Improved Resource Allocation for Dredge Scheduling and Procurement

Heather Nachtmann, Ph.D.
Chase Rainwater, Ph.D.
Edward Pohl, Ph.D.
Department of Industrial Engineering
University of Arkansas

Kenneth Ned Mitchell. Ph.D.
Coastal and Hydraulics Laboratory
U.S. Army Engineer Research and Development Center

CMTS/TRB Conference
June 2012 – Washington, D.C.

Project Overview

- Each year the U.S. Army Corps of Engineers (Corps) dredges hundreds of navigation projects through its fleet of government dredges and individual contracts with private industry
- Decision of assigning dredging resources to navigation projects is predominately being made at the District-level through lowest-cost contracts
- Efficiencies can be gained by studying the dredging project portfolio at the system-level
- Goal is to develop a system-level decision support approach that optimizes the decision of allocating dredge resources to projects under necessary system constraints such as environmental windows, dredge resource cost and availability, and District-level project requirements

Research Objective

- To minimize the aggregate cost the Corps incurs to complete their dredging portfolio while achieving compliance and desired system performance
  - What is optimal dredging resource mix (government vs. private)?
  - What are optimal project-resource assignments?
  - Given a finite budget and limited dredging resources, what is the optimal dredging project sequence (including project duration dates)?
  - How does future placement of new environmental windows and potential relaxation of overly restrictive environmental windows impact system efficiency?

Environmental Windows

- “Temporal constraints placed upon the conduct of dredging or dredged material disposal operations in order to protect biological resources or their habitats from potentially detrimental effects” (Dickerson, et al., 1998)
- Environmental windows are intended to minimize environmental impacts by limiting the conduct of dredging activities when biological resources are not present or are least sensitive to disturbance
- USACE surveys indicate that approximately 80% of all Civil Works O&M dredging projects are subject to some form of environmental window constraint

Dredge Fleet Scheduling & Assignment

Minimizing Demobilization and Mobilization Travel Time/Distance

Subject to

- Environmental Windows: The EPA and state departments of environmental quality place restrictions on when dredging can take place due to migration patterns of turtles, birds, fish, and other wildlife.
- Resources Limitations: Not all dredge equipment can complete every type of project and the amount of dredge equipment available is limited.
- Equipment Productivity: Dredge equipment has varying productivity rates that affect project completion times and environmental impacts

Sets

- Require the following set definitions to account for the key components of our scheduling problem

- D (indexed by d) be the set of dredging equipment resources available in each time period;

- T (indexed by t) be the set of consecutive time periods comprising the planning horizon;

- J (indexed by j) be the set of dredge jobs that need to be completed over the planning horizon;

- W_j (indexed by w) be the set of environmental windows applicable to dredging job j.

Parameters

- Elements of the various sets contain specific properties that drive the decisions made by our model

- b_w is the beginning of environmental window w $(w \in W_j;\ j \in J)$;
- e_w is the end of environmental window w $(w \in W_j;\ j \in J)$;
- t_j^d is the time (in days) that it takes for dredging equipment piece d $(d \in D)$ to complete j $(j \in J)$;
- $t_{j,j'}^m$ is the time (in days) that it takes to move dredging equipment piece d $(d \in D)$ from job site j to job site j' $(j \in J; j' \in J; j \neq j')$.

Decision Variables

- y_{dj} is a binary variable with value 1 if dredging equipment piece d is used to complete job j;
- z^{-}_{djt} is a binary variable with value 1 if dredging equipment piece d *begins* work on job j in period t;
- z^{+}_{djt} is a binary variable with value 1 if dredging equipment piece d *ends* work on job j in period t;
- α_{dj} is the day that dredging equipment piece d *begins* work on job j;
- β_{dj} is the day that dredging equipment piece d *ends* work on job j.

Objective Function

- Minimize the number of dredging days
  - Equivalent to minimizing the cumulative span across all jobs

$$\sum_{j \in J} \sum_{d \in D} (\beta_{dj} - \alpha_{dj})$$

Constraints

- Single Assignment Restriction
  - Each job must be assigned to a single piece of equipment

$$\sum_{d \in D} y_{dj} = 1 \quad j \in J$$

- Specifying Start/End of Job
  - If job *j* is satisfied by equipment *d*, exactly one start and end day for that work must be specified for that assignment

$$\sum_{t \in T} z^{-}_{djt} = y_{dj} \quad j \in J;\ d \in D$$

$$\sum_{t \in T} z^{+}_{djt} = y_{dj} \quad j \in J;\ d \in D$$

Constraints (cont.)

- Translating Binary Indicator Dates to Integers

$$\alpha_{dj} = \sum_{t \in T} z^{-}_{djt} \times t \quad j \in J;\ d \in D$$

$$\beta_{dj} = \sum_{t \in T} z^{+}_{djt} \times t \quad j \in J;\ d \in D$$

- Feasible Job Spans
  - If job *j* is satisfied by equipment *d*, the time between the start and end of that job must be consistent with time required for the equipment to complete job *j*

$$\beta_{dj} - \alpha_{dj} = t^{d}_{j} y_{dj} \quad j \in J;\ d \in D$$

Constraints (cont.)

- Equipment Travel Time
  - If job *j* is concluded in period *t*, by equipment *d*, then equipment *d* cannot begin another job, *j'*, until an appropriate number of periods have passed (i.e. the time to travel to job *j'*)

$$\sum_{t'=t}^{t+t^m_{jj'}} z^-_{dj't} \leq 1 - z^+_{djt} \quad j \in J;\ j' \in J;\ j \neq j';\ d \in D;\ t \in T$$

- Environmental Windows
  - Must prevent a job from beginning, or ending, on a day that overlaps with an environmental window

$$\sum_{d \in D} \sum_{t=b_w}^{e_w} (z^-_{djt} + z^+_{djt}) = 0 \quad w \in W_j;\ j \in J$$

Current Model Facts

- Model complexities create a difficult problem to solve
- For a 30 job, 5 resource (equipment), 365 day planning problem
  - # of decision variables is 109,950
  - # of constraints that must be considered is over 1.5 million (without even considering the environmental restrictions)

Sample of 10 Dredging Projects

Dredging Projects	
1	Barnegat Inlet-000950
2	Calc River And Pass-002440
3	Chesapeake And Delaware Canal-008160
4	Grays Harbor And Chehalis River-006770
5	Miss River - Br To Gulf-000068
6	Mobile Harbor-011670
7	Morro Bay Harbor Ca-011860
8	Ocean City Harbor And Inlet And Sinepuxent-073567
9	Pascagoula Harbor-013680
10	Philadelphia To The Sea-

Sample Dredge Project Distance Matrix

Dredge Project	Dredge Project (Distances in Nautical Miles)									
	1	2	3	4	5	6	7	8	9	10
1	0	2077	114	7666	2195	1772	6705	419	1847	87
2	2077	0	2104	5589	423	458	4628	1886	409	2191
3	114	2104	0	7693	1994	1571	6732	218	1646	87
4	7666	5589	7693	0	6012	6047	961	7475	5998	7780
5	2195	423	1994	6012	0	348	5051	1776	273	2081
6	1772	458	1571	6047	348	0	5086	1353	75	1658
7	6705	4628	6732	961	5051	5086	0	6514	5037	6819
8	419	1886	218	7475	1776	1353	6514	0	1428	305
9	1847	409	1646	5998	273	75	5037	1428	0	1733
10	87	2191	87	7780	2081	1658	6819	305	1733	0

Sample Dredge Resource Data

Dredge Resource	Productivity Rate (CY dredged/day)
A	5,000
B	24,867
C	1,774
D	9,879
E	3,721

Sample Dredge Project Data

Project Number	Cubic Yards Dredged	Restricted Period Begin Date	Restricted Period End Date	# of Restricted Days
1	136,230	18-May	13-Dec	209
2	1,573,729	14-Mar	18-Dec	279
3	67,221	14-Mar	18-Dec	279
4	357,149	1-Jan	20-Mar	78
		15-May	31-Dec	230
5	404,418	1-Jan	15-Aug	226
		27-Oct	31-Dec	65
6	11,329	14-Mar	18-Dec	279
7	156,000	14-Feb	29-Sep	227
8	19,505	22-Mar	26-Aug	156
9	112,574	14-Mar	18-Dec	279
10	25,200	18-May	13-Dec	209

Optimal Dredge Project-Resource Assignment

Project Number	Dredge Start Date	Dredge End Date	Assigned Resource
1	18-Jan	1-Feb	D
2	5-Jan	10-Mar	B
3	1-Jan	8-Jan	D
4	21-Mar	5-Apr	B
5	26-Aug	12-Sep	B
6	25-Dec	27-Dec	D
7	30-Sep	7-Oct	B
8	3-Sep	5-Sep	D
9	19-Dec	24-Dec	B
10	1-Jan	3-Jan	B

Total Dredge Days: 135

Relaxed Dredge Project Data

Project Number	Cubic Yards Dredged	Restricted Period Begin Date	Restricted Period End Date	# of Restricted Days
1	136,230	1-Jun	30-Nov	182
2	1,573,729	1-Apr	30-Nov	243
3	67,221	1-Apr	30-Nov	243
4	357,149	1-Jan	15-Mar	73
		31-May	31-Dec	214
5	404,418	1-Jan	31-Jul	211
		1-Nov	31-Dec	60
6	11,329	1-Apr	30-Nov	243
7	156,000	1-Mar	15-Sep	198
8	19,505	1-Apr	15-Aug	136
9	112,574	1-Apr	30-Nov	243
10	25,200	1-Jun	30-Nov	182

Note: # of Restricted Days per Job relaxed by ~13%

Optimal Relaxed Dredge Project-Resource Assignment

Project Number	Dredge Start Date	Dredge End Date	Assigned Resource
1	1-Jan	15-Jan	D
2	26-Jan	31-Mar	B
3	27-Dec	30-Dec	B
4	29-Apr	15-May	B
5	10-Oct	27-Oct	B
6	29-Dec	31-Dec	D
7	12-Nov	19-Nov	B
8	1-Jan	2-Jan	B
9	12-Dec	17-Dec	B
10	16-May	18-May	B

Total Dredge Days: 130

Conclusions and Future Work

- Developed a preliminary model formulation for the dredge fleet scheduling and assignment problem
- Future work
  - Consider mob-demob time including travel
  - Understand realities of dredge scheduling decision process in order to reduce solution space
  - Develop innovative solution approach
  - Scale to realistic problem size
  - Study impacts of system behavior
    - Environmental windows