping—Daily progress reports of various dredgers is collected from site on regular basis and it has been updated on dredging geo-database. ArcGIS tracking analyst extension helps to keep track on records of all the dredgers. It helps dredging planners for planning and calculating cost and time of projects.

Performed Analysis

Based on past 5 year’s experiences and records, an analysis is performed. This analysis helps in evaluating the standard performance that can be expected from existing dredgers under varying conditions. Various factors which impact the production level of dredgers on daily basis are incorporated in the software for better and actual approximation of the project cost and time required henceforth. These factors are stated as follows:

- Material Type- The material type is generally classified on the basis of grain size, type and compactness of the material.
- Discharge Distance- Discharge distance is defined as the distance at which the dredged material is disposed. It includes floating pipeline and shore pipeline.
- Unhindered dredging- Continuous dredging and pumping is required for higher production rate.
- Dredger Movement and depth of cut- Depth of cut and dredger movement have a great impact on the production rate of dredgers. Depth of cut is defined as the depth of material being dredged at the designated area. With shallow depth of cut, dredger shifting/movement increases. Thus, production per hour reduces.
- Original Condition of pump and pump parts- With aging of pump and pump parts, efficiency of the pump decreases. Hence a correction factor is incorporated on the basis of time lag that is actually present because of wearing pump and pump parts.
- Bends in pipeline (FPL & SPL)- Bends in FPL depends on the project site conditions. The number of Bends present in the pipeline is directly proportional to the resistance to the flow of material. Dredged material being a slug material, might choke the pipeline while passing through the bend and hence greater power and capacity is required to pump to the discharge end.
- Geodetic Head- Geodetic head is the height of shore pipeline take-off point from water level.
- Out of the above mentioned factors, the two that are most important and have a prominent effect on production rate are material type and discharge distance.
Dredge productivity

Dredge productivity can be estimated by following ways:

- By analyzing the capabilities of the dredger on current location and then comparing the performance of the same dredger on a different site but having the same project conditions.
- By reference to similar projects in the past i.e. on the basis of past records.
- By combining the above mentioned factors - Using ‘extend’ references

Theoretical Performance

Various tests are being performed by the dredge building companies to analyze the standard performance of dredgers. These tests are performed under various ideal conditions to know and analyse the workability range of the dredgers. With our 65 series and 75 series dredgers being IHC built, we have production graph provided by IHC.

<table>
<thead>
<tr>
<th>Criteria/Parameter</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original condition of Pump &amp; Part</td>
<td>Newly Built dredgers are Tested</td>
</tr>
<tr>
<td>Dredging Depth</td>
<td>-18mCD</td>
</tr>
<tr>
<td>Depth of Cut</td>
<td>1.5 to 2m</td>
</tr>
<tr>
<td>Continuous dredging time</td>
<td>4 hours continuous Dredging(without hindrance)</td>
</tr>
<tr>
<td>Pumping Distance</td>
<td>2000m</td>
</tr>
<tr>
<td>Floating Pipeline Length</td>
<td>Not more than 500m</td>
</tr>
<tr>
<td>No of bends in Pipeline</td>
<td>Only 1 bend in FPL, with not less than 45</td>
</tr>
<tr>
<td>Geodetic Head</td>
<td>4m</td>
</tr>
</tbody>
</table>
Figure 1: Production Graph Provided by IHC

However, in our projects, the conditions depend on different project sites and project requirements such as FPL length, Bends in FPL and SPL, Depth of Cut, Hindrances (like tree stumps, debris, and ship movements and traffic etc.). So incorporating all these factors along with the ideal case results, we can calculate the actual efficiency and workability of dredgers.
Table 2: A comparison of practical condition at our project sites with ideal conditions

