OPEN WATER DISPOSAL OPTIMIZATION USING LINEAR PROGRAMMING

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ABSTRACT

A linear programming optimization model has been developed to assist in the development of dredging plans at open water disposal sites. The model formulation for a linear programming model that has been developed based on conditions at an open water disposal site E near the mouth of the Columbia River is described. Ultimately the linear programming models developed will be integrated with the MDFATE computer program to automate the generation of dumping plans. This program is being developed as a module of the Goethals Dredging Operations Decision Support System. Initial testing of the linear programming model indicates that it produces reasonable dumping plans.

Keywords: Dredging, dredged material disposal, modeling, decision support systems, disposal plans

INTRODUCTION

An iterative process is often used to help manage the utilization of open water disposal sites. The MDFATE computer program can be used to determine the short and long term fate of the dredged material to assist planners in determining dumping plans that will best utilize the disposal site. A site that is managed in this way is Site E at the mouth of the Columbia River. Corps of Engineers planners use knowledge of how disposed materials are dispersed at a disposal site to continuously modify and update dredging plans during the dredging season. Output generated by modeling techniques like MDFATE, and expert knowledge gained from past dumping activities are used by the Corps of Engineers to update the dredging plans.

The major constraints considered by the Corps of Engineers are to remain within the target capacity of a given site including both height and area. Management of an open water disposal site is predicated on the need to efficiently utilize the site's capacity while minimizing impacts to navigation and offsite environment, and meet statutory requirements. The capacity of a dredged material disposal site is the volume (or height and area) of dredged material that can accumulate within a site's boundaries without unacceptable adverse impacts to navigation or the environment. The potential effect of dredged material accumulation upon waves (mound-induced wave shoaling) is also an important consideration when planning disposal activities (Moritz et al. 1999).

MDFATE Computer program

MDFATE is a numerical simulation for open water dredged material disposal sites. Inputs to the MDFATE model include existing the bathymetry, the locations of dredged material disposals, the nature of the disposed material, tides, and currents. The output of MDFATE is a spatial calculation of the bathymetric changes caused by the dredged material placement operations (Moritz 1994).

Purpose of the Paper

The purpose of this paper is to describe how linear programming can be applied to assist in the production of dredging plans. The linear programming model we have developed will accept elevation inputs from the MDFATE model and then produces an optimized dumping plan based on the constraints at the ocean dumping site. The goal of this system is to enhance the revisions made to dredging plans so they utilize an open water disposal site in the optimal manner. The potential benefit of this system is to maximize the amount of material that can be dumped at a particular disposal site. The improved utilization of a site can result in reduced dredging costs because cheaper near shore sites can be fully utilized rather than transporting the material to more expensive sites farther offshore. Additionally, the used of the optimization model combined with MDFATE may allow for dumping plans to be updated more frequently, and for the production of dumping plans with longer time horizons.

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Goethals DODSS

The dredging optimization model is being constructed as a component of the Goethals Dredging Operation Decision Support System. The Goethals DODSS will provide dredging operation managers with a decision support tool to provide a synthesis of past and present data, execute mathematical models and simulations, reason with heuristic knowledge, and an easy to understand visual interface.

Linear Programming

A linear programming model is a mathematical program that attempts to identify an extreme point of a function which satisfies a set of constraints. Both the objective function and the problem constraints are linear. Linear programming is an optimization tool which allows the rationalization of many managerial and or technological decisions (Reveliotis 1997). In this paper we are exploring how linear programming can be used to assist in dredging plans that utilize the disposal site in an optimal manner.

TEST PROBLEM AND LINEAR MODEL FORMULATION

The initial open water disposal site that we have applied the linear programming technique to is a site near the mouth of the Columbia River. The site, Location E, has several constraints. The Location E site is near the shore, and is managed to prevent mounded dredged material from excessively amplifying waves due to shoaling and refraction (Site Plan 2003). Because the sight is near shore, it is also sometimes more difficult to dump in some areas of the site due to tides and currents. Additionally, normal dredging practice requires that a dump occurs in all of the dredging cells before a second dump can be made in the cell. All of these concerns are reflected in the linear programming model.

Linear Programming Model

The linear programming model has been developed to fully utilize each part of the disposal site. First we will define the decision variables and parameters. The decision variables are the volumetric amount of placement by each vessel at every part of site. To achieve full utilization of the entire disposal site, the site was partitioned into a system of cells (about 500 x 500 ft). The following variables are defined:

X_{ik}= volumetric amount of placement by vessel k at cell i (1)

E_{ik}= volumetric residual placement by vessel k at cell I (2)

R_{ij} =existence of a path from cell i to cell j (R_{ij} is a binary variable) (3)

Cell Capacity and Objective Function

The capacity of a cell is the volume of dredged material that can accumulate within a cell's boundaries without unacceptable adverse impacts to the environment. The target capacity for a given cell is defined by target height and area over which dredged material can accumulate, with respect to a baseline condition. The capacity of each cell is defined as:

C_i=capacity of cell i (4)

Based on the cell capacity and location, there are 3 levels that will be used for managing disposal site:

- Level 1 (Dredged material accumulation is less than the cell capacity): Continue to use area of this cell appropriately
- Level 2 (Dredged material accumulates is equal to cell capacity or Cell Located on the edges): Avoid placement, continue to use adjacent areas within site appropriately
- Level 3 (Capacity level exceeded): Avoid placement in this cell and in adjacent cells

