New software helps estimate trenchless job costs—Part 2

While no substitute for sound engineering judgment, spreadsheet routine provides methodical procedure

J. D. Hair, J.D. Hair & Associates, Inc., Tulsa, Oklahoma

First step in accurately estimating the cost of specialized horizontal directional drilling services so they can be compared to conventional construction is to establish the contractor's direct job costs.

Direct job costs are composed of two components: daily shift costs and non-daily costs.

Daily shift costs are dependent on the number of days it takes to conduct operations. This is accomplished by calculating the cost of a given operation per shift and multiplying that figure by the number of shifts required to complete the operation.

Non-daily costs are not dependent on how long it takes to do the job. Examples are equipment hauling for mobilization and demobilization.

The owner's cost is determined by adding a mark-up to the contractor's direct costs. This mark