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Analysis of Decision Support System for Dredging Operations Management

NONLINEAR PROGRAMMING MODEL TO OPTIMIZE THE USE OF OPEN WATER DISPOSAL SITES FOR DREDGED MATERIAL

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Submitted by

Trefor P. Williams*
Professor

Mohsen Jafari **
Professor

Haleh Valian **
Graduate Research Assistant

* Center for Advanced Infrastructure & Transportation (CAIT)
Civil & Environmental Engineering Department
Rutgers, the State University of New Jersey
Piscataway, NJ 08854-8014

** Center for Advanced Infrastructure & Transportation (CAIT)
Department of Industrial Engineering
Rutgers, the State University of New Jersey
Piscataway, NJ 08854-8014

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16. Abstract

This research developed an improved method for optimizing the disposal of dredged material at offshore disposal sites. A nonlinear programming model has been developed to assist in the development of dredging plans at open water disposal sites. The model has been developed based on conditions at the near-shore open water disposal site near the mouth of the Columbia River. The optimization model considers available capacity of cells within the disposal area to produce a dredging plan that minimizes mounding within the site. Ultimately, the optimal dumping plans will be loaded in the MDFATE computer program to simulate various stages of the dredging disposal cycle. Initial testing of the optimization model indicates that it produces reasonable dumping plans.

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INTRODUCTION

This research developed an improved method for optimizing the disposal of dredged material at offshore disposal sites. A nonlinear programming model has been developed to assist in the development of dredging plans at open water disposal sites. The model has been developed based on conditions at the near-shore open water disposal site near the mouth of the Columbia River. The optimization model considers available capacity of cells within the disposal area to produce a dredging plan that minimizes mounding within the site. Ultimately, the optimal dumping plans will be loaded in the MDFATE computer program to simulate various stages of the dredging disposal cycle. Initial testing of the optimization model indicates that it produces reasonable dumping plans.

An iterative process is often used to help manage the utilization of open water disposal sites. The MDFATE computer program is used to predict the bathymetric changes caused by the dredged material placement operations and can be used to determine the short and long term fate of the dredged material to assist planners in determining dumping plans that will attain best utilization of site volumetric capacity. 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 the 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 is numerical simulation software for open water dredged material disposal sites. Inputs to the MDFATE model include the existing 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). This report describes the development of a nonlinear optimization program that will be linked with MDFATE to produce dredging plans that improve the utilization of offshore disposal sights.

BACKGROUND

Dredging, involving the removal of accumulated bottom sediments, is necessary to maintain channel depths for safe and efficient vessel operations. In U.S. waters, the U.S. Army Corps of Engineers (USACE) is authorized to maintain 131 navigation-related projects, nearly all of them commercial and recreational harbors and navigation channels. Many of these projects require periodic dredging. For other commercial and recreational harbors, some are privately owned and maintained or state and local jurisdictions have responsibility (Thorp, 1996). After the sediment has been excavated, it is transported from the dredging site to the placement site or disposal area. Once the dredged material has been collected and transported, the final step in the dredging process is placement in either open-water, confined disposal, or for beneficial uses (USACE, 1992).

Open-water disposal means that dredged material is placed at designated sites in oceans, estuaries, rivers and lakes such that it is not isolated from the adjacent waters during placement (USACE, 1992). Open-water disposal sites adjacent to maintenance dredging areas typically provides the least cost disposal option, but most of the designated open-water sites have either filled to capacity or have been discontinued due to environmental concerns, so that it is essential that the remaining capacity of available open-water sites be maximized in an environmentally acceptable manner (Panageotou, 2002)

The appropriate disposal of material dredged from navigation projects is a nationwide issue but has important implications for the use, management and protection of waters in the Columbia River (Thorp 1996). The U. S. Army Corps of Engineers is responsible for the operation and maintenance (O&M) of the federal deep-draft navigation channel at the Mouth of the Columbia River (MCR). Each year, the Corps of Engineers-Portland District dredges 3-5 million cubic yards (MCY) of sand at the mouth of the Columbia River (MCR) to maintain the inlet's 6-mile long deep draft navigation channel. The dredged material that is to be placed within available MCR disposal sites will originate from the MCR channel navigation and the Lower Columbia River (LCR) navigation channel. Dredging is limited to summer when wave conditions are favorable for working on the bar (USACE 2003a). Between available disposal sites, site E is preferred. This means that priority will be given to utilize the available capacity of the site E (USACE 2005).Site E is located on the ebb tidal delta of the Columbia River, about ¼ mile seaward of the MCR north jetty.

The Management objective for site E is to efficiently utilize the site's capacity for the disposal of MCR dredged material, while limiting the average vertical accumulation of placed dredged material so as to avoid adversely affecting navigation at or near the site, and meet statutory requirements (USACE 2003). 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).

The US Army Engineer District, San Francisco developed a model for dredged-material disposal Management (SPN-D2M2). This model solves the problem of allocating material to different disposal sites to minimize the cost of operating the system. The SPN-D2M2 model only considers cell capacity as a constraint. This paper develops a nonlinear model and considers the additional constraints of the dredged material would be placed though out the entire site using a regimented procedure to produce a uniform continuous layer on the seabed, avoiding the formation of any localized mounding.

Ratick et al. (1992) developed a reliability based dynamic dredging decision model that employs a simulation-optimization approach combining a simulation model of stochastic channel conditions with a dynamic location model to schedule the optimal deployment and activity levels for dredges. The multiobjective optimization model assigns demobilization and mobilization costs in periods when a facility is moved from one location to another, and allows for advanced maintenance dredging, ‘over-dredging’ in some time periods, in order to reduce overall costs. The dredging costs considered in the model are comprised of fixed costs that are assessed each period and vary by size and type of dredge employed and variable costs that are dependant upon the amount of material dredged in any month, and mobilization and demobilization costs — incurred each time a dredge is moved to a new location. The multiobjective optimization has been developed to minimize dredging cost. Our paper develops a model for minimizing environmental costs of disposal allocation. The crux of this problem is to choose an appropriate disposal plans from the vast range available. This paper contributes to resolving this selection process through the application of a simulation-optimization approach.

REASONS FOR NONLINEAR MODEL DEVELOPMENT

There are several ways in which a nonlinear programming model can be applied to assist in the production of dredging plans. The goal of this modeling is to enhance the revisions made to dredging plans so they utilize an open water disposal site in the optimal manner. The model produces an optimized dumping plan based on the constraints at the ocean dumping site. The potential benefit of this system is to maximize the amount of material that can be dumped at a particular disposal site. 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.

THE NONLINEAR PROGRAMMING MODEL

The model has 4 parameters as follows:

1. Capacity_i=capacity of cell i

The capacity of cell is the volume of dredged material that can accumulate within the 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.

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.

2. $Road_{ij}$ =existence of way from cell i to cell j

   Based on the location of the cells, there are 3 values for Road:

   - $Road_{ij} = 0$ if cell i and cell j are not neighbors
   - $Road_{ij} = -1$ if cell i and cell j are neighbors and common area is only one point
   - $Road_{ij} = 1$ otherwise

3. $Cost_i$ =cost of dump in cell i

   The cost of cell is specified depending on the location and remaining capacity of the cell. Different cost is allocated to each cell based on the level of the cell:

   - $Cost_i=1$ if cell i is in level 1
   - $Cost_i=10$ if cell i is in level 2
   - $Cost_i= Cost_j=100$ if cell i is in level 3 and $Road_{ij}=1$

4. CapV= capacity of the vessel

   The capacity of the vessel is the volume of dredged material that can be in each vessel.

Objective Function

The object of the model is to fully utilize capacity of cells and prevent any placement on the avoiding zone. The objective function is defined as:

$$\text{Min} \sum_i \sum_j \text{Cost}_{(X_{ij})} . A_{ij}$$

Where X_{ik} =the cell number of placement in plan ith at dump kth,and A_{ik} = volumetric amount of placement in plan i^{th} at dump k^{th} .The coefficients of the objective functions are specified based on the revised capacity assessment after every plan.

Constraints

To be realistic, the model also must include equations to limit the decision variables as follows:

1. The values of the decision variables must be nonnegative.
   $A_{ij}>=0$
   $X_{ij}>=0$
2. Amount of dredged material that can be placed in every cell is limited by the cell's capacity
   $\sum_i \sum_k A_{ik} < capacity_j$ for all i,k which $X_{ik}=j$
3. The total volume placed by each plan can't exceed the capacity of the vessel
   $\sum_i \sum_k A_{ik} < CapV$
4. Every dump in each plan shall be chosen uniformly
   X_{i1} is not member of the $\{X_{kj}, k=1\ldots i-1; j=1\ldots 5\}$
   X_{i2} is not member of the $\{X_{kj}, k=1\ldots i-1; j=1\ldots 5\}$
   X_{i3} is not member of the $\{X_{kj}, k=1\ldots i-1; j=1\ldots 5\}$
   X_{i4} is not member of the $\{X_{kj}, k=1\ldots i-1; j=1\ldots 5\}$
   X_{i5} is not member of the $\{X_{kj}, k=1\ldots i-1; j=1\ldots 5\}$
5. There is a path between each dump.
   $RoadX_{i1},X_{i2}\neq 0$
   $RoadX_{i2},X_{i3}\neq 0$
   $RoadX_{i3},X_{i4}\neq 0$
   $RoadX_{i4},X_{i5}\neq 0$
6. All dumps should be placed in one of the 87 cells
   $X_{ik}\geq 1$
   $X_{ik}\leq 87$

Programming Language

We are developing computer code for the nonlinear 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 nonlinear programming model to be included in the Goethals Dredging Operations Decision Support System. 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.

MODEL TESTING: SITE E AT THE MOUTH OF THE COLUMBIA RIVER

This nonlinear programming (NLP) model is applied to a disposal site near the mouth of the Columbia River. To achieve full utilization of the entire disposal site, the site was partitioned into a system of cells (about 500 x 500 ft) and capacity of each cell is defined. Figure 1 shows an example of cell capacity for Site E.

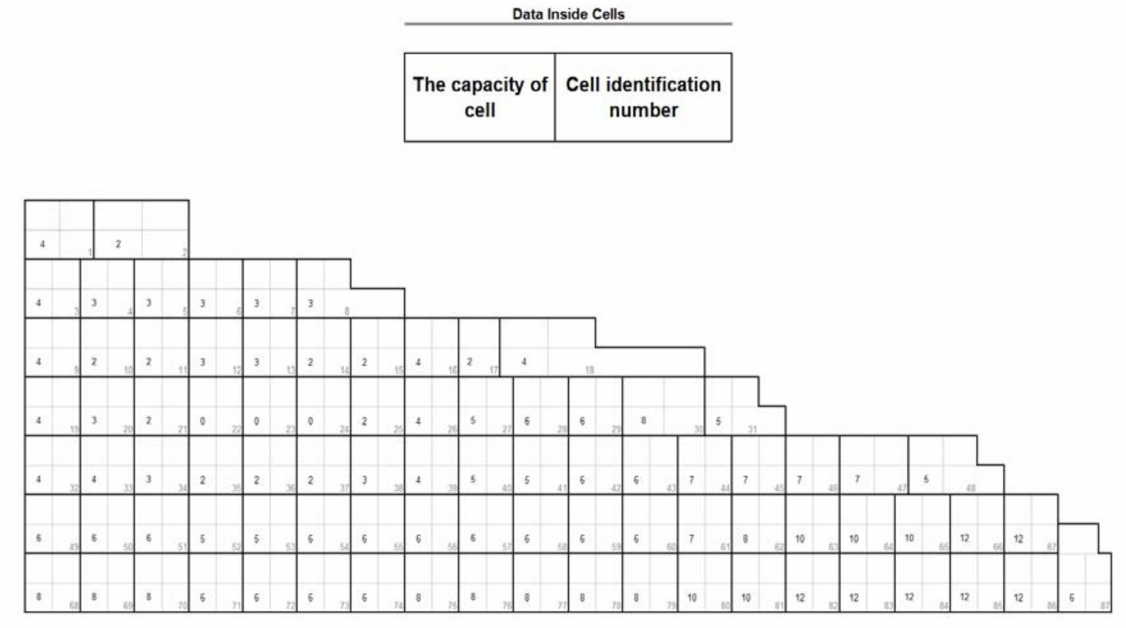

Figure 1. Example of cell capacity for site E

Site E has several constraints. First, the site E is near the shore, and is managed to prevent mounded dredged material from excessively amplifying waves due to shoaling and refraction. Second, normal dredging practice requires that a dump occurs in all of the dredging cells before a second dump can be made in the cell. Third, each plan shall be distributed across no less 2 cells and no more than 5 cells. Fourth, no part of the site can be filled more than its capacity. All of these concerns are reflected in the nonlinear programming model. The model is coded as program written in MATLAB. Output of program is cell numbers and volume of dredged material in each dump.

For instance, if a period of 14 days is considered, 160 plans will be assumed. By running the program, the dredge will have 160 disposal plans within the disposal site. As an example, consider cell 76 with capacity 8 thousand cubic yard. Output of program will give us 160 disposal plans which cell number 76 has placements at plan 10, plan 35 and plan 141 with amounts of 0.6 thousand cubic yard, 0.5 thousand cubic yard, and 0.9 thousand cubic yard by sequence. Based on that, material shall be credited to cell number 76 and a new capacity will be calculated. That means, the original capacity in cell number 76 before generating 160 dumping plans in the site is 8 thousand cubic yards. This compares to a capacity of 6 cubic yards (8-(.6+.5+.9)) after 160 plans. Figure 2 shows the capacity of cells before and after 160 plans. The result of the optimization model (figure 2) indicates that the program produces reasonable dumping plans, because as it shows in figure 2, after placement the dredging material we do not have any new cell with capacity zero and also produces a uniform continuous layer on the seabed.

VALIDATION

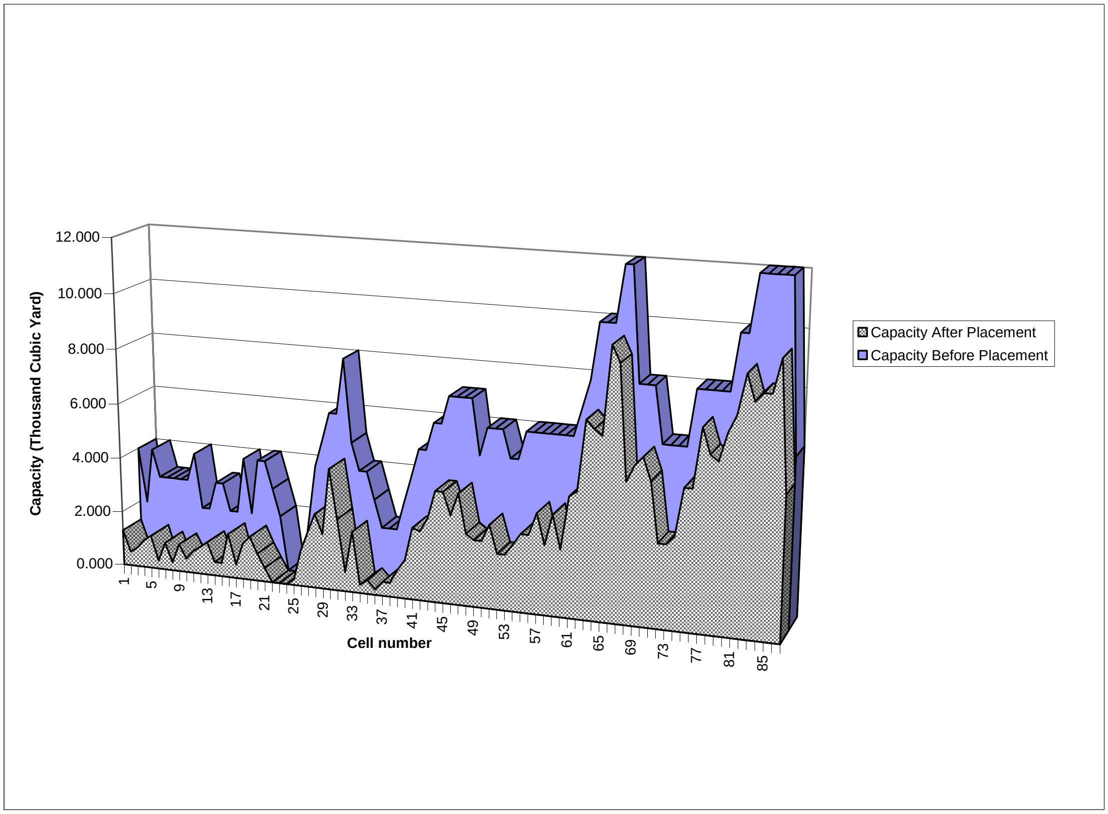

Figure 2. Capacity of cells before and after 160 dumps

The model was run varying the cell capacities and vessel capacities randomly to examine the sensitivity of the optimal solutions to these parameters. Random values of cell capacities for each cell were generated assuming normal distributions around the mean values with a standard deviation equal to 10 percent of the mean. As the objective was to examine the sensitivity of the results, such an arbitrary approach is adequate.
The model was run 10 times. The optimal level of the objective function was found to be highly sensitive to the cell and vessel capacities.

Every dump in each plan shall be chosen in a way that they produce a uniform continuous layer on the seabed, avoiding the formation of any localized mounding. Proportion of uniformity is calculated in each run as follows:

- Step 1.Subtract capacity after Running MDFATE from capacity before placement dredging material for each cell.
- Step 2.Find number of cells which result of step 1 is equal to mode.
- Step 3.Divide the result in step 2 by 87.

If first dump is chosen uniformly and the other dump is chosen randomly the proportion of uniformity will be as figure 3, but if all dump is chosen uniformly the proportion of uniformity will be improved.

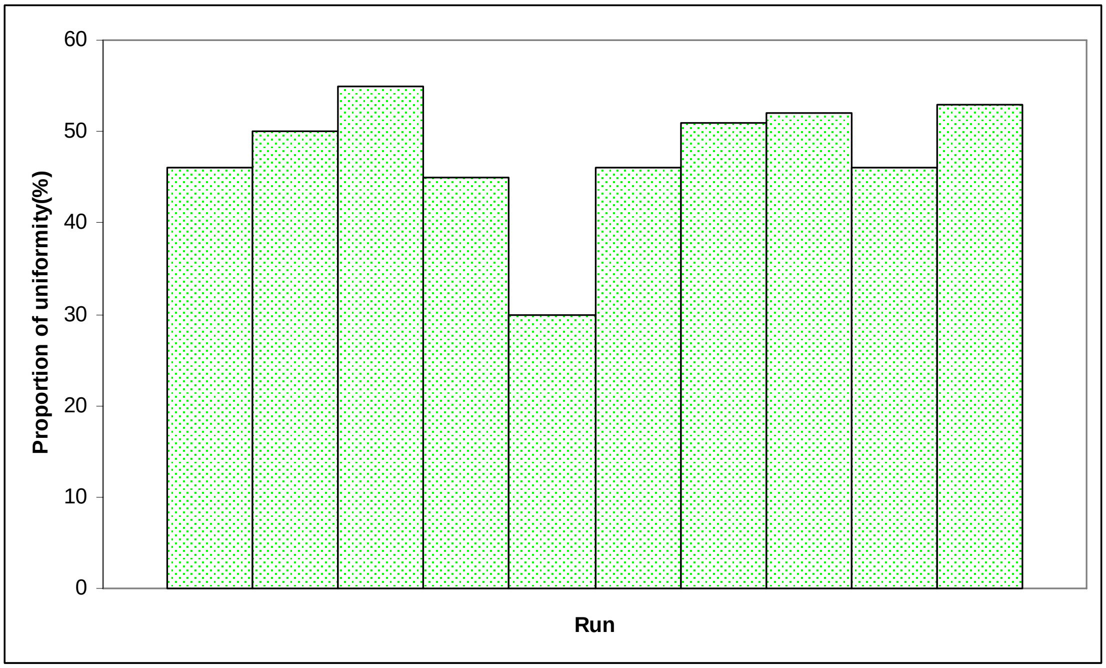

Figure 3. Proportion of uniformity in 10 runs

This graph shows that we have from 30 to 58 percent proportion of uniformity in our placement. Actual placement plans have 31% proportion of uniformity. Therefore, the result of this model has better proportion of uniformity than the actual dredging plans.

CONCLUSIONS AND FUTURE DEVELOPMENT WORK

This paper describes a nonlinear programming optimization model that produces disposal 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 testing we have done with this model indicates that it produces feasible disposal plans. We plan on continuing to develop the program 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.

The nonlinear programming model is currently being tested. We will then link the nonlinear 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.

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.

NOMENCLATURE

X_{ik} =the cell number of placement in plan i^{th} at dump k^{th},
A_{ik} = volumetric amount of placement in plan i^{th} at dump k^{th}
~~1.~~$Cell_i$=partition i of the disposal site
~~2.~~$Capacity_i$=capacity of cell i
~~3.~~$Path_{ij}$ =existence of way from cell i to cell j
~~4.~~$Cost_i$ =cost of dump in cell i
~~5.~~CapV= capacity of the vessel

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At the time of preparation of this report, Dr. James R. Houston was Director of ERDC, and COL James R. Rowan, EN, was Commander and Executive Director.

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