The coefficients of the objective functions are specified depending on the location and remaining capacity of the cells. We allocate different coefficients to each cell based on the level of the cell. The objective of our model is to prevent any placement in any cells that are above level 1 and in any cells that are adjacent to cells at level 3. Therefore we have:

Co_i=1 if cell i is in level 1 (5)

Co_i=10 if cell i is in level 2 (6)

Co_i=Co_j=100 if cell i is in level 3 and $R_{ij=1}$ (7)

The objective function is defined as:

$$\text{Min} \sum_i \sum_j \sum_k Co_i.X_{ij} \tag{8}$$

Additional Constraints

To be realistic, the model also must include equations to limit the decision variables. First, the values of the decision variables must be nonnegative.

$$X_{ij}>=0 \tag{9}$$

$$E_{ij}>=0 \tag{10}$$

Second, the amount of dredged material that can be placed in a disposal site is limited by the site's capacity to disperse or accumulate the material without adversely affecting the environment.

$$\sum_i \sum_j (X_{ij}+E_{ij})<=C_i \tag{11}$$

Third, the total volume placed by each vessel cannot exceed the capacity of the vessel.

$$X_{ij+} R_{ik} \sum_k E_{kj}<=\text{Vessel Capacity} \tag{12}$$

$$E_{kj} <= 1000^* R_{ik} \quad \text{for every cell k} \tag{13}$$

Forth, all cells must be filled before placing a second load in any cell; all cells designated for two loads must be filled before placing a third load in any cell.

For every vessel j:

X_{ij} <=M* (1- Y_{ij}) (M is a big number, Y_{ij} is a binary variable) (14)

$$\text{If} \sum_{k=1}^{j-1} X_{ij} - \text{Min}_i \sum_{k=1}^{j-1} X_{ij} >0 \text{ then } Y_{ij}=1 \tag{15}$$

$$\text{If} \sum_{k=1}^{j-1} X_{ij} - \text{Min}_i \sum_{k=1}^{j-1} X_{ij} =0 \text{ then } Y_{ij}=0 \tag{16}$$

Suppose we have 8 cells and 4 vessels. Now for example consider vessel number 3 enters the site so that j=3. For cell 5 we have:

$$X_{51}+X_{52}-\min\{(X_{11}+X_{12}),(X_{21}+X_{22}),(X_{31}+X_{32}),(X_{41}+X_{42}),(X_{51}+X_{52})\} \tag{17}$$

If our min is ($X_{51}+X_{52}$) it means that all cells are filled) and $\sum_{k=1}^{j-1} X_{ij} - \text{Min}_i \sum_{k=1}^{j-1} X_{ij}$ will be 0 and Y_{53}=0. From equation (14) we have X_{53}<=10000(1-0) so we can have dump at cell 5. If our min isn't ($X_{51}+X_{52}$) it means that all cells aren't filled and $\sum_{k=1}^{j-1} X_{ij} - \text{Min}_i \sum_{k=1}^{j-1} X_{ij}$ will be >0 and Y_{53}=1. From equation 14 we have X_{53}<=10000(1-1) so X_{53} should be zero and we cannot dump in that cell. Therefore, all cells must be filled before placing a second load in any cell.

Programming Language

We are developing computer code for the linear programming model as a MATLAB function. MATLAB is a high performance language for technical computing (Mathworks 2004). MATLAB was employed because this will allow the linear programming model to be included in the Goethals DODSS system.

Next Steps in Model Development

The linear programming model is currently being tested. Initial results indicate that the model produces reasonable dredging plans. We will continue to test the model and will compare it to actual dredging plans. We will then link the linear programming model to the MDFATE program to develop a system that can automatically accept the output of the MDFATE program and use it to automatically modify dredging plans.

FUTURE DEVELOPMENT WORK

This initial model has been developed specifically for the conditions at Site E. We plan on exploring how various constraints in the model could be turned on and off to allow it to be tailored to conditions at different sites. We will also explore how real time data from the Silent Inspector system could be used to provide rapid updates of dredging plans. We will continue to explore how the model can be incorporated in the Goethals DODSS framework.

CONCLUSIONS

This paper describes a linear programming optimization model that produces dredging plans. The model constraints have been developed based on the conditions at an open water disposal site near the mouth of the Columbia River. The initial testing we have done with this model indicates that it produces feasible dredging plans. We plan on continuing to develop the model so that it exchanges data with the MDFATE program to automate the production of dredging plans and improve the utilization of open water disposal sites..

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REFERENCES

Mathworks Inc., (2004) Getting Started with MATLAB, Natick, MA.

Moritz, Hans R. (1994) Users Guide for the Multiple Dump Fate Model, Contract Number DACW39-94-M-1304, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Moritz, H.R., Kraus, N.C., Hands, E.B. and Slocum, D.B. (1999). “Correlating Oceanographic Processes with Seabed Change, Mouth of the Columbia River, USA, Proceedings of the Coastal Sediments ’99 Conference, American Society of Civil Engineers, pp. 1643-1659.

Reveliotis, S., (1997) “The LP formulation and underlying assumptions,” An Introduction to Linear Programming and the Simplex Algorithm, www.isye.gatech.edu/~spyros/LP/node1.html (April 14, 2005).