<table>
<thead>
<tr>
<th>Criteria/Parameter</th>
<th>Ideal Conditions</th>
<th>Practical conditions in our projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original condition of Pump and Part</td>
<td>Dredgers are tested with new pumps</td>
<td>Pump, Pump parts are used till replacement is required, high wear &amp; tear</td>
</tr>
<tr>
<td>Depth of Cut</td>
<td>1.5 to 2m</td>
<td>Depends on project design. Desilting, sweeping etc. Activities need very shallow depth of cut (max 0.5m)</td>
</tr>
<tr>
<td>Continuous Dredging time</td>
<td>4 hr continuous dredging</td>
<td>Frequent breakdowns, anchor shifting, traffic, hindrance, site constraints etc. May not allow long periods of continuous dredging.</td>
</tr>
<tr>
<td>Pumping Distance</td>
<td>2000m</td>
<td>May vary based on priorities of dredging &amp; reclamation as per project requirements.</td>
</tr>
<tr>
<td>Floating Pipeline Length</td>
<td>Not more than 500m</td>
<td>Generally ranges from 400 m to 1000m, based on project requirements.</td>
</tr>
<tr>
<td>No. Of Bends in Pipeline (Both FPL &amp; SPL)</td>
<td>Only 1 bend, with not less than 45</td>
<td>Depends on traffic &amp; movements, site restrictions, Dredging &amp; reclamation plan, other project activities (likely jetty construction etc.)</td>
</tr>
<tr>
<td>Geodetic Head</td>
<td>4m</td>
<td>Goes up to 9m</td>
</tr>
</tbody>
</table>

Customized tool in ArcGIS for DIMS

GIS acts as a tool in DIMS and it designed to provide quick and fast results /output, under all the practical conditions. There are two customized tools for DIMS. First being the Productivity Estimation tool. It gives the information about production rate of a dredger with respect to the change in discharge distance. And second being the Time Estimation Tool. It calculates that how much time is required to reclaim the target area.

Productivity Estimation tool

For the customization of this tool following parameters are considered:

- Type of Dredger
- Dredger Model
- Rock Density
- Rock type
- N value of rock
- Depth of Cut
- Discharge Length
- Pumping Capacity
- No of bends
- Dredging Time
- Geodetic Head

It requires discharge distance as an input from user. Depending upon the model it calculates the productivity rate of dredger.
Time Estimation Tool

For evaluating this tool we require two inputs from user. First is the volume required to reclaim the area of interest, the volume is indeed obtained from the ‘cut fill analysis’ and the second input is the productivity rate of the dredger that is obtained from the above mentioned productivity estimation tool.

Methodology

Currently Mundra Port has dredgers, along with off-shore support resources as well as onshore support resources. The Ultimate goal is to achieve optimum dredging production and operating costs that will meet the project requirements as planned and desired by the management.

Work Flow

Following steps are involved to get desired output from ArcGIS:

- **3D Mapping of borelog data**: Borelog data is collected and mapped 3Dimensionally to prepare grounds for performance of subsurface mapping.

- Subsurface mapping with the help of borelog information and ArcGIS functionalities.

![Figure 2: Showing 3D Mapping of borelogs, dredging lines and subsurface](image-url)
• Dredging Material is used to raise ground level or reclamation purpose. In the project where high ground level is required, dredging material is used for that.

• For reclamation first we require cut-fill volume of that location. It could be obtained by ArcGIS built in tools.

Use of Productivity Estimation Tool:

Figure 3: Showing Borelog Data Window on Clicking the desired Borelog layer

Figure 4: It requires discharge distance from user as input. It is a variable parameter. On the click of button it ask for material density.
Use of Time Estimation Tool

Figure 5: The output (productivity rate) as shown after computation to be 250 (cu. Meter /hour) after providing density input from the user.

Figure 6: The output in days i.e. 87 days that is being evaluated after providing the fill volume and production rate.
Conclusion

It can be concluded that after preparing the database, doing cut fill analysis, choosing the pipe length for dredged material (both onshore and off shore), dredger type and entering the density of dredged material i.e. 2200 kg/m3 here, we get the production rate to be 250 cubic meter/hour. From this production rate we obtained the fill volume to be 313411 cubic meter and further time estimation tool gives the value to be 87 days.

This data is useful for dredger planners in computing the dredger efficiency, accuracy output and to schedule accordingly the location of dredger at different sites after getting to know the amount of time that could be spent by a single dredger at a particular location.

References

- Nil Guler, "Evaluation of port development projects by the benefit cost analysis", December 2003.
- Report on "Understanding dredging production and cost"