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View of a Spillway at a Placement Site

IN THIS ISSUE

AIMS & SCOPE OF THE JOURNAL

The *Journal of Dredging* is published by the Western Dredging Association (WEDA) to provide dissemination of technical and project information on dredging engineering topics. The peer-reviewed papers in this practice-oriented journal will present engineering solutions to dredging and placement problems, which are not normally available from traditional journals. Topics of interest include, but are not limited to, dredging techniques, hydrographic surveys, dredge automation, dredge safety, instrumentation, design aspects of dredging projects, dredged material placement, environmental and beneficial uses, contaminated sediments, litigation, economic aspects and case studies.

OPTIMIZATION OF MECHANICAL DREDGING OPERATIONS FOR NAVIGATIONAL PURPOSES

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ABSTRACT

The investment and fixed costs of dredging are significantly higher than the same type of costs for many other construction operations. Productivity improvement and equipment usage need to be addressed in order to reduce these costs. Software called REMSIM (REMediation SIMulation) can be used to help reduce these costs. REMSIM that was developed at the University of Wisconsin to simulate sediment remediation processes includes the capability to select the equipment for a mechanical dredging operation, in order to increase productivity and minimize cost. This paper presents unit dredging costs and production rate comparisons between actual dredging projects from the Great Lakes and the results of REMSIM. The simulated production rate provides good approximations to the actual project rate and unit costs. Various parameters are examined for selecting combinations of resources that optimize productivity and minimize costs. Parameters include loading/unloading bucket capacities and rates, number and capacities of scows, transportation distance between the dredge and the disposal site, and shift times of the dredge. An optimization method is presented for determining the minimum scow size for maximum productivity. The purpose of this paper is to help Dredging Contractors to estimate dredging costs and performance and select equipment that minimizes costs.

INTRODUCTION

There have been some suggestions for bringing economy to dredging decisions. In general, cost reductions can be achieved by increasing the productivity of a dredging operation (PIANC, 1989). Mayer and Stark (1984) suggested that the operations research method of linear programming be applied to dredging management decisions because dredging deals with the common problem of allocating limited resources among competing activities. Contractors try to keep the dredge working efficiently with a minimum of downtime. To do this, scows (barges) and tugs are added, larger scows substituted for smaller scows, or dredging and unloading bucket capacities are changed.

This paper describes an approach for improving productivity and equipment use in mechanical dredging for navigation projects, with the help of a new software program called REMSIM (REMediation SIMulation). This dredging module was inspired by the earlier dredging model

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development by Hayes (1983) for the Norfolk District of the U.S. Army Corps of Engineers. REMSIM was developed at the University of Wisconsin-Madison with assistance of researchers at the University of Minnesota-Duluth and University of Windsor (Ontario). REMSIM simulates the sediment remediation processes from site characterization through disposal, including dredging.

The REMSIM dredging module is based on information about navigation dredging that was obtained from contractors, project records and the dredging literature. REMSIM can be used as a tool to improve productivity, reduce the costs of dredging, and understand the effects of changing the dredging plant or limiting the dredging process in particular projects. These effects are shown in simulations as changes in project duration, unit project costs, and production rate of the dredging system. REMSIM is suitable for making budget-level decisions about whether and how to dredge.

The purpose of this paper is to show some of the insights into improving the productivity of mechanical dredging gained by examining the mechanical dredging model used in REMSIM. There are a number of parameters that influence dredging productivity and costs. The relative importance of these parameters is shown by the sensitivity analysis in this paper. This paper also provides some methods for optimizing productivity in a mechanical dredging system.

A MECHANICAL DREDGING SYSTEM

Figure 1 shows the sequence of actions followed in a typical mechanical dredging operation. The REMSIM model for mechanical dredging calculates the dredging cycle time and the production rate. The production rate is defined as the *in situ* volume of sediment removed per hour. The production rate depends on the sum of the action times that make up the dredging cycle.

Dredging Cycle

A dredging cycle includes the movement of sediment from the bottom of the water-body to a storage site. For a multiple scow cycle, the cycle begins at the time the dredge starts to load the first scow and ends at the time the dredge is ready to load the first scow again. The cycle time is the summation of the following sequence of times for N number of scows.

- loading times of the N scows
- shift time(s) of the dredge to a new position while loading N scows
- waiting times of the dredge for N scows to return

REMSIM computes the times for each scow to proceed through the four phases of the dredging cycle that are shown in Figure 1. This time accounting is used to compute any dredge wait time so that the user can minimize that wait time.

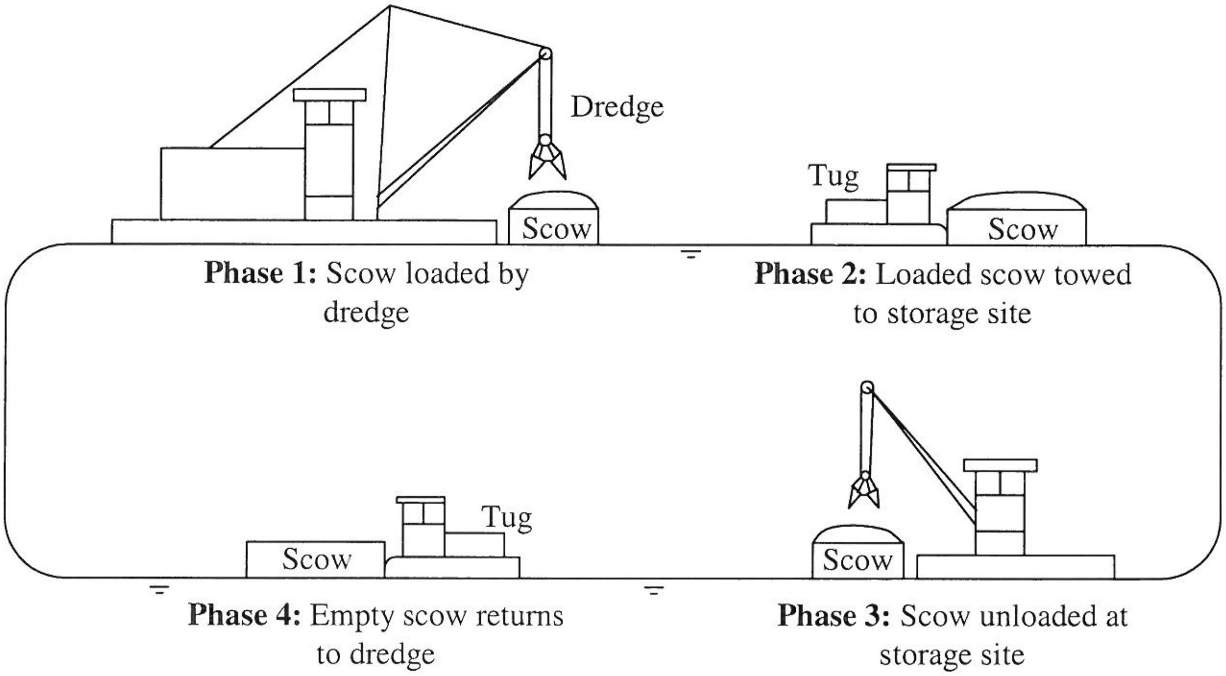

Figure 1: Dredging Cycle

Phase 1: Loading Time. The loading rate is calculated as shown in Equation 1, from Roorda and Vertreght (1963).

$$Q_{ml} = I_l * n_l * z_l \tag{1}$$

Where:
Q_{ml} : loading rate (cubic meters per hour)
I_l : loading bucket capacity (cubic meters)
n_l : loading bucket filling coefficient
z_l : number of bucket loads filled per hour (loads per hour)

The time for loading scow i, Tl_i, is calculated with Equation 2.

$$Tl_i = \frac{V_i}{Q_{ml}} \tag{2}$$

Where:
Tl_i : loading time of scow i (hours)
V_i : volume of material in scow i (cubic meters)
Q_{ml} : loading rate (cubic meters per hour)

Phase 2: Transport Time. Assumptions used in calculating a transport time include: a) a tug positions an empty scow next to the dredging crane before moving a loaded scow, b) the deceleration time of the loaded scow (with tug) is one half of the acceleration time, and c) the tug and scow travel at constant speed to the disposal site once having reached a final velocity v_f. Equation 3 calculates the transport time of the loaded scow from the dredge to the unloading site:

$$T_t = \frac{S_S}{v_f} + \frac{3\,v_f}{2a} \qquad (3)$$

Where:
T_t : transportation time of scows (hours)
S_s : transportation distance (kilometers)
v_f : final constant velocity of the moving scow and the tug after acceleration (kilometers per hour)
a : rate of acceleration, assumed constant (kilometers per hour squared)

Hayes (1983) used default values of 11.3 km/hr (7 miles/hour) for v_f, 16.1 km/hr^2 (10 miles /hr^2) for a. REMSIM uses 8 km/hr (5 miles/hour) and 16 km/hr^2 respectively for acceleration a and ½ a for deceleration. Both acceleration and deceleration are included in the second term of Equation 3.

Phase 3: Unloading Time. Equation 4 presents the rate of unloading a scow.

$$Q_{mu} = I_2 * n_2 * z_2 \qquad (4)$$

Where:
Q_{mu} : unloading rate (cubic meters per hour)
I_2 : unloading bucket capacity (cubic meters)
n_2 : unloading bucket emptying coefficient
z_2 : number of bucket loads emptied per hour

The unloading time for scow i, Tu_i, is shown in Equation 5.

$$Tu_i = \frac{V_i}{Q_{mu}} \qquad (5)$$

Where:
Tu_i : unloading time of scow i (hour)
V_i : volume of material in scow i (cubic meters)
Q_{mu} : unloading rate (cubic meters per hour)

Table 1 shows various values of I, n, and z for Equations 1 and 4, that have been suggested by different authors and contractors. The choice of values depends on the type of sediment material (mud, sand, stones, etc.).

Table 1: Suggested values for bucket sizes I, fill ratios n, & filling (emptying) per hour z.

Parameter	Values	Reference
I: Using conventional clamshell bucket	0.14–1.02 m^3 (0.19–1.33 yd^3)	Cooper (1958), Roorda and Vertregt (1963)
	(1-12 yd^3) is common up to 38 m^3 (50 yd^3)	USACE (1983), PIANC (1989)
I: Using cable arm bucket	3.25 –30.50 m^3 (4.06–39.9 yd^3)	Bergeron (2000)
n_1	0.75 for mud	Cooper (1958), Roorda and Vertregt (1963)
	0.9 ideal and 0.75 typical	Dredging Contractors (1999)
n_2	0.6 – 0.7	Dredging Contractors (1999)
z_1	40 loads per hour 20 to 30 loads per hour typical	Hayes (1983) USACE (1983)
	55 loads per hour ideal 48 loads per hour typical	Dredging Contractors (1999)
	80 loads per hour for mud	Roorda and Vertregt (1963)
z_2	60 loads per hour ideal 48 loads per hour typical	Dredging Contractors (1999)

Phase 4: Return Time of the Empty Scow to the Dredge. The return time is calculated using Equation 3 and the same assumptions are used in calculating the times for Phase 2. The model compares the time when a scow returns empty to the dredge with the time when the next scow was filled. If the return time is later, then the time difference is the dredge wait time for the empty scow, Tw_i.

Total Cycle Time. The total cycle time TCT in hours is shown in Equation 6. Shift time, Ts_i, is an input to the model.

$$TCT = \sum_{i=1}^{N} (Tw_i + Tl_i + Ts_i) \qquad \text{for } i = 1,..,N \tag{6}$$

The dredging cycle accounts for the activities necessary to dredge and load, transport, and unload N scows, shift the dredge to a new site, and return the first scow to the dredge. The productivity of this dredging cycle depends upon the combined productivity of each activity in the cycle. Therefore, using the total cycle time TCT obtained above and the volume of the scows V, the production rate Q for N scows is calculated by using Equation 7.

$$Q = \frac{\sum_{i=1}^{N} V_i}{TCT} \qquad \text{for } i = 1,..,N \tag{7}$$

The loading/unloading rate ratio R is calculated using Equation 8. This ratio depends on the equipment selected and the operational conditions used. A value of 2 was computed for R to represent navigational dredging. This means that the scows are loaded at double the rate of unloading. A range of R values between 0.4 and 2.4 is considered in some sections of this paper.

$$R = \frac{Q_{ml}}{Q_{mu}} \tag{8}$$

COST ANALYSIS

The dredging system production rate influences the total dredging cost as shown in Equation 9 (adapted from Henshaw et al, 1999). A cost equation was developed by Henshaw and his co-authors using a regression analysis of cost and productivity data from 30 dredging projects. The data was from 11 Public Works Canada projects costing less than \$400,000 each and from 19 U.S. Army Corps of Engineers projects costing more than \$400,000 each. The mobilization term has $r^2 = 0.58$, and the volume-dependent term has $r^2 = 0.72$. The range of values in the Henshaw cost equation were retained and represent the 95 percent confidence interval of cost values developed by Henshaw et al. Small modifications to the Henshaw equation were made and are explained later in this section.

Total dredging cost TDC is inversely proportional to the production rate Q. Figure 2 shows the total dredging cost for various production rates using Equation 9. For low production rates the cost is very high. As the production rate increases, the total dredging cost decreases rapidly. The minimum, mid-range, and maximum values of MDC, MDF, and VDF are used respectively to compute the minimum, mid-range, and maximum value of TDC. Comparisons between REMSIM values for TDC and actual project values for TDC are shown in Figure 3.

$$TDC = MDC + MDF\left(\log X_s\right) + VDF\left(\frac{V_d}{Q}\right)\left(\frac{1}{EWT}\right) \tag{9}$$

Where:
TDC : total dredging cost (\$US, 1994)
MDC : mechanical dredging fixed cost (\$184,000 ± \$124,000)
MDF : mobilization/demobilization factor (\$19,000 ± \$8,100)/log km
VDF : volume dependent factor (\$420 ± \$130 /hour)
V_d : volume of sediment dredged (m^3)
Q : production rate (m^3/hour)
X_s : mobilization distance (kilometers). Must be greater than 40 kilometers.
EWT : effective working time factor

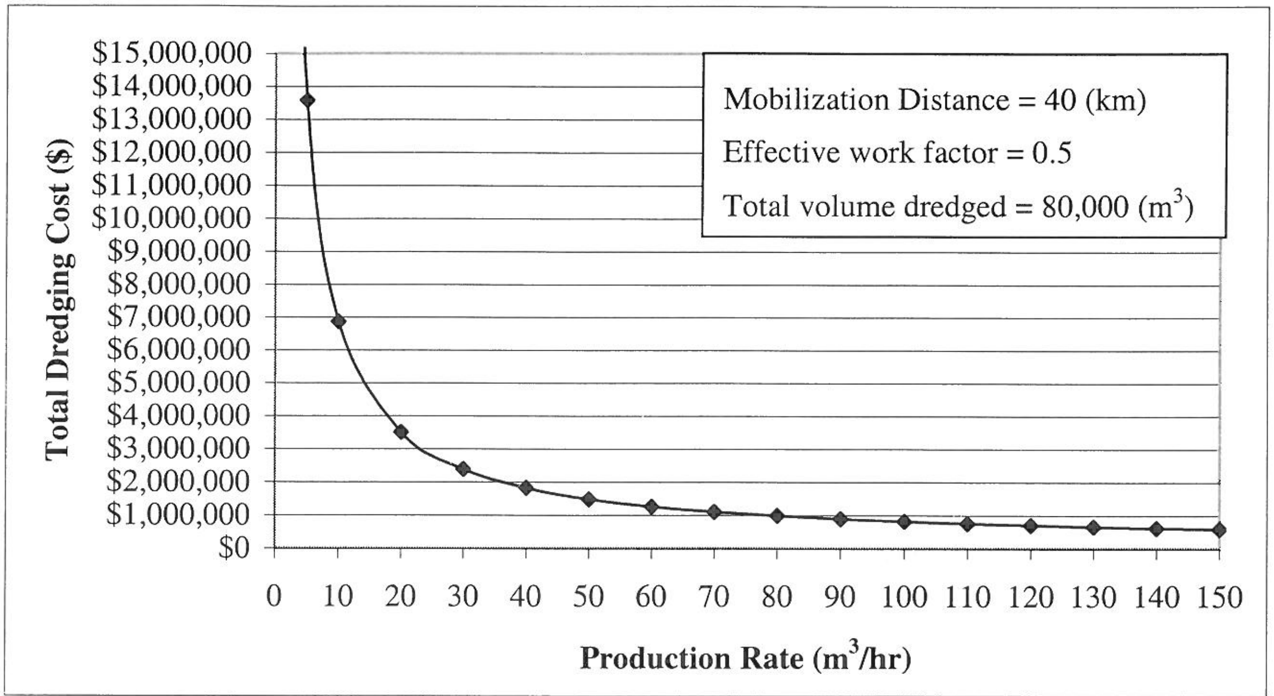

Figure 2: Mid-range total dredging cost for various production rates.

The fixed cost MDC of mechanical dredging is variable in actual dredging projects. This is reflected in the range of values given by Henshaw et al (1999). Dredging Contractors (1999) suggested that a higher MDC be used for rock dredging, a lower MDC be used for dredging silt and loose sand, and that the minimum MDC is $50,000 to $60,000. The minimum and mid-range values for MDC in Equation 9 are offset from those suggested by Henshaw et al to avoid the possibility of a negative number and to match the contractors' recommended minimum value. The maximum values of MDC in Equation 9 and in the comparable equation in Henshaw et al (1999) are the same: $308,000.

Mobilization/demobilization costs as shown by Henshaw et al (1999) are non-linear with respect to mobilization distance. Equation 9 uses the $\log_{10} X_s$ term to represent the non-linear cost increase logarithmic with mobilization distance. Consequently, increasing the mobilization distance significantly increases cost.

The volume dependent factor derived by Henshaw et al (1999) is an equivalent combined hourly rate for labor and equipment working on site. Dredging Contractors (1999) suggested that higher VDF be used for rock dredging and lower VDF be used for dredging silt and loose sand.

The EWT factor is the decimal fraction of a 24 hour day in which labor and dredging equipment are working at the production rate Q. The EWT is used for the entire dredging cycle, even though unloading operations may have less downtime than the dredging (loading) operations. Table 2 shows some suggested values and the value used in the sensitivity analysis.

In preparing bids, contractors sometimes over estimate their EWT by as much as a factor of two (Dredging Contractors 1999). This over estimate results in contractors underestimating the unit variable costs of dredging (VDF in Equation 9). EWT accounts for all downtime factors, including weather delays. Mechanical dredges typically operate 17 to 18 hours per day. When dredging is done in waters exposed to significant wave action, EWT is reduced.

Table 2: Effective working time EWT

Condition	Value	Reference
Spring and Fall, typical values	0.6	Dredging Contractors (1999)
Summer, best conditions	0.8	same
Winter, worst conditions	0.1	same
Value used in analysis	0.5	-------------------------------

COMPARISONS WITH RESULTS FROM DREDGING PROJECTS

Dredging Contractors (1999) provided data from 12 navigational dredging projects in harbors of the Great Lakes. The projects were completed in the period 1986-1999 and the data were used for production rate and unit cost comparisons. REMSIM was used to calculate production rates and dredging costs, using the operational parameters that the contractors provided (bucket size, number and capacities of scows used, distance that dredged material was hauled, unloading method, and effective working time) or suggested (dredging and unloading rates and bucket fill ratios).

Table 3: Comparison between actual production rates and simulated production rates.

Project	Actual Prod. Rate (m^3/hour)	Simulated Prod. Rate (m^3/hour)
A	317	324
B	298	303
C	329	324
D	268	270
E	214	218
F	226	226
G	73	69
H	138	132
I	190	185
J	188	185
K	161	163
L	233	227

Table 3 and Figure 3 show that REMSIM adequately models the production rate of mechanical dredges operating in the Great Lakes. REMSIM can be used to compute actual production using the operational parameters that dredging contractors suggest, even when the unloading mode is quite different.

In most of these projects, unloading was performed in ways that are not modeled in REMSIM: open-water disposal (4 projects), and hydraulic unloading (7 projects). For these projects, it was assumed that the disposal activity would minimize dredge wait times. To model this in REMSIM, the parameters for unloading bucket capacity and unloading rate were increased until the dredge wait time was minimized. However, for a few projects, the dredge wait time could not be eliminated with this approach. This indicates that the dredge cycle for these projects did include wait times. The following projects had significant wait times when run in REMSIM because of long haul distance, small scow capacity, or because only two scows were used:

Project D: wait time = 0.9 hours, haul distance = 48 kilometers, three scows each having 1530 m^3 capacity.

Project F: wait time = 1.0 hours, haul distance = 22 kilometers, two scows each having 1530 m^3 capacity.

Project H: wait time = 1.6 hours, haul distance = 0.8 kilometers, two scows each having 459 m^3 capacity.

Closer matches of production rates than those shown in Table 3 could have been obtained with more iterative runs of REMSIM. This matching of rates is possible because there are relatively few unstated dredging variables and because there is a common contractor strategy to minimize dredge wait times.

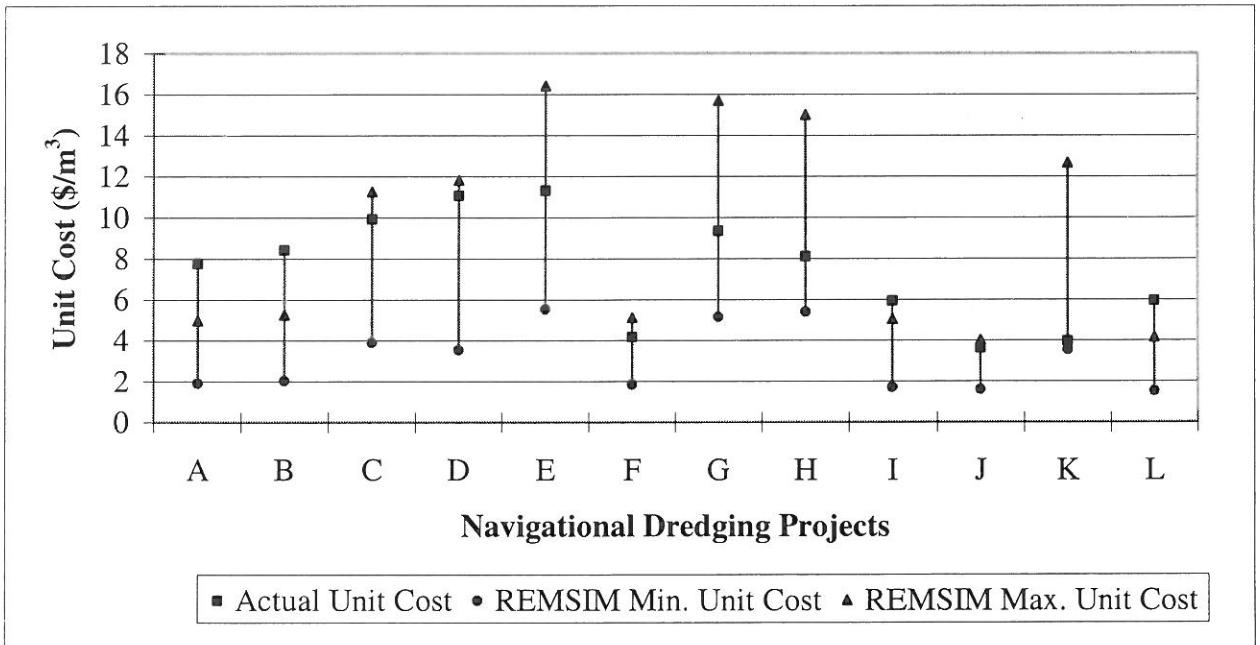

Figure 3: Comparison between different navigational dredging projects using REMSIM software and actual unit costs.

Figure 3 compares unit dredging costs from the same 12 projects to the estimated unit dredging costs computed with REMSIM. High, low, and mid-range costs are calculated in REMSIM, using Equation 9. Only the high and low unit dredging costs were used in Figure 3. The mobilization costs were subtracted from the REMSIM results for all projects because the contractors did not provide them. The iterative running of the project conditions in REMSIM until production rates were nearly matched was intended to reduce or eliminate the variability due to uncertainty about particular project dredging parameters. The near-match of production rates and the exclusion of mobilization costs means that remaining difficulties in matching REMSIM costs and actual costs must lie in the cost equation adapted from Henshaw et al (1999).

Figure 3 shows that actual unit dredging costs were outside of the REMSIM unit dredging cost range for five of the 12 projects, but the difference was substantial on only two of the projects: Projects F and H, where actual costs exceeded maximum estimated REMSIM costs by 70 percent and 64 percent, respectively. This comparison indicates that the REMSIM cost range is a reasonable approximation to actual dredging costs on most projects. However, circumstances affecting bid prices on some projects are not modeled in REMSIM. Two factors that are not modeled in REMSIM are: a) the nature of competition for particular projects, and b) the schedule of future work for contractors winning bids.

SENSITIVITY ANALYSIS

The effect of variations in the value of model parameters may be observed through a sensitivity analysis. This analysis identifies which parameters have greater impact on production rate, and establishes the tolerance of these parameters. The following sensitivity analysis explores some, but not all, of the possible combinations of dredging equipment rate and capacity. Table 4 shows the parameter values for navigational dredging system used in the sensitivity analysis.

Table 4: Selected Navigational Dredging Parameters.

Parameters	Navigational
z_1	60
z_2	60
n_1	0.75
n_2	0.75
I_1	6.1
I_2	3.1
Q_{ml}	274.5
Q_{mu}	139.5
R	2
N	2
V	780
S_s	4
v_f	8
a	16
EWT	0.5
Ts	1
V_d	80,000

Loading and Unloading Bucket Capacities I_1 and I_2

If both dredging and unloading bucket capacities are increased, the loading and unloading rates increase causing an increase in the overall production rate. The same effect is true for increases in fill ratios, and bucket filling and emptying rates. Figure 4 shows an increase in productivity as the bucket sizes increase in unison, using a scale factor α with values between 1 and 3.25. There is a slight marginal decrease, however, for this example. Tripling of bucket size nearly triples production rate with the largest scows, but less than doubles the rate with the smallest scows. Scow capacity becomes a more important limiting factor when the buckets are larger.

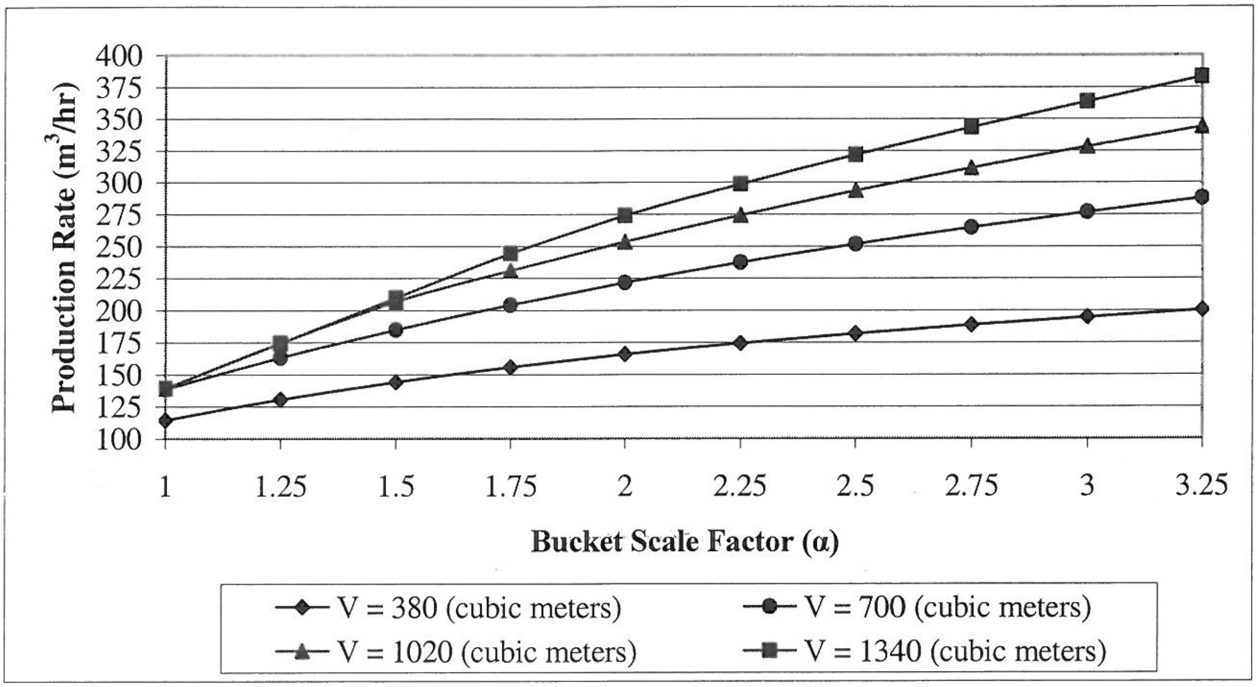

Figure 4: Production rate for navigational dredging [R=2] for different bucket capacities using two scows of equal size.

Numbers and Capacities of Scows N, V_1, V_2 and V_3

The range of scow capacity considered in this analysis is 380 to 1500 cubic meters. Typical scow capacities in the Great Lakes range from 50 to 1520 cubic meters (66 to 2,000 cubic yards) according to Dredging Contractors (1999). Ocean scows may have capacities of 5,000 to 7,000 cubic meters (6,600 to 9,240 cubic yards).

Figure 5 presents optimal scow size combinations that yield maximum productivity in a two-scow dredging system for loading/unloading rate ratios R greater than or equal to 1.4. Any scow size combination above the curve will yield maximum productivity, which is bounded by the unloading rate. For example, if the volumes for the two scows are $V_1 = 860$ m^3 and $V_2 = 688$ m^3, then the ratio between the scow size $\frac{V_2}{V_1}$ is 0.8. Using the curve, a ratio of 1.75 is obtained.

Thus, the scow volume of equal capacity for maximum productivity in a two-scow system must be greater than or equal to 492 m^3.

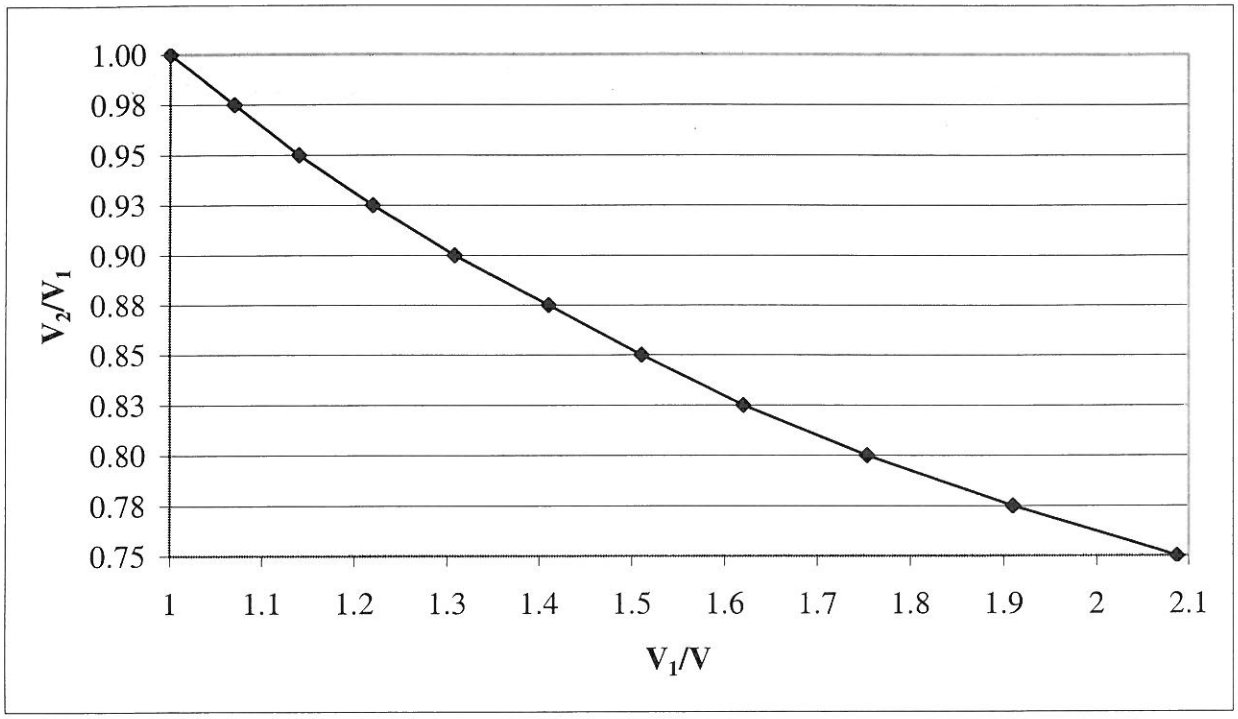

Figure 5: Optimal scow size combination for various rates of operation [R≥1.4] using two scows.

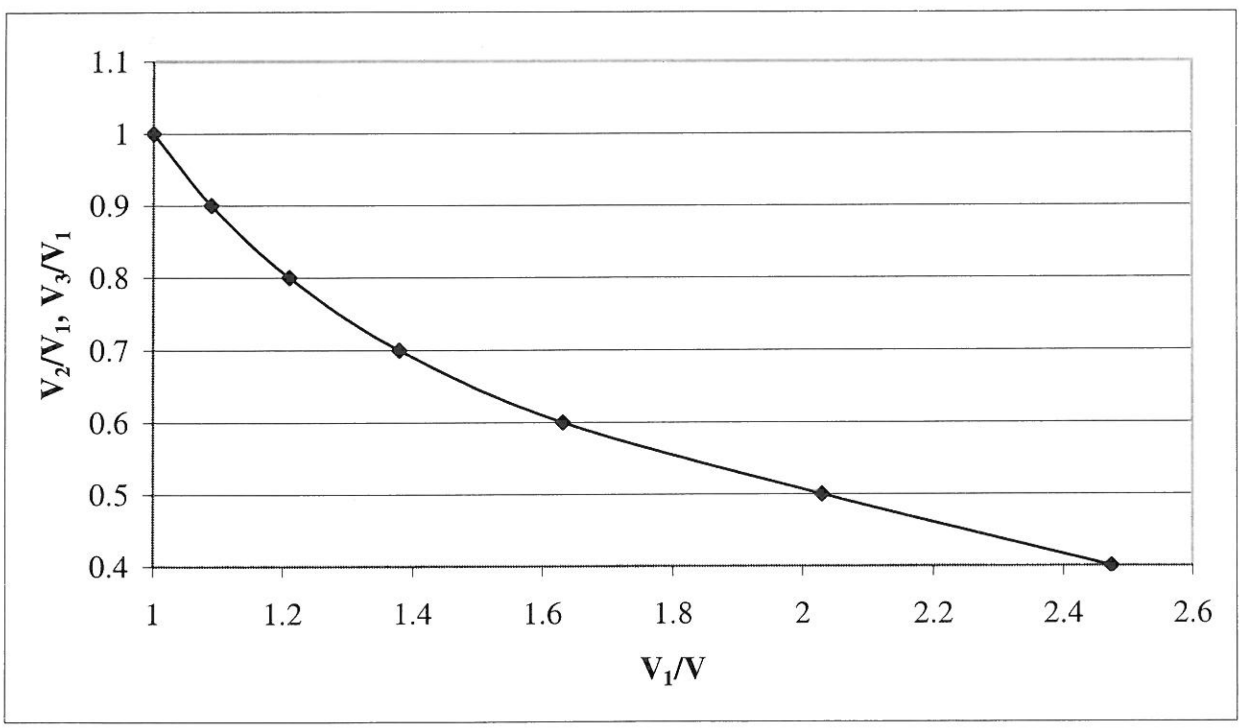

Figure 6: Optimal scow ratio for various rates of operation [R≥1.4] using three scows.

It is common for three scows to be used: one being loaded at the dredge, one in transit with a tug and one being unloaded (Dredging Contractors, 1999). In a multiple scow system with unequal scow sizes, the order in which the scows are filled is not important. The scows operate in a continuous cycle, producing the same results. The model assumes that a tug is put to work with every two scows. A 1,000 horsepower tug in 1999 costs roughly one dollar per horsepower per day.

Figure 6 can be used to select combinations of scow capacities, which will produce maximum productivity in a three-scow dredging system. The feasible region is above the curve. In Figure 6, V is the minimum capacity of a system with three equal-capacity scows and V_1, V_2, and V_3 are the individual capacities of three scows.

If $\frac{V_1}{V} = 1.6$ then, from Figure 6, the capacities of V_2 and V_3 must be greater than or equal to $0.6*V_1$ in order to maximize productivity. For example, let V = 780 cubic meters, then V_1 = 1.6*780 = 1248 cubic meters, and V_2 and V_3 must be greater than or equal to 0.6*1248 = 749 cubic meters.

Loading/Unloading Rate Ratio R

The easiest way to understand the effect of the parameter R is by considering a two-scow system. In a two-scow system, greater productivity is always obtained when the scows have equal capacity. Therefore, the effect of R is examined in the sensitivity analysis where the two scows have the same capacity V.

Figure 7 shows the trade off between scaling the minimum scow volume for maximum productivity, by using the scow size scale factor β, and the loading/unloading rate ratio R. The minimum scow volume is normalized with a scow capacity equal to 780 m^3 for R equal to 2. As shown in this figure, if the loading of the scows increases (R increases), a smaller scow volume is needed to maximize productivity. If the dredge operates very slowly relative to the unloading at the disposal site then extremely large scows are required to reach the maximum productivity. For example, if the loading/unloading rate ratio R is decreased from 2 to a value of 1.3, then the minimum volume of the scows has to double in order to maintain maximum productivity.

Transportation Distance S_s

Figure 8 shows the trade off between the minimum scow size and travel distance for R equal to 2. The travel distance is normalized with a transportation distance of 4 km, and the minimum scow volume is standardized with the scow base volume of 780 m^3 for a two-scow dredging system of equal size. The figure shows that as the transportation distance increases, the minimum scow size to maximize productivity also increases. For example, if the travel distance is increased by 1 km, then the minimum scow volume should increase by 20% in order to maximize productivity. Different combinations of travel distance scale φ, and scow size scale ß located above the curve yields the maximum productivity.

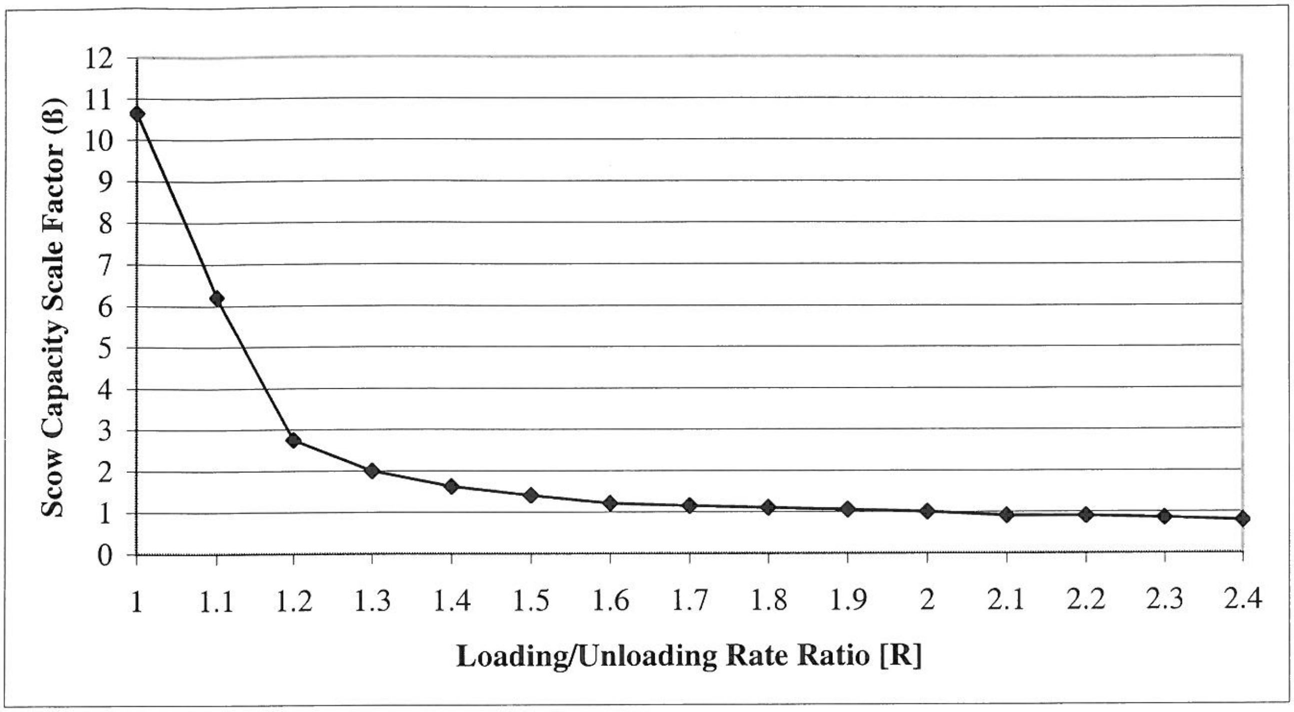

Figure 7: Minimum scow volume ratio using various loading/unloading rate ratios for two scows of same capacity.

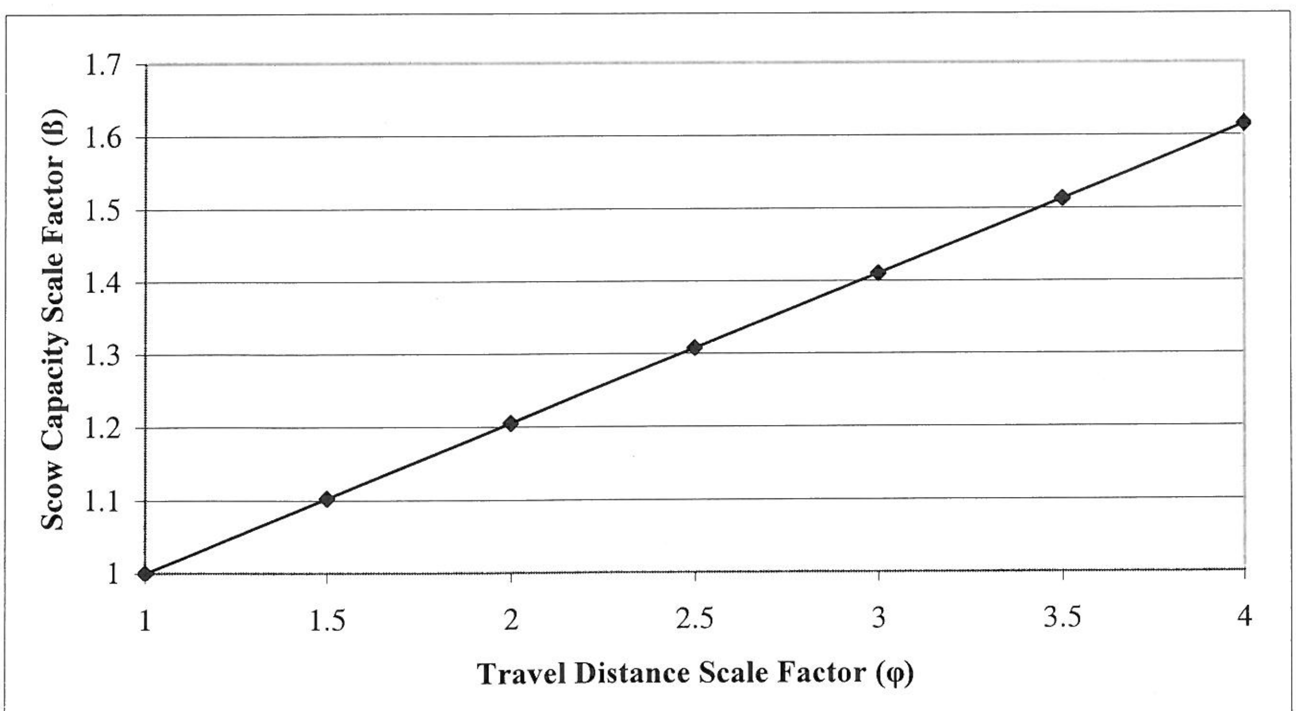

Figure 8: Optimal scow volume ratio for navigational dredging [R=2] using different travel distance ratios.

Shift Time Ts

Dredging contractors (1999) reported that dredge shift times on an area to be dredged were typically 5 to 10 minutes (0.08 to 0.16 hours) as the bucket is used to move the dredge. When moving to another area to be dredged, shift times are longer because a tug is required to move the dredge. The sensitivity analysis was done with a shift time of one hour. When shift times are shorter, there are significant increases in the production rate and small reductions in mid-range total dredging cost (Table 5). The baseline conditions for the sensitivity analysis are modified by increasing the unloading bucket capacity from 3.1 to 6 cubic meters in order to make the dredge wait time zero.

Table 5: Effect of shift time on dredging productivity and cost under modified baseline conditions.

Shift time (min.)	Prod.rate (m^3/hr)	Percent change	mid-range TDC	Percent change
60	203	Mod. Baseline	$540,000	Mod. Baseline
30	233	+15	$499,000	-7
15	252	+24	$479,000	-11
10	259	+28	$472,000	-13
5	267	+31	$465,000	-14

MECHANICAL DREDGING PRODUCTIVITY OPTIMIZATION

Method for Selecting Minimum Scow Size

In planning a dredging project, one decision is to select a scow size that optimizes productivity. Based upon the results of the sensitivity analysis, maximum productivity is bounded by the unloading rate. This bound, which corresponds to the maximum productivity, is quickly reached after a few dredging cycles. Under this situation, the total dredging cycle time TCT is equal to the unloading time of the scows. Subsequently, Equation 10 is derived from this concept to determine the minimum scow volume for maximum productivity Vmin in a two-scow dredging system, for R values between 1.4 and 2.4.

$$Vmin = (Ts + Tw) * Q_{mu} * \frac{R}{R-1} \tag{10}$$

The summation of the waiting time of the dredge Tw and the shift time of the dredge to reposition Ts from Equation 10 is constant for a given velocity (8 km/hr), acceleration (16 km/hr^2), deceleration (8 km/hr^2) of the scows, and distance between the dredge and the storage site. This constant has been named the Shift-Wait Time constant (SW = Ts + Tw) for R greater than or equal to 1.4. Maintaining the conditions used in Equation 10, there is also a linear relationship between the constant SW and the distance S_s between the dredge and the storage site. Thus, the minimum scow volume for maximum productivity Vmin can be calculated as in Equation 11. This equation indicates that if the travel distance decreases and the loading/unloading rate ratio R increases, the smaller is the minimum scow size needed for maximum productivity.

$$Vmin = (0.15929 * S_s + 1.89504) * Q_{mu} * \frac{R}{R-1} \tag{11}$$

CONCLUSIONS

The REMSIM mechanical dredging module is useful as a tool in improving productivity, for estimating and reducing the costs of dredging for navigation. REMSIM is useful in understanding the effects on productivity, project duration, and dredging cost that result from changing the dredging plant or from limitations imposed on the dredging process in particular projects.

REMSIM adequately models the production rate of mechanical dredges operating in the Great Lakes. This modeling of production rates is possible because there are relatively few unstated dredging variables and because there is a common contractor strategy to minimize dredge wait times. REMSIM can be used to predict actual production rates even when the unloading mode is quite different from the crane and bucket mode used in REMSIM.

REMSIM models a dredging cost range which is a reasonable approximation to actual dredging costs on most projects. However, circumstances affecting bid prices and dredging costs on some projects are not modeled in REMSIM. REMSIM should not be used alone for bid preparation.

This paper has shown different approaches to improve productivity and equipment use, and to reduce costs in a mechanical dredging system for navigational purposes. The sensitivity analysis presented the impact of important parameters in dredging productivity. The following conclusions were derived from this analysis.

If the dredging and unloading bucket capacities, the fill ratios, or the fillings rates are increased, larger scow loading and unloading rates can cause a large increase in the overall production rate. The scow capacity becomes an important limiting factor when the bucket sizes are larger. Productivity also increases as the size difference between scows decreases.

A two or three-scow system yields higher productivity than a single scow system. The highest productivity is obtained when the scows working in a mechanical dredging system are equal or nearly equal in size. If the two scows have equal capacity, maintaining all other parameters constant mentioned in this paper, the maximum production rate can be reached at a scow capacity of 780 cubic meters each.

Figure 5 and 6 can be used to select combinations of scow capacities which will produce maximum productivity in a two-scow and three-scow dredging system, respectively. These scows may have equal or different individual sizes. This idea was explained through simple examples in this paper.

From the productivity optimization analysis, Equations 10 and 11 were derived to select minimum scow sizes necessary for maximum productivity. These equations help to determine the optimum combination of scows so to achieve higher dredging performance.

The maximum productivity achieved in a dredging system is bounded by the unloading rate at the storage site. If the unloading rate increases, then the maximum production rate increases and the minimum scow size needed to maintain the maximum production rate increases. This is true when the loading/unloading rate ratio R is greater than 1.4. If R is less than 1.4, then maximum productivity is not reached within the typical scow sizes used in this paper. Figure 7 shows that the minimum scow size for maximum productivity diminishes as R increases. The loading/unloading rate ratio R influences productivity considerably.

The travel distance between the dredge and the storage site also impacts productivity. Figure 8 shows that the minimum scow size for maximum productivity increases as the transportation distance increases. At greater distances, and with smaller scow capacities, a third scow should be added to maintain production rates.

The production rate comparison between actual project data and results calculated using REMSIM was encouraging. The values nearly matched which indicates that REMSIM is a useful tool for estimating dredging performance.

The cost analysis presented the total dredging cost formula and various factors values suggested by Dredging Contractors (1999) and Henshaw et al (1999). In general, discrepancies exist between actual and REMSIM costs which indicates the need to revise the dredging cost equation.

NOMENCLATURE

a	=	rate of acceleration	km/hr^2
EWT	=	effective working time factor	
I_1	=	loading bucket capacity	m^3
I_2	=	unloading bucket capacity	m^3
MDC	=	mechanical dredging fixed cost	\$
MDF	=	mobilization/demobilization factor	\$/log km
N	=	number of scows	
n_1	=	loading bucket filling coefficient	
n_2	=	unloading bucket emptying coefficient	
Q	=	production rate	m^3/hr
Q_{ml}	=	loading production rate of scows	m^3/hr
Q_{mu}	=	unloading production rate of scows	m^3/hr
r	=	correlation coefficient	
R	=	loading/unloading rate ratio	
S_s	=	transportation distance	km
SW	=	shift-wait time constant	hr
Tl_i	=	loading time of scow i	hr
Ts	=	Shift time for dredge to reposition in one cycle	hr
Ts_i	=	Shift time for dredge to reposition after loading scow i	hr
T_t	=	transportation time of scows	hr
Tu_i	=	unloading time of scow i	hr
Tw	=	total waiting time of the dredge in one cycle	hr
Tw_i	=	waiting time of the dredge for scow i	hr

TCT	=	total cycle time	hr
TDC	=	total dredging cost	$
V	=	capacity of scows of equal size	m^3
V_d	=	volume of sediment to be dredged	m^3
v_f	=	final constant velocity of scows	km/hr
V_i	=	volume of material in scow i	m^3
V_1	=	volume of material in scow 1	m^3
V_2	=	volume of material in scow 2	m^3
V_3	=	volume of material in scow 3	m^3
Vmin	=	minimum scow volume for maximum productivity	m^3
VDF	=	volume dependent factor	$/hour
X_s	=	mobilization distance	km
z_1	=	number of bucket loads filled per hour	loads/hr
z_2	=	number of bucket loads emptied per hour	loads/hr
α	=	bucket size scale factor	
β	=	scow capacity scale factor	
φ	=	travel distance scale factor	

Subscripts

i	=	positive integer index
1	=	index related to filling scows
2	=	index related to emptying scows

ACKNOWLEDGEMENTS

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REFERENCES

Bergeron, R. (2000). Cable Arm data sheet and personal communication. Cable Arm Inc., Trenton, MI.

Bruun, Per (1976). "*Port Engineering*." Gulf Publishing Co., Houston, TX.

Cooper, H. R. (1958). "*Practical Dredging*." Brown, Son and Fergunson, Ltd. Glasgow, Scotland.

Dredging Contractors. (1999). Information obtained personally during evaluations of REMSIM at Andrie, Inc.; Great Lakes Dredge and Duck Co.; Luedke Engineering; and Zaretske Construction, located in Illinois, Michigan, and Wisconsin, respectively.

Frankel , E. G. (1980). *"Cost and Economic Analysis of Navigational Channel Dredging."* Bulletin of the Permanent International Association of Navigation Congresses, No. 35, Belgium.

Hayes, D. F. (1983). "*A Method for the Cost Analysis of Dredging and Disposal Alternatives in Norfolk Harbor.*" Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, Report No. TA7 W343.E55.H3 1983 C2.

Henshaw, P. F., Cervi S., and McCorquodale J. A. (1999). *"Simple Cost Estimator for Environmental Dredging in the Great Lakes."* Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 125, No. 5, ASCE.

Mayer, R. H. Jr., and Stark, R. M. (1984). *"Linear Programs for Dredging Management Decisions."* Proceedings of Dredging, ASCE, Clearwater Beach, Florida.

PIANC. (1988). *"Minimizing the Cost of Maintenance Dredging."* Bulletin of the Permanent International Association of Navigation Congresses, General Secretariat of PIANC, Bulletin, No. 63, Brussels, Belgium.

PIANC. (1989). *"Economic Methods of Channel Maintenance."* Bulletin of the Permanent International Association of Navigation Congresses, General Secretariat of PIANC, Supplement to Bulletin, No. 67, Brussels, Belgium.

Roordas, A., and Vertregt, J. J. (1963). "*Floating Dredges.*" H. Stam NV Publishing Company, Haarlem, The Netherlands.

USACE. 1983. *"Dredging and Dredged Material Disposal"*. Engineer Manual EM 1110-2-5025. U.S. Army Corps of Engineers.

Webb, R.J. (1974). "*Dredging costs: their estimation and implications to the management of maintenance dredging operations.*" The Dock and Harbour Authority, periodical, United Kingdom.

A 'DREDGING INFORMATION SYSTEM' FOR THE RIVER SCHELDT

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ABSTRACT

Maintenance dredging works are carried out on the river Scheldt throughout the whole year in order to maintain the accessibility of the Port of Antwerp (Belgium). To optimise and supervise the maintenance dredging it was decided - in the early nineties - to develop a computer based system for the automated follow up of the dredging activities. The development of the system was done in phases. The final phases are being implemented now and the system proves to be a useful instrument for the follow-up, supervision and evaluation of the dredging works. This paper deals with the design and implementation of this 'Dredging Information System' and evaluates the overall performance of the system. The paper shows that - on the condition that appropriate tools for managing and presenting the information are provided for - a computer based information system can be successfully used to manage the huge amount of data involved in the follow-up and supervision of maintenance dredging works.

INTRODUCTION

In the beginning of the nineties the Maritime Scheldt Division of the Ministry of the Flemish Community decided to start developing a system that should allow automated supervision of the dredging works on the river Scheldt. The project was carried out in several phases. The first phases mainly focused on the verification and supervision of the dredging depth and position, because of the strict regulations concerning these two aspect. These phases were discussed in detail in a previous paper (Claessens et al., 1997). A short description of these phases is included here.

The main task of the system is to provide an efficient tool for supervision and verification of the dredging works. All information should thus be presented in a way that allows easy interpretation of the data, from a supervisor's point of view. Means have to be provided to detect any non-conforming situations quickly. Another task of the system is to provide the means for short time evaluation - and thus planning - of the dredging works. An important aspect is the feed-back of information to the crew. To achieve efficient and correct dredging it is not only necessary to supervise the operation. The crew must also have feedback. This is done by integrating an extended navigation system in the software on board. This system not only shows the position of the ship in relation to the dredging area but also provides access to most data available in the registration system and shows information about the actual state of the dredging area.

A recent addition covers the registration and reporting of a dredge's operation : time-usage and production are recorded on board. A fully automated reporting system imports the recorded data in a database and generates trip reports and week reports. The automatic

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reporting system is discussed in more detail in this paper. The current phase of the project concerns the making of a geographical inventory of the dredged and relocated material. For every relevant location on the river Scheldt, the amount of dredged and relocated material is kept in a database. Linking this information to depth soundings and the results of mathematical models, this inventory will lead to a better understanding of the morphological processes in the river.

DESIGN OF THE SYSTEM

Measured Signals

The dredging depth is computed from the depth of the draghead under the waterline and the value of the tide at the dredging location. The depth under the waterline is measured as an analogue signal. The tide is measured by a chain of tide gauges along the river. Tide values are transmitted by radio to a receiver on board of each dredger. The position of the dredges is measured by means of a DGPS (Differential Global Positioning System). The differential corrections are provided by two private short-range base stations. The whole area involved is covered with an accuracy better than 2 meters.

Other signals are measured for determining the status of the dredger (dredging, dumping sailing). These signals include mixture concentration; indication whether the ship's hopper is open or not; position of the swell compensator (indicating whether the draghead is touching the bottom or not); dredge pump(s) operation and open/closed indication for some valves on the pressure side of the dredging pumps. Finally, some signals are measured for the purpose of production calculation such as pressure transducers in the keel of the ship, measuring draught and ultrasonic distance transducers above the hopper, measuring the load level in hopper.

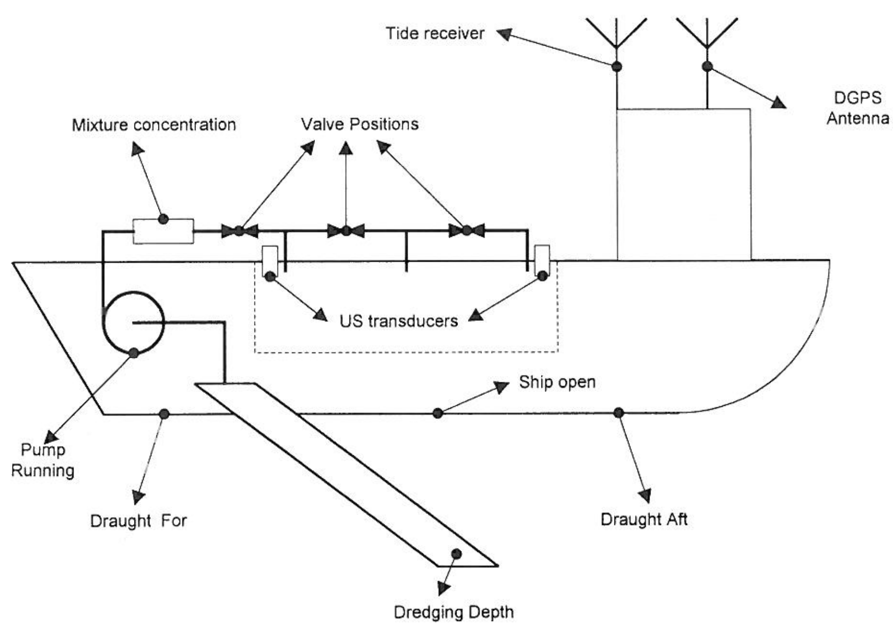

Figure 1: Measured signals overview

Information Flow

The main information handled by the system are as follows:

- The 'Dredging program' (from shore to ship) - The planned activities for the next period (typically one week) are summarised in a so-called 'dredging program'. The 'dredging program' indicates the assigned dredging and disposal areas for each dredger and contains additional information about the imposed dredging depth and instructions on when to dredge what area.
- Information needed for the evaluation and supervision of the dredging works (from ship to shore). This information consists of: (a) periodic registrations of the ship's position and dredging depth. This information allows to detect dredging or disposal outside the designated areas and to detect under-dredging or over-dredging; (b) information needed for in-between evaluation of the dredging areas; (c) time-usage information; and (d) production data.

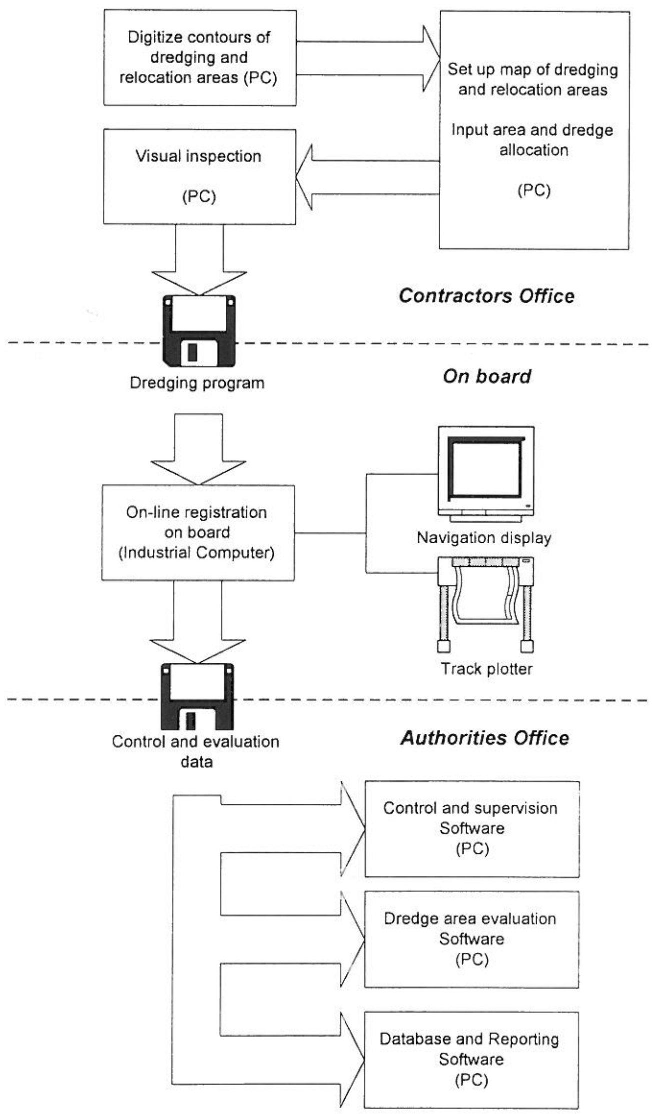

Figure 2: Information flow and procedures

The different stages of the information flow are the following (see Figure 2):

1. Based on soundings and the state of the dredging area, the dredging program for the next week is set up. Dredging and disposal areas are selected. A map of these areas is fed into the system. Dredging and disposal areas are assigned to dredges in the 'dredging program'.
2. After a visual inspection, the 'dredging program' is copied to floppy disks and distributed over the dredges.
3. The 'dredging program' is read by the computer on board of each dredger. All relevant data are shown on a navigation display.
4. While the dredger is operating all measured signals are recorded on hard disk by the computer on-board. The registered data are also shown on the navigation display to give feedback to the crew.
5. The registered data are copied to floppy disk for transfer to a PC. This is done at least twice a week. The floppies are transferred to the authorities for further analysis. On the PC a number of software programs are provided that allow to analyse the data. A PC on board is provided to allow the supervisors to make in-between evaluations.
6. The results of the analysis, together with information provided by soundings, are used to set up the dredging program for the next week, which brings us back to step 1.

PREPARATION OF THE DREDGING WORKS

Preparation of the dredging works is done making up the 'Dredging Program'. The 'dredging program' consists of the following: (a) the geographical contours of the dredging and disposal areas, with indication of areas that need special attention; (b) the assignment of dredging and disposal areas to a dredger and (c) miscellaneous information such as dredging depth.

Input of geographical data is done by digitising. The co-ordinates are transferred to a software program that allows to create a digital map from the digitised co-ordinates. All information needed to draw a digital map is stored into a database. Two kinds of information are stored in the database: (a) fixed geographical information - These geographical data are not likely to change very often. Among these data we have banks, position of buoys, landmarks and other navigation aids, and (b) variable geographical information - This geographical information may change frequently. One example is the information about dredging and disposal areas for one week.

Once geographical data are entered, the database and the 'dredging program' can be checked. After selection of a ship, software shows the dredge area in overlay with the fixed geographical data. Additional data such as imposed dredging depth are also shown. This allows to have a visual verification of the data before transferring them to the ship. An example screen is given in figure 3. Once approved, the program is distributed to all dredges involved in the work.

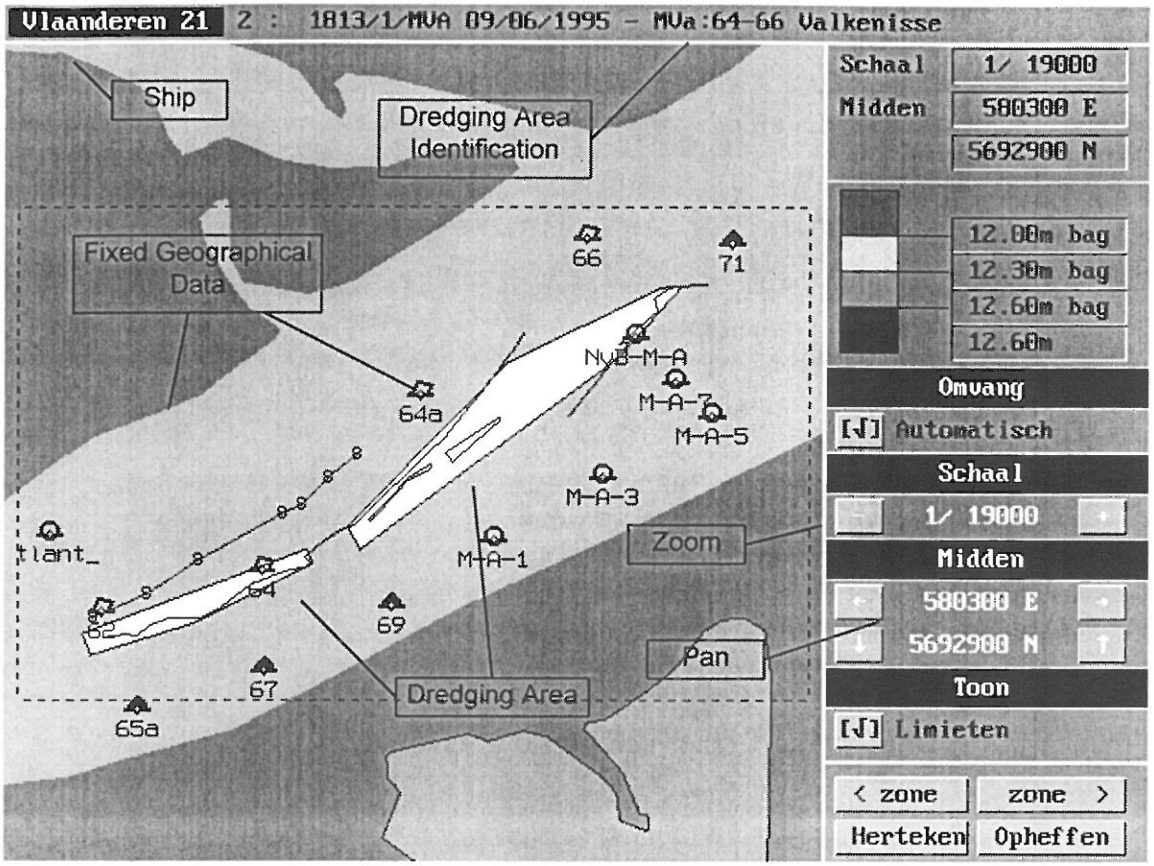

Figure 3: Visual verification of input data on PC

OPERATION OF THE SYSTEM ON BOARD

The system on board performs two task: (a) the system registers all dredging activities for supervision and evaluation purposes; and (b) the system provides the crew with feedback, so that dredging is done in the most efficient way.

Registration of the Dredging Activities

All signals are measured and recorded. The next sections explain how these recordings can be used for supervision and evaluation of the dredging activities.

Feedback to the Crew

The crew must have all information to be able to work efficiently within the limits imposed. For this reason special attention was paid to provide the crew with this information. Most on-line information is shown on the navigation screen near the skipper. The same display is shown on a smaller screen near the dredgemaster. An example of this navigation display is given in Figure 4.

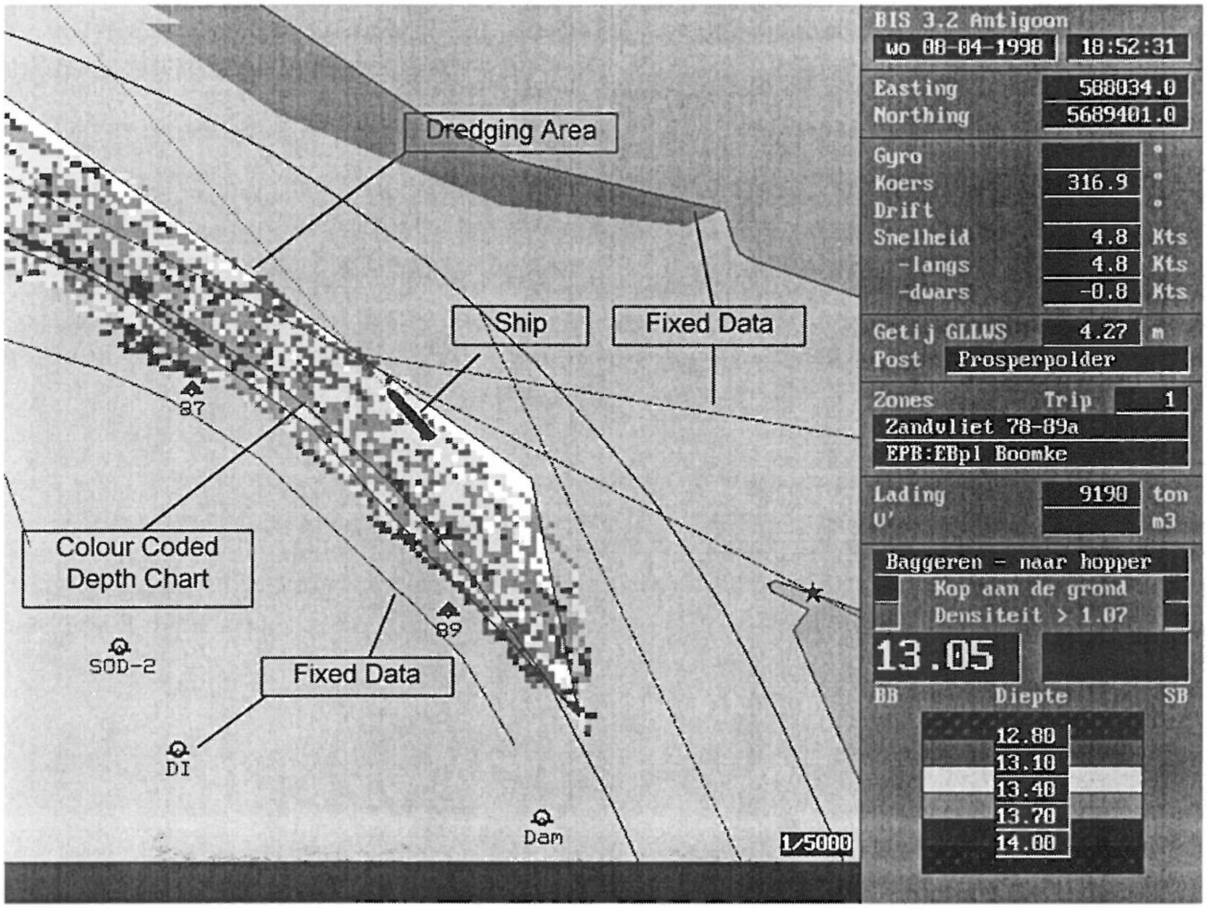

Figure 4: Navigation display for skipper and dredgemaster

The right part of the display shows - on a digital map - the position and heading of the ship relative to the environment. A colour coded depth map for the dredging area is also shown. This map is the result of recording the last dredging depth in a square grid. The depth map is updated on-line. Colours indicate whether the imposed dredging depth has been reached or not. A depth map generated by recording dredging depths has not the same quality and precision as a depth map generated by conventional echo soundings. Nevertheless this approach proved to be a valuable means for immediate on-line feedback of dredging operations and for in-between evaluations. The main purpose is to decide on what part of the dredging zone the dredging should be focused.

The left of the screen shows - in alphanumeric form - the most relevant measured signals, together with a status indication. In the bottom area of the display, messages are shown to the skipper and dredgemaster, indicating warnings or possible malfunctions of a subsystem.

SUPERVISION AND VERIFICATION

All supervision and verification tools are gathered in a single software program. The primary means of supervision is a graphic display presenting the tracks as sailed by the ship. These tracks are colour-coded where the colour depends on the state of the dredger (dredging, sailing, dumping) and the dredging depth (in case the vessel is dredging). These tracks are shown in overlay with the assigned dredging and disposal areas.

This graphical presentation is a simple but powerful means for supervision : at one glance the supervisor can check the main constraints - Was dredging and disposal done within the assigned areas? Was the imposed dredging depth met?

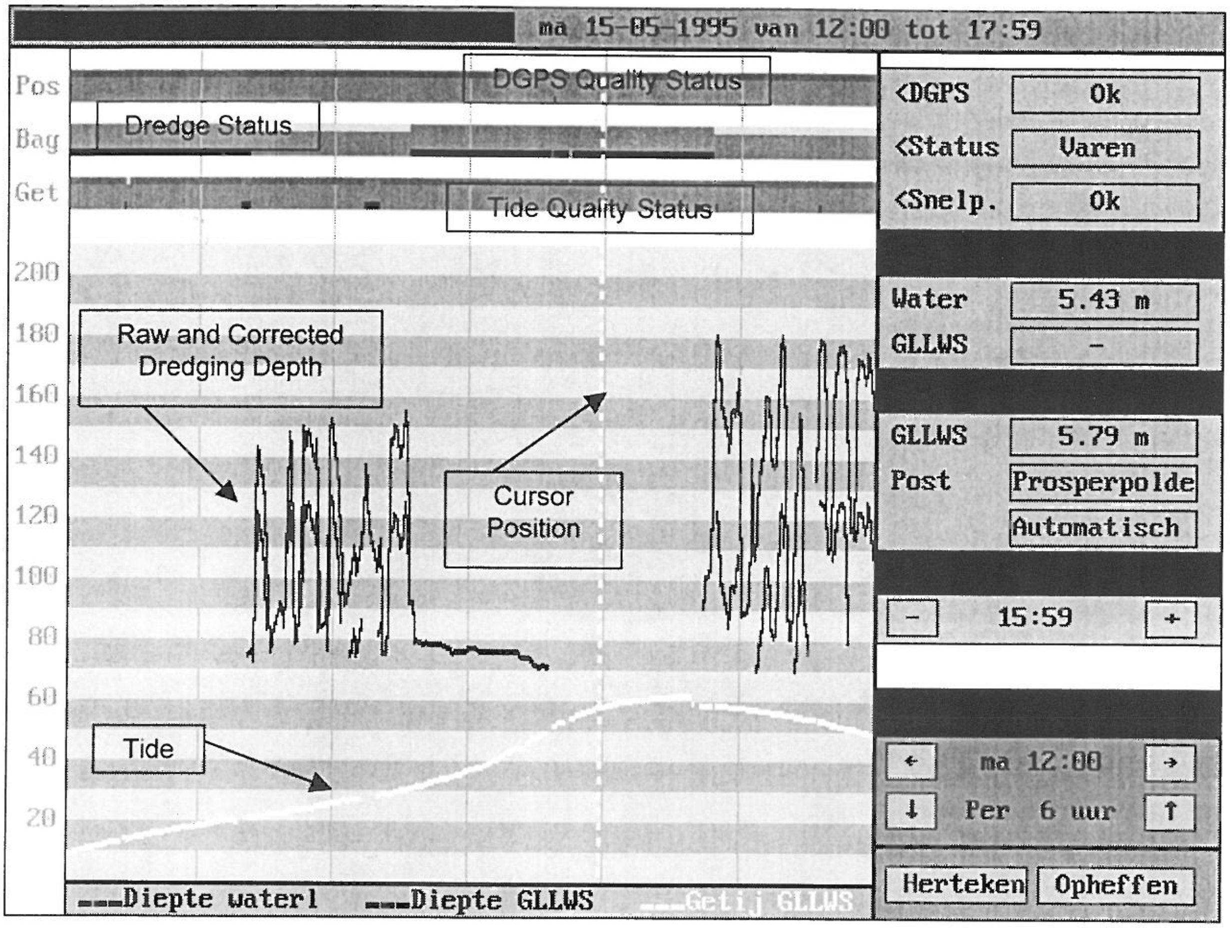

Figure 5 : Recorded signals and status information

The supervision software also allows the generation of several reports. Among these we have depth statistics, overview of available data, start time and end time of trips, positioning system quality statistics, tide measurement system quality statistics, etc. In case of anomalies in the interpretation of data, some graphical screens are available, showing the recorded signals and status information. An example is shown in Figure 5.

EVALUATION

Evaluation of the dredging area is done on a chart similar to the depth chart on the navigation screen (Figure 4). The chart shows the colour coded dredging depths. As mentioned before, this colour coded map of dredging depths is not intended to replace conventional echo-soundings. It must be considered as a quick way to evaluate the state of the dredging zone in-between echo-soundings. From the result of these evaluations the on-going dredging can be adjusted.

AUTOMATED REPORTING

Generating reports that describe the operation of a dredger is common practice. These reports typically include information about time-usage and actual production. For hopper dredges, time usage data consist of start and duration of the distinct phases of the dredging cycle (trip). Production data consist of information about the dredged quantities for every trip.

In most cases reporting involves the following three steps: (a) Collection of data : This is frequently done manually by the crew or by a supervisor on board; (b) Recording of data : if the information is collected manually, the data for a trip are entered into a logbook. This can be done by writing down the data or by entering the data in an electronic form (e.g. spreadsheet); and (c) Generation of reports : based on the trip data, a number of reports can be made. Trip reports show all details about one trip, day reports or shift reports summarise the data in less detail. Weekly reports or progress reports give a general overview of the operation of the dredger for the period concerned. Generation of these reports can be done manually or in a more or less automated way.

The reporting system that was implemented as a part of the dredging information system is fully automatic : the gathering of the needed data is done by the on-board registration system. The data are imported in a database. From this database, users can generate trip reports, weekly reports and periodic reports. The key issue in reporting systems is the collection of data. If the collected data are correct, the process of storing the data in a database and the generation of the reports is quite straightforward.

Time Usage

The basic cycle in the operation of hopper dredges is the 'trip'. The 'dredge cycle phases' considered in the reporting system are: dredging; turning; sailing to disposal area; disposal of the material by dumping; disposal of the material by pumping ashore; sailing back to dredging area; and downtime periods.

An automatic reporting system must be able to recognise these distinct phases. The recognition must be robust and consistent. Robustness means that the recognition mechanism should be relatively insensitive to sensor failures. Consistency means that all possible situations should be handled. The basic idea behind the implemented dredge cycle phase recognition is that only digital (on/off) signals are used. Analogue sensors need calibration and are generally more error-prone than digital sensors. Digital sensors are relatively simple, cost less and can be interfaced in a simple way. Malfunctions are easily detected and sensors can be replaced by the crew.

The signals actually used for the phase recognition are: (a) hopper open/closed; (b) suction pipe(s) overboard; (c) dredge pump(s) operation; and (d) position of some valves on the pressure side of the dredging pumps. Experience shows that due to the presence of dirt or other material, a valve position sensor may not be working properly. By using the 'valve closed' sensor as well as the 'valve open' sensor for each valve and taking into account the position of all valves, it is however possible to design a recognition mechanism that not only works correctly but even is capable of detecting and correcting single sensor failures. Once dredge cycle phase recognition is correct, it is straightforward to obtain start time and duration for the distinct phases of the dredge cycle.

Production Data

A reporting system normally includes production data : the amount of material dredged or relocated on a trip is measured and included in the report. In case of the maintenance dredging works on the river Scheldt, the production for a trip is defined as the amount of material carried to the disposal area during the trip. In most cases the dredged material is sand and - until now - the production is measured by manually sounding the actual volume of sand in hopper.

For hopper production calculation the volume of dredged material in hopper and the weight of this material are needed. These quantities can not be measured directly in an easy way. For the evaluation two types of measurements were implemented :

- Measurement of the vessel's draught by means of pressure sensors on the keel of the ship (front and rear). Using the hydrostatic tables of the vessel, these draughts can be converted to water displacement and thus total weight of the vessel. Draught sensors are present on most dredges.
- Measurement of the level in hopper by means of two ultra-sonic sensors mounted above the hopper (front and rear). By means of 'hopper tables' the levels can be converted to the volume of the total amount of material in hopper.

Taking into account the weight of the empty vessel, the weight and volume of the hopper load can be established. The hopper load however usually consists of a mixture of dredged material and water. One common way to get an actual amount of dredged material is the 'Tons Dry Solids' method that allows to calculate volume and weight of the load, assuming a stated density value for the material. Known characteristics of this method are the following:

- The weight of the empty ship must be known in order to obtain the total load weight from the total vessel's weight. In case the filling of trim tanks can influence the weight of the vessel, the volumes in these trimtanks should also be measured. To compensate for slow changes in the vessel's weight - e.g. due to fuel consumption - a measurement of the weight of the empty vessel should be done at regular intervals. Measurements of the weight of the empty vessel influence all following load measurements.
- The density of water has an influence on the draught measurement. In the Scheldt estuary the density of water depends on the dredging location. In some locations it depends on the actual value of the tide. Fortunately when calculating the vessel's weight from transducer pressures, the influence of water density is very small.

In a first measurement campaign, an evaluation of the basic measurements (vessels weight and total hopper volume) was done : manual recordings of the vessel's weight and hopper volume were done on regular intervals during several weeks. These recordings were compared with the measurements done by the automatic reporting system. Production measurements were made on a moment short before dumping. In the mean time, manual and automatic recordings compare well. The results of individual measurements however depend largely on the circumstances. In our opinion, the indication of the quality of a measurement is nearly as important as the measurement value itself, especially in the case of unattended automatic logging. In case of automated production measurement it appeared that the establishment of reliable quality indicators is not evident : most influencing factors are fairly difficult to measure and quantify. It appeared that the relatively simple quality indicators we used (ship's speed relative to ground, turning rate, rate of change for sensor values, etc.) do not have a direct relationship with differences between manual and automatic measurements. These issues are still under investigation.

Implementation of the Reporting System

Dredge cycle recognition is done by the registration system on board. The results are shown on the navigation display near the skipper. Detected sensor failures are also shown on this screen. Hopper load and volume are measured by the registration system. The measurement is not initiated by the registration system but is done on external command. As explained in the previous paragraph hopper load and volume measurements are still under investigation. The recorded data are copied on a floppy disk and transferred a PC. On PC the data are imported in a database. During import consistency checks on the data are done. We selected a 'personal' database (MS Access ®) on PC and not a 'company' database on server or workstation. The database can thus be used on a PC on-board. From the database, standard reports are generated on screen and on printer, including periodic reports, trip reports and weekly reports.

The fact that all data from the automatic reporting system are stored in a database allows other applications - such as spreadsheets - to access the data by means of queries. The presentation and analysis of the recorded data is thus not restricted to the predefined standard reports. Dredge cycle phase recognition and time usage reporting proved to be robust and accurate in practice. Automatic production measurement is still under evaluation.

SUMMARY

This paper described the design and implementation of a 'Dredging Information System' for the supervision and follow-up of the dredging works on the river Scheldt. The general purpose of this system is to gather all information relevant to the maintenance dredging works and to provide the means to process, present and report these data.

Future plans for the system involve incorporation of a linkage between morphological processes and dredging. A known problem here is the availability of field data which can be used to set up, calibrate and evaluate mathematical models. The goal of future work would be to collect information about the exact amount of material that has been dredged or relocated on different locations in the river. The registration system on board keeps track of the amount of material that was dredged or relocated on every location during one week. The data is be collected in a grid (measuring between 5x5 meters and 10x10 meters). The amounts are obtained by distributing the trip production over the track sailed by the vessel during the trip. The total trip production - that can only be measured at the end of the trip - is not distributed uniformly over the track : for each position it is weighted by the suction production on that position.

For every dredger, the data for one week is exported to a central computer. The data on the central computer consists of 'grids' containing the total amount dredged or relocated in the grid cells. These grid-data are managed by a database. The database allows to filter the data on a time base (from week, to week) and on a geographical base (a specified dredging or disposal area or an arbitrary area on the river). Software allows to process the data : for a specified region and period totals can be computed. The results can be shown graphically or can be exported for use in other software (e.g. GIS programs). It is also possible to compute and show the evolution of the total amount dredged or relocated over a period.

REFERENCES

Claessens J., Van de Velde P. and Smits J. (1997). *"Automated Supervision and Follow-up of Dredging Works"*, Proceedings of the Second Asian and Australian Ports and Harbours Conference, Ho Chi Min City, Vietnam.

Hahlbrock U., and Freese I. (1997). *"Hopper Load Measurement - Some Recent Experiences with a Remote Operated Data Acquisition and Analysing System"*, Proceedings of the CEDA Dredging Days 1997, Amsterdam, Netherlands.

Rokosh W.D. (1989). *"Measuring Dry Matter in Trailing Hopper Dredges"*, Terra et Aqua No. 41, IADC, The Netherlands.

Rosati J., and Welp T.L. (1994). *"Silent Inspector - An Aid to Dredge Inspection"*, Proceedings of the Second International Conference on Dredging and Material Placement , Lake Buena Vista, FL.

NOTATIONS

Translations of some Dutch words in computer printout figures are given below.

Dutch	English
diepte	depth
diepte water	depth relative to waterline
diepte GLLWS	depth relative to a reference level
getij	tide
getij - GLLWS	tide relative to a reference level
getijpost	tide measuring station
herteken	redraw map
koers	course over ground
lading	load
limieten	limits
midden	center point
omvang	map extent
opheffen	cancel
schaal	map scale
snelheid	speed
snelheid - dwars	transverse speed
snelheid - langs	forward speed
snelp.	name of the tide reception chain
toon	show (redraw) map

NOTES FOR CONTRIBUTORS

GENERAL

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Keywords

Please provide 5 keywords that are not already contained in the title, on a separate sheet of paper.

MANUSCRIPT PREPARATION

Order of contents

Title, author(s), affiliations, addresses, countries
Abstract (not to exceed 300 words).
Introduction, main body, and following text, conclusions, nomenclature (if necessary), and references.
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Refer to a previous issue of the journal for general guidelines on format.

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The text should be submitted on unlined white 8½ x 11 inch paper with **single line spacing**, and top and side margins of 1 inch. Use full justification. **The image area or block of text will then be 6.5 x 9.0 inch.** The bottom margin should be 1½ inch. Page numbers should be marked in pencil and placed at the bottom center of each page. **Do not leave additional margins. Do not use company letterhead paper.**

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Equations

All symbols must be defined in the nomenclature section that follows the conclusions. The SI system of units should be used. If units other than SI units are included, they should be given in parenthesis after the relevant SI unit. Equations should be successively numbered (in parenthesis) flush with the right-hand margin (see example below).

$$y = a + b + cx^2 \qquad (1)$$

References

References in the text should be given as: Smith (1988), (Smith, 1988) or (Jones et al., 1986). References should be listed alphabetically in the References section at the end of the paper. Give the names and initials of all authors, followed by the title of the article and publication, the publisher and the year of publication. References to conference papers or proceedings should include the name of the organizers. References to articles published in journals should also include the name of the journal, the number of the issue and page numbers (see example below). References to publications in a foreign language should give all details in the original language followed by a translation of the title.

Hunt, J.B. (1995). "*Environmental Dredging*". Smith & Son, Inc., New York, NY.

Donegan, T.M., and Dinicola, W.J. (1986). "*Turbidity Associated With Dredging Operations*". Technical Report, XYZ Consultants, Inc., Baltimore, MD., 60 p.

Jones, F., Doe, A., Hart, E.J.E., and Next, J.P.J. (1986). "*The Design of Dredged Material Disposal Sites.*" Proceedings XIVth World Dredging Congress, CEDA, Amsterdam, The Netherlands, pp. 350-368.

White, F.K. and Jones, J.M. (1991). "*The Analysis of Flow Fields Around Dragheads.*" Journal of Waterway, Port, Coastal and Ocean Engineering, ASCE, Vol. 121, No. 5, pp. 1-16.

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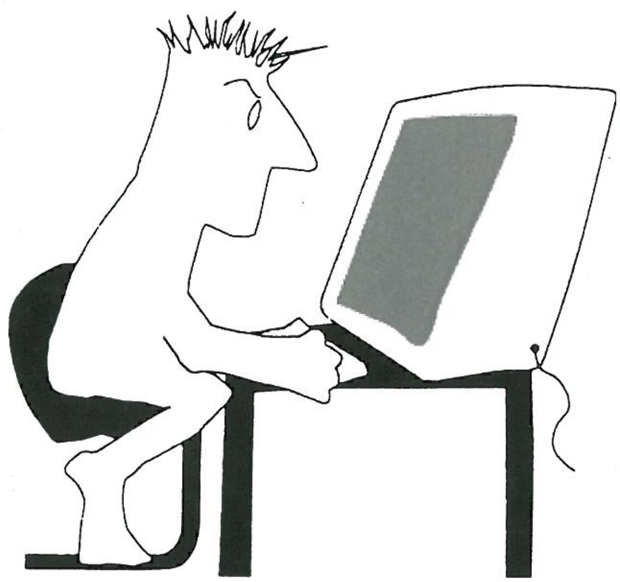

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