Process Simulation for Guide Wall Construction Using Mobile Cofferdams

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Proper planning for marine construction projects that involve new concepts is necessary for efficiency and economy. However, planning is difficult because there are no previous experiences to draw from. In such situations, simulation programs are an effective aid. Plans may be improved by iteratively simulating various construction sequences and resource allocations. Resources can include cranes, barges, and temporary structures. Simulation models assign probabilistic durations to work tasks, allowing more realistic analysis. After each simulation, results may be reviewed and improvements may be made. In this paper, simulation modeling is used to improve the resource allocation and construction schedule for a guide wall using a mobile cofferdam. A guide wall assists vessels as they enter and exit locks, and a mobile cofferdam provides a dewatered area for constructing a segment of the structure. The first model served as a point of comparison for modified versions. Modifications were made to the number of cranes, their work assignments, and the number of mobile cofferdams. The model logic was improved to enhance work flow. In all, six versions of the model were developed. The final version required 47 percent less time than the first version to complete 40 guide wall segments.

The construction of locks and guide walls represents a major portion of the cost involved in the construction of inland navigational facilities. Conventional methods of construction are costly. The U.S. Army Corps of Engineers (USACE) is trying to develop strategies for building more economical navigation projects that fit within the constraints of the Inland Waterway Trust Fund and the current federal budget. The resulting cost reductions would enable USACE to start planned projects earlier and to construct additional projects.

This study focuses on the use of a mobile cofferdam, a reusable cofferdam that allows construction of a lock guide wall or dam segment in the dry. Although this method has not been used to construct a lock, elements of the process have been accomplished in previous construction efforts such as floating dry docks, tremie concrete placements for bridge piers, and offshore oil drilling. This type of construction here is repetitive in nature, which is simulated in this paper. A wicket box (similar to a mobile cofferdam) is being constructed for use on the Olmsted dam, and the concept will be tested at the Smithland Dam (*1,2*).

OBJECTIVE

The objective of this study was to develop methods for mobile cofferdam construction that save time and money, with the aid of a simulation program. Methods for resource allocation and sharing were also investigated. Conclusions were drawn by comparing simulations that had different resource allocations. The results of this research complement the current efforts of the USACE.

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MicroCYCLONE

MicroCYCLONE is the simulation program that was used for this study (*3–5*). Flowcharts of MicroCYCLONE models use four basic components (Figure 1):

1. Circles represent queues or waiting positions for resources (the idle state). Examples of resources are equipment, materials, workers, and workspace.
2. Square nodes represent work tasks (the active state). The constrained work task (i.e., a work task that requires more than one resource) is modeled as a square node with a slash called a COMBI node.
3. Arcs represent the path of a resource as it moves between idle and active states.
4. Special function nodes can be used for generating and consolidating resources, or for counting cumulative production. These components are arranged to represent the logical flow of resources in the construction projects. Examples of resources are equipment, material, workers, and work space.

MicroCYCLONE supports probabilistic duration inputs (uniform, triangular, beta, normal, and exponential).

CONSTRUCTION OF GUIDE WALLS USING MOBILE COFFERDAMS

Guide Walls

Locks provide navigational routes through dam complexes; they are steps in an "aquatic staircase" by which vessels are lifted or lowered from one pool to the next, while the pools themselves remain level (*6*). Guide walls are built to assist vessels as they enter and exit the locks. Guide walls also allow temporary berthing for vessels waiting to enter the lock. They vary in length from 30 m to 450 m (100 ft to 1,500 ft) depending on the site conditions (*1*).

Description of the Process

A reusable mobile cofferdam (MC) (Figure 2) is a large steel box with walls that are 4.5 to 6 m (15 to 20 ft) thick. It provides a dewatered area for construction. The steel box is formed with a space truss, covered by steel plate inside and out. The rear wall has an opening shaped to accommodate the in-place guide wall. The volume within the MC walls can be filled with water or emptied to facilitate moving.

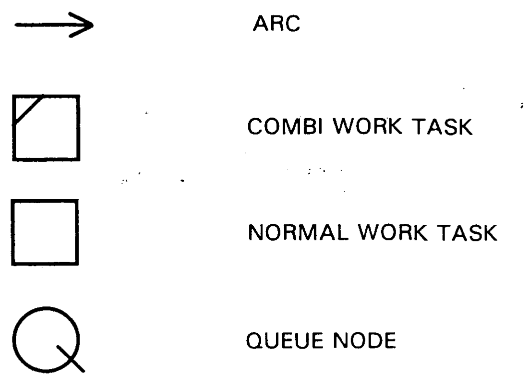


Figure 1 Basic modeling elements.

The operations involved in the construction of a guide wall using an MC follow a linear sequence of activities. The following steps are required for each section of the guide wall.

1. Excavation. The segment location is initially excavated in the wet to obtain the desired elevation of the base of the structure. Excavation is carried out with a barge-mounted clam bucket or dragline. Hydraulic dredging is also possible. The side slope for soft soils should be no steeper than 1 vertical on 2.5 horizontal. Better foundation conditions may allow steeper slopes.
2. Pile Driving. Driven piles are the most common foundation treatment for marine works. The piles can be driven with an underwater hammer in telescopic leads or driven from above the water and cut off to grade. For this simulation, the piles are assumed to be driven using pile drivers above water. A floating driver is assembled by placing a crane and pile hammer on a barge. Supplying the pile driver with piles requires a supply barge and a tug.
3. Float MC to location and position. Next, the MC is moved to the location where the segment is to be cast. The MC is lowered at the desired location in the construction and aligned, leveled, and maintained in position by spud piles at its four corners.
4. Tremie concreting. The tremie concrete seal, placed at the bottom of the MC, resists hydraulic uplift pressure. In addition, modern designs often use the seal as part of the permanent structure, as a distribution or footing block that transfers the load to the piles. The tremie method is often used for placing structural underwater concrete. Tremie pipes are used to limit the contact of fresh concrete with water. Rates of pour in standard practice cause the concrete to rise at a rate of 0.45 to 1.8 m/hr (1.5 to 6 ft/hr). For this simulation model, the rate of pour is 0.9 m/hr (3 ft/hr) (*7*).
5. Dewatering. After the tremie concrete has attained the required strength, the work area is dewatered with pumps.
6. Forming and Pouring. After the cofferdam is pumped dry, reinforcing steel is placed and the segment is formed. The reinforcing is placed in prefabricated units. The walls of the cofferdam act as side forms. Additional formwork is required only for the upper half of the cofferdam, where the wall segment thickness is less than the inner width of the cofferdam. Instead of using manual forming, an automated forming system can be incorporated into the MC. This system consists of forms mounted on tracks attached to the MC. These forms can be retracted, raised, and reset mechanically. The concrete is poured after the forms are all set in position. It should be possible to concrete a segment in a single pour.

DESCRIPTION OF SIMULATION MODELS

Several versions of the simulation model for the mobile cofferdam were developed. Version 1 provided a point of comparison for subsequent versions. For all the versions, construction of 40 segments was simulated. In later models, in which two MCs were used, construction of 20 segments was simulated for each of two guide walls. After the 40 segments were completed, the simulation stopped and the required construction time was recorded. The following resources were considered in the models.

1. Cranes: assisted in excavation, tremie concreting, forming segment, pouring concrete and pile driving.
2. Mobile Cofferdam: required for tremie concreting.
3. Location: also a resource. A location is an area where a guidewall segment will be built.

Activity Durations

It would be desirable to select the duration input by analyzing historical data from many similar construction activities. For MC construction, however, such an analysis would be difficult for several reasons. Although many of the activities have been performed on past construction projects, they have not been applied to MC construction. It is necessary to modify estimates in response to project-specific circumstances. Historical data may be presented in an inconvenient format and stored in scattered locations. In some cases the data are proprietary, owned by a particular construction contractor. In other cases there may not be enough data to perform a complete statistical analysis.

An alternative method for obtaining duration input is to ask marine construction experts to give estimates for activity duration and the range of expected productivity values. Program evaluation and review technique methods may be used to define an equivalent normal distribution (*8*). The expected duration is as follows:

$$t_e = \frac{a + 4b + c}{6}$$

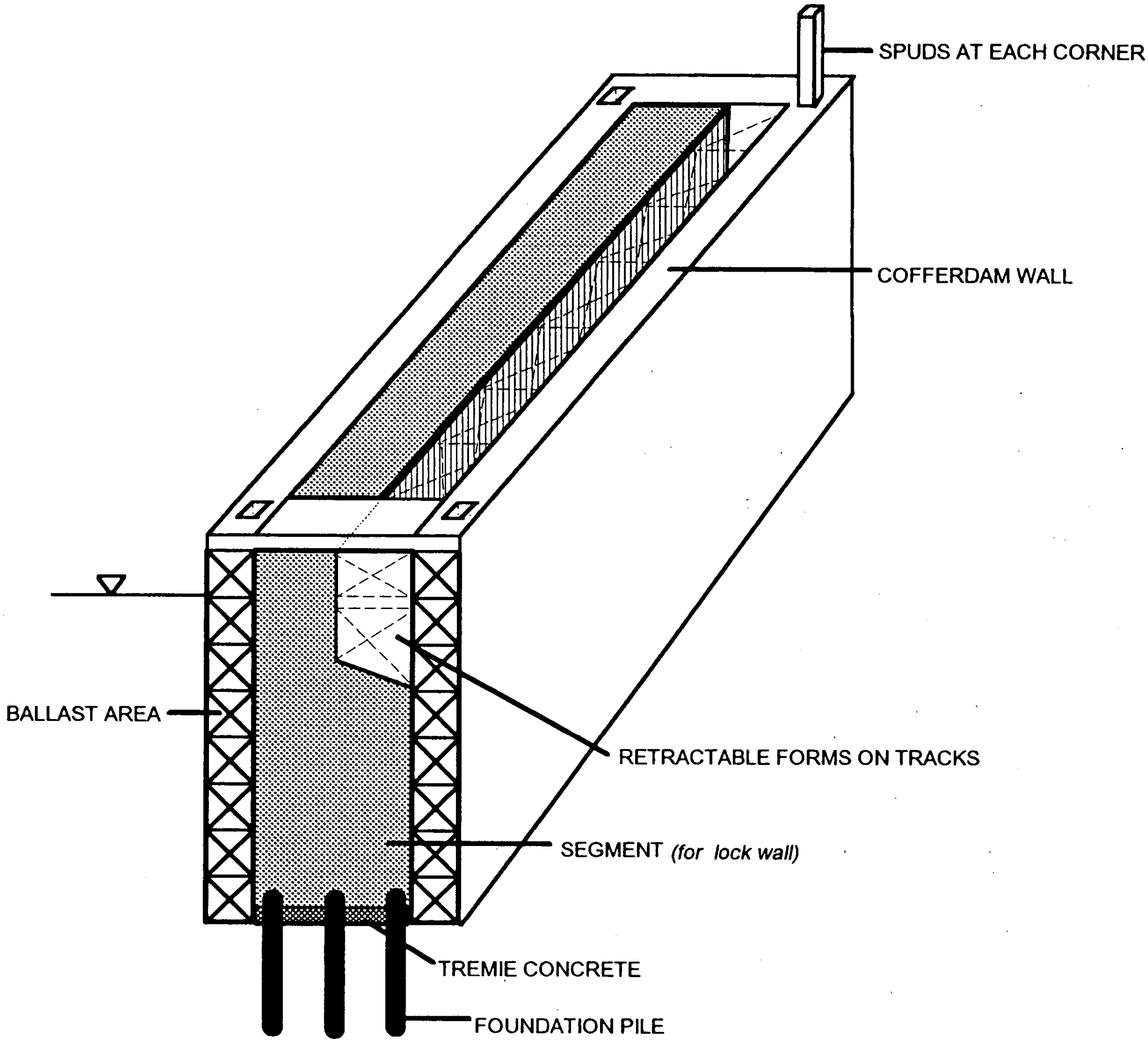
The standard deviation is as follows:

$$\sigma = \frac{c - a}{6}$$

where

t_e = expected duration,
a = optimistic duration,
b = most likely duration,
c = pessimistic duration, and
σ = standard deviation.

Three experts were consulted to find the most likely duration: two from marine construction contractors (M. Schnoeblen, Massman Construction Company; T. Pirtle, Traylor Bros., Inc.) and one (B. McClellan) from the USACE Louisville District. The first author personally reviewed the project requirements with the experts and requested duration or productivity estimates for each operation. The experts only gave estimates for operations about which they were knowledgeable. The estimates for the most likely



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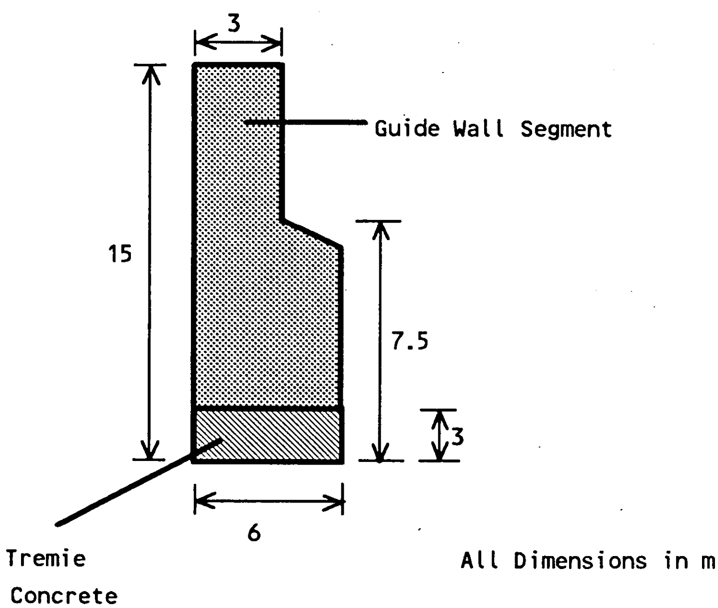


FIGURE 2 Mobile cofferdam and guide wall: (*a*) oblique pictorial view; (*b*) cross section of guide wall.

duration represent a consensus. In cases for which experts provided productivity information, the expected duration was found by the following equation:

$$t_e = \frac{Q}{fp}$$

where

Q = quantity of work,
P = productivity, and
f = efficiency factor, 0.83 (50 min/hr).

An efficiency factor of 0.83 is commonly used by construction estimators.

Some operations have little schedule variance. Concrete placement must be accomplished in a single day to avoid cold joints. Contractors will extend work hours to complete such activities in a single day. Deterministic duration is satisfactory for such activities. Other actives such as dredging, pile driving, positioning the mobile cofferdam, dewatering, and forming have a stochastic duration. Six marine construction experts were consulted in telephone interviews by the second author to find the typical range of duration as a percentage of the expected duration. The results are provided in Table 1. The duration range percentages were averaged and rounded to the nearest percentage. They were used to calculate the optimistic and pessimistic durations (*a* and *c*) and the standard deviation (σ). The activity durations are summarized in Table 1. Additional details regarding duration calculations are as follows:

1. The mobile cofferdam is 18 m (60 ft) long, 15 m (50 ft) wide (exterior) and 15 m (50 ft) high. The dimensions were from the drawings in reference (*1*). The internal work space is 6 × 18 m (20 × 60 ft).
2. The river bed soil is sand and a trench 3.6 m (12 ft) deep is assumed. Digging using a clamshell is relatively easy up to this depth. Thus, a 3-m^3 (4-yd^3) clam bucket can be used. Excavation duration is based on dredging productivity of 245 m^3/hr (320 yd^3/hr). The side slope of the excavation is assumed to be vertical on 2 horizontal.
3. Steel H-piles are driven to a depth of 6 m (20 ft) below the base of the cofferdam [total length of each pile is 9 m (30 ft)]. Hard soil exists at a depth of 4.5 m (15 ft) below base. The row spacing is assumed to be 3 m (10 ft). Six H-piles are assumed in each row. There are 5 rows of piles and a total of 30 piles, giving a total length of 270 m (885 ft). The duration estimate is based on a piling rate of 6 m/hr (20 ft/hr).
4. The bottom 2.7 m (9 ft.) of the cofferdam is tremie concreted and the rest of it is poured using a bucket. The production rate for tremie concreting is 55 m^3/hr (70 yd^3/hr). For dewatering calculations, the depth of water is assumed to be an average of 10.6 m (35 ft). Duration estimate is based on a dewatering rate of 5500 L/min (1200 gal/min).
5. A 2-m^3 (2.5-yd^3) bucket is used for concreting; the production rate is 75 m^3/hr (100 yd^3/hr). Although 15 hours are necessary, placement would be completed without a break, using two work crews, so that construction joints could be avoided. Thus, only one calendar day is required.

Resource Costs

The costs of labor and equipment directly involved in mobile cofferdam construction were considered in the analysis. These costs are known as direct costs. Material costs such as concrete and reinforcing steel were not considered because they were not changed in the simulation. In MicroCYCLONE costs can be either fixed or variable. Variable costs are only incurred when the resource is operating. Fixed costs are incurred whether or not the unit operates. For cranes, the crew costs were considered fixed costs, as the cranes were seldom idle for long periods during which crews would be reassigned to other tasks. The equipment costs were split into variable and fixed costs. The variable costs included the cost of fuel, oil, and repairs. The fixed costs were based on the rental charges. The variable costs were one-third of the fixed costs for all equipment. The resource costs are listed in Table 2.

It is assumed that the mobile cofferdam will be used on three similar projects. The total fabrication and material costs including labor are estimated at $1,500,000 (*1*). A fixed cost of $500,000 was assigned to this project. The crew costs were considered to be variable because the MC remains idle for long periods, especially during the initial stages of the project. It is expected that the MC crew will be assigned other work.

In some cases, the project duration can be reduced by increasing the direct project cost. When should this be done? When a project duration is reduced, both the contractor and the government save project management expenses, known as time-related overhead. Waterway users also save, due to reduced delays. By considering

TABLE 1 Activity Durations

Activity	Calculated Durations	Distribution	Percent Variation	Standard Deviation
Excavation	6.2 hrs	**Normal**	15	0.3
Pile driving	35 hrs	**Normal**	15	1.75
MC Positioning	8 hrs	**Normal**	15	0.4
Dewatering	7.3 hrs	**Normal**	10	0.23
Tremie Concreting	5.7 hrs	**Deterministic**	0	0
Forming	16 hrs	**Normal**	20	1.07
Placing Concrete	15 hrs	**Deterministic**	0	0
Stripping MC	4 hrs	Normal	20	0.27

TABLE 2 Resource Costs

CRANE FOR CONCRETE PLACEMENT AND EXCAVATION				
Item	Quantity	Unit cost	Daily Cost—Variable	Daily Cost—Fixed
Crane Operator	2	35/hr	-	560
Deckhand	1	25/hr	-	200
Tugboat Operator	1	30/hr	-	240
Supply Barge	1	200/dy	50	150
Welder	1	50/dy	12.5	37.5
Tug Boat	1	800/dy	200	600
Crane (165T)	1	1750/dy	435	1315
TOTAL			**697.5**	**3102.5**

CRANE FOR PILE DRIVING				
Item	Quantity	Unit cost	Daily Cost—Variable	Daily Cost—Fixed
Crane Operator	2	30/hr	-	480
Foreman	1	35/hr	-	280
Deckhand	1	25/hr	-	200
Tugboat Operator	1	30/hr	-	240
Journey men	4	30/hr	-	960
Barges	2	200/dy	100	300
Welder	3	50/dy	37.5	112.5
Pile driving Hammer	1	1000/dy	250	750
Tug Boat	1	800/dy	200	600
Crane (165T)	1	1750/dy	435	1315
TOTAL			**1022.5**	**5237.5**

MOBILE COFFERDAM				
Item	Quantity	Unit cost	Daily Cost—Variable	Total Cost—Fixed
Foreman	1	35	280	
Workers	5	30	1200	
Mobile Cofferdam Fabrication and Material	-	LS	-	500,000
TOTAL			**1480**	**500,000**

these savings, the value of the time and cost trade-off may be estimated and used as a decision aid.

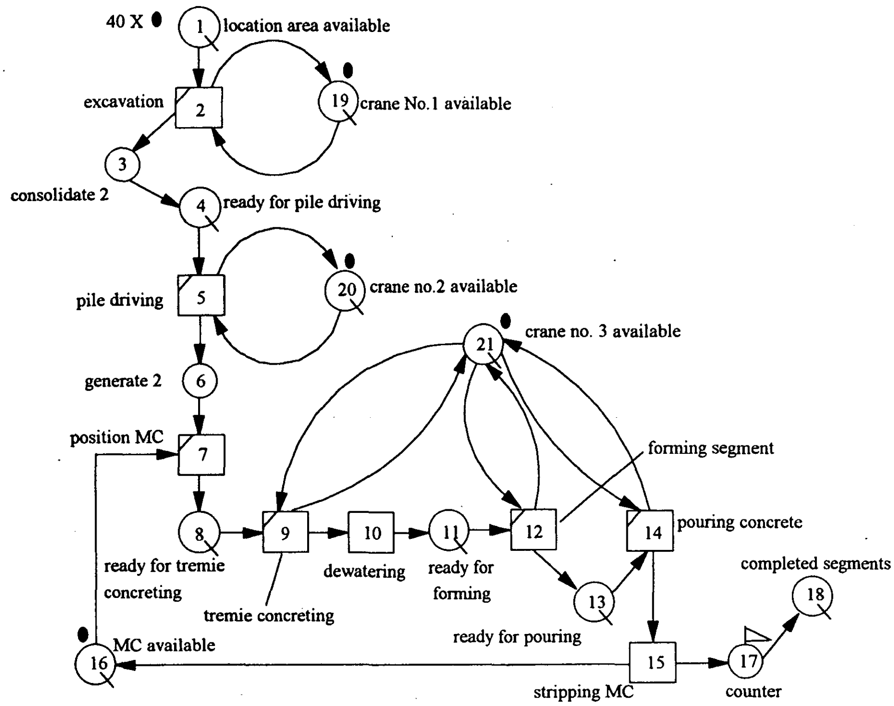
Most lock and dam construction contracts contain liquidated damage clauses that specify an amount that will be deducted from the payments due to the contractor for each day the project is delayed beyond the target completion date. The amount is usually based on government's time-related overhead expense. Liquidated damage amounts on the order of $10,000 per day are common for lock construction projects. To illustrate the process of making time and cost trade-off decisions, the amount of $10,000 per day is used in this analysis. This amount serves as a lower bound for the likely value of the time and cost trade-off.

Version 1

Version 1 (V1) used three cranes. The first was used for excavation, the second for pile driving, and the third for concreting and other cofferdam-related activities. To provide working space, it is desirable to maintain separation between activities such as excavation, pile driving, and positioning of the mobile cofferdam. This was accomplished by consolidating two segment locations before entering the pile driving node. The consolidation node released one resource entity for every two incoming entities. Thus two segments were completed before the next activity could start. Subsequently a generation function was used to free the consolidated resources.

This paragraph tracks the flow of resources through V1 (Figure 3*a*). The simulation begins with a queue node (Node 1—location area available) with 40 segment locations. The first activity is excavation (Node 2), for which the crane in Node 19 is a required resource. The segment location is released from Node 2 and enters the function node (Node 3), which only half of input resources will leave. Pile driving occurs at Node 5, where a crane with pile driving attachments is an input resource. The duration is adjusted to allow for driving for two segments. The segment is then released to the generation node (Node 6), where resources are restored to their original number. Node 7 simulates the positioning of the MC; an MC must be available before this activity can start. The segment then flows to Node 8, tremie concreting, where the third crane is an input resource, and Node 10, for dewatering. Then the segment goes through queue Node 11 to Node 12 (forming) and Node 14 (pouring concrete) where Crane No. 3 is an input. The MC flows through Node 15 (stripping and moving the MC to the next segment) before returning to the queue node (Node 16). The segment goes to the counter Node 17 where the production of one segment is recorded; then the segment goes to queue Node 18 where completed segments are collected. The simulation runs until all 40 segments are constructed and pass the counter Node 17.

Construction of 40 segments requires 267 days (6.67 working days per segment). The cost is $2,846,000 (Table 3) to complete the project, which gives a unit cost of $71,000 per segment. The production curve (Figure 3*b*) shows system cumulative productivity.



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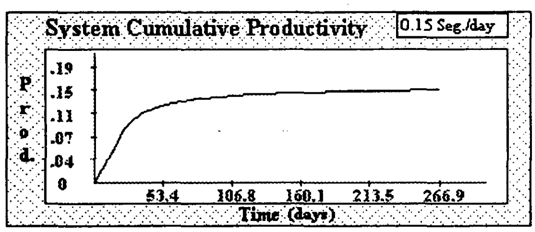


(b)

FIGURE 3 Model Version 1: (*a*) flowchart; (*b*) production curve.

TABLE 3 Time-Cost Trade-Offs

Comparing Version Nos.	Duration (days)	Direct Labor and Equipment Cost (K$)	Change in Cost (ΔC) (K$)	Change in Duration (ΔD) (days)	|ΔC/ΔD| (K$/day)	Better Alternative
1 and -	267	2,846	-	-	-	-
2 and 1	287	2,837	-9	+20	.45	1
3 and 1	246	3,231	+385	-21	18.3	1
4 and 1	198	3,153	+307	-69	4.5	4
5 and 4	191	3,630	+477	-7	68.1	4
6 and 4	141	3,412	+259	-57	4.5	6

Note:

- *If both ΔC and ΔD are positive, reject the new alternative.*
- *If both ΔC and ΔD are negative, accept the new alternative.*
- *If ΔC is positive and ΔD is negative, accept the new alternative if |ΔC/ΔD| < $10,000*
- *If ΔC is negative and ΔD is positive, accept the new alternative if |ΔC/ΔD| > $10,000*

Assumption: The time-related costs equal $10,000/day.

TABLE 4 Simulation Results

MODEL VERSION	% IDLE & DAYS USED						DAYS TO COMPLETE 40 SEGMENTS
	CRANE 1	CRANE 2	CRANE 3	CRANE 4	MC 1	MC 2	
1	0%, 32 X	1%, 177 P	4%, 267 T,F,R	-	4%, 267	-	267
2	1%, 177 P	33%, 287 X,T,F,R	-	-	4%, 287	-	287
3	1%, 178 P	22%, 246 X,T,F,R	-	-	7%, 149	40%, 246	246
4	1%, 179 P	3%, 198 X,T,F,R	-	-	25%, 193	6%, 198	198
5	1%, 178 P	49%, 190 X,T,F,R	39%, 190 X,T,F,R	-	32%, 191	26%, 183	191
6	2%, 90 P	2%, 90 P	31%, 140 X,T,F,R	31%, 140 X,T,F,R	7%, 141	8%, 140	141

Note: X- Excavation; P- Pile Driving; T- Tremie Concreting; F- Forming; R- Pouring.

The shape of this curve is typical for construction operations; it starts at zero, climbs quickly, and flattens out to a steady state. This indicates low productivity in the start-up phase and steady productivity after operations are established. The graph (Figure 3*b*) smoothly flattens out toward the end of the project, indicating that the system has reached its maximum possible efficiency with the given resources. Idle time was low for two of the cranes (excavation, 0 percent; pile driving, 1 percent) and high for the third (concreting, 40 percent) (Table 4). The concreting crane could also excavate or pile drive, thus eliminating a crane.

This model addresses the key issues of activity sequence and duration and serves as a base on which to improve. Other versions were developed to increase the productivity and maximize the utilization of the resources.

Version 2

In Version 2 (V2), two cranes were used: one for excavating, tremie concreting, forming, and placing concrete and the other for pile driving. This reduced the crane idle time. Compared to V1, there is a savings in cost of $9,000, however, 20 more days are required for construction. Thus $450 is saved for each day the project is extended (Table 3). Because time-related costs are $10,000/day, such a time extension cannot be justified.

Crane 1 (Node 2) is idle 33 percent of the time, while Crane 2 (Node 30) is idle 1 percent of the time (Table 4). The sequence of activities is similar to that of V1. The MC can be identified as the critical resource because it is idle only 4 percent of the time (Table 4). The production curve (Figure 4) shows that the system is not balanced, as the slope of the curve increases suddenly after day 40, indicating a bottleneck of some sort that restricts production. The simulation results show that during the initial stages, Crane 2 finishes excavation of 40 segments before tremie concreting segments. This should not happen, because it creates a bottleneck as segments queue up for tremie concreting. Moreover, excavated segments should be cofferdammed and tremie concreted as soon as possible to prevent silting. This issue is dealt with in Version 4, in which the node priorities were changed to improve the production rate and prevent this bottleneck. In the next model, the objective was to increase the utilization of Crane 1.

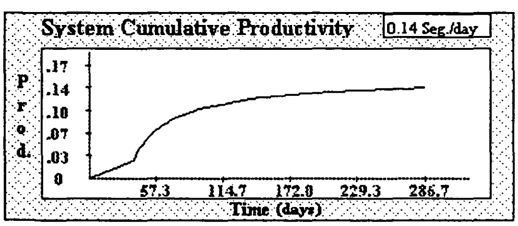


FIGURE 4 Production curve for Model Version 4.

Version 3

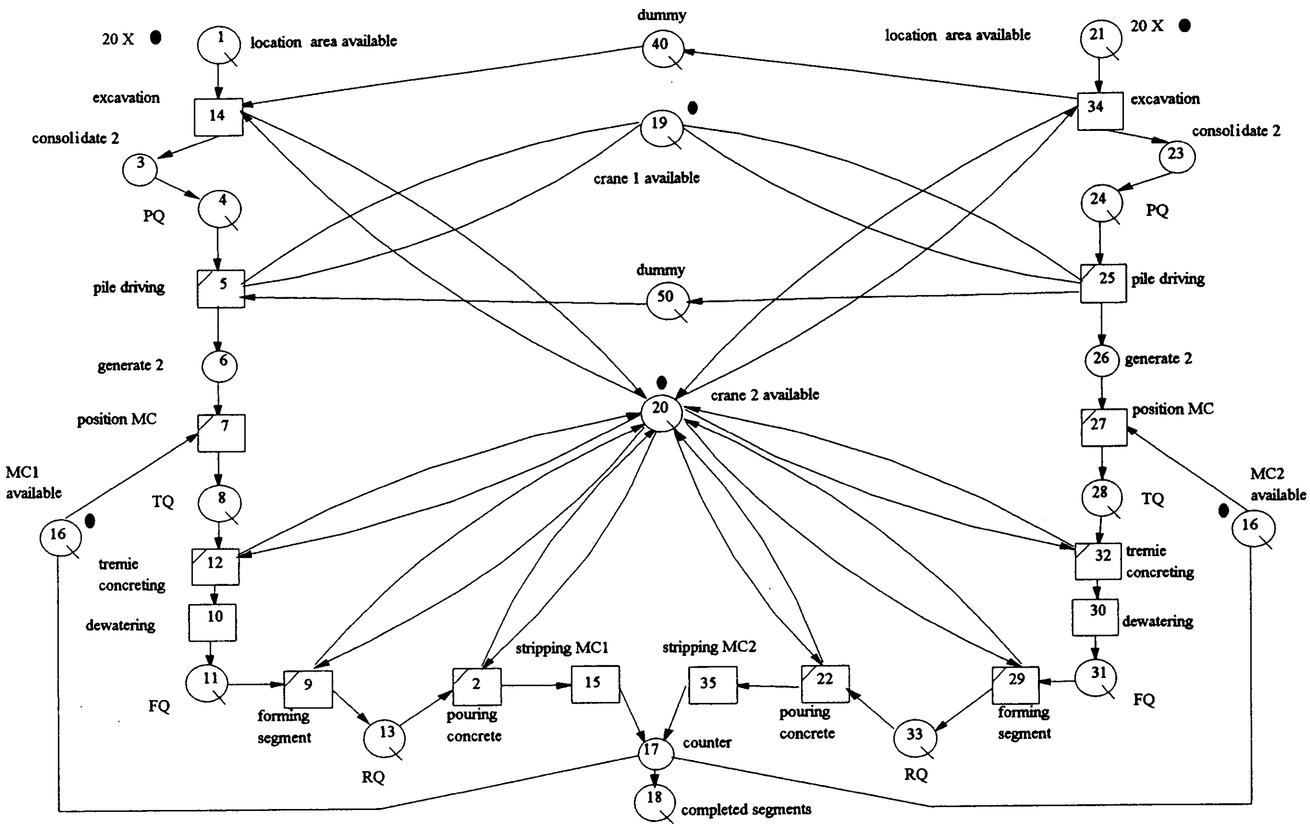
Version 3 (V3) used two mobile cofferdams to construct two parallel guide walls simultaneously. It was presumed that greater efficiency would result if the cranes were shared. One crane was used for excavation and concreting while the other was used for pile driving.

The results show that the productivity does increase. The construction of 40 segments took only 246 days, a savings of 21 days over V1; the costs increase by $385,000 to $3,231,000. The cost increased by $18,300 for each day saved (Table 3). Since this exceeds the $10,000/day of time-related costs, V1 is preferred over V3.

The cranes are used more efficiently in this version. Crane 1 is idle 22 percent of the time, and Crane 2 is idle 1 percent of the time (Table 4). MC 1 is used efficiently (7 percent idle), but MC 2 is idle for 40 percent of the time (Table 4). As the MCs are a valuable resource, it is essential to increase their utilization. At this point, balancing the system is more important than increasing resources, as idle time for both Crane 1 and MC 2 is high. This was done in the next version.

Version 4

If two activities call for using a resource simultaneously, MicroCYCLONE assigns the resource to the activity with the lower node number. The node numbering in Version 4 (V4) was changed, so that later activities have lower numbers and a higher priority. This



Note: PQ, TQ, FQ, and RQ denote the pile driving, tremie concreting, forming, and pouring queues, respectively, for segments

FIGURE 5 Process chart for Model Version 4.

prevents the segments from queuing in the middle of the construction process. Also, two dummy nodes were included, which cause the cranes to alternate between the two guide walls, spending equal time on each guide wall (resulting in a more balanced system). In the previous model, one guide wall had priority over the other. Figure 5 shows the process chart for this version.

The project was completed in 198 days, a savings of 69 days over Version 1. The cost was $307,000 more than V1, saving $4,500/day (Table 3). For most lock and dam construction projects, this would be an attractive alternative. Idle time decreases for both the cranes (3 percent for Crane 1, 1 percent for Crane 2) and the mobile cofferdams (25 percent for MC 1 and 6 percent for MC 2) (Table 4).

Version 5

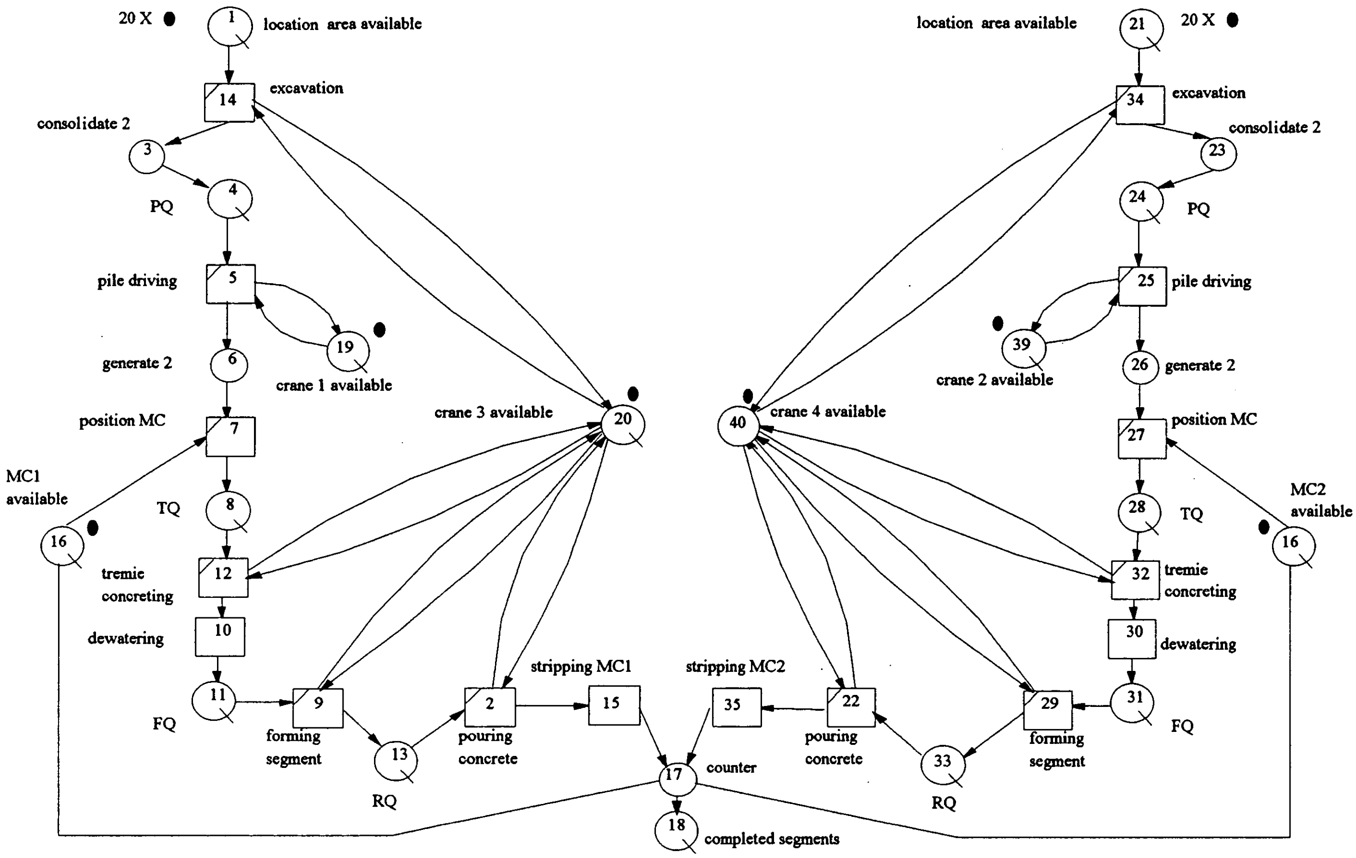
In Version 5 (V5), two cranes were used for excavation, tremie concreting, forming, and concrete placement. The duration was 191 days, a savings of 7 days over V4. Compared to V4, an additional $477,000 was required, or $68,100/day (Table 3). V5 is not preferred over V4 because $68,100/day exceeds the time-related costs of $10,000/day. The cranes used for excavation and concreting activities were idle 44 percent of the time (the average of Crane 1 and Crane 3). Crane 2 was used almost continuously (idle 1 percent of the time; see Table 4). It is the bottleneck in this model. The MCs were idle 29 percent of the time (average for MC 1 and MC 2, Table 4).

Version 6

In the final version, Version 6 (V6) (Figure 6), two cranes were used for pile driving. This was done because the previous model showed that the pile driving was the bottleneck. Compared to V4, the schedule was reduced by 57 days (141-day duration) and the cost increased by $259,000 ($3,412,000 total cost). An additional cost of $4,500 was required for each day the schedule was shortened (Table 3). V6 is preferred over V4 because $4,500 is less than the $10,000 of time-related costs. The MC was idle 7.5 percent of the time, the pile-driving cranes were idle 2 percent and the cranes tending the mobile cofferdam were idle 31 percent. As expected, looking at the high utilization of resources, the production curve for this version does not indicate any bottlenecks (Figure 7). The sawtooth pattern exists because two completed segments from each guide wall are being counted simultaneously. V6 is the recommended construction method.

SUMMARY AND CONCLUSIONS

A simulation model that includes all of the basic resources and work tasks has been developed. The model has been modified to



Note: PQ, TQ, FQ, and RQ denote the pile driving, tremie concreting, forming, and pouring queues, respectively, for segments

FIGURE 6 Process chart for Model Version 6.

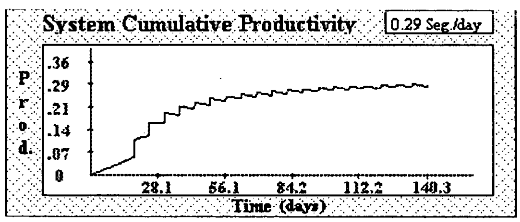


FIGURE 7 Production curve for Model Version 6.

experiment with changes in method that will increase construction efficiency.

In the transition from V1 to V2, one crane was eliminated and the productivity decreased only slightly. Incremental productivity improvements came with each subsequent modification. There was a 47 percent decrease in duration between V1 and V6. The resources were more completely utilized and better allocated so that bottlenecks were reduced. Although the direct equipment and labor costs increased, those costs were offset by time-related cost savings. The analysis shows that V6 is the preferred alternative.

The simulation process described here could be applied to other navigation structures. It provides planners with an effective method of testing the feasibility of new concepts and of refining construction plans. The ultimate result will be a reduction in construction costs for navigation structures.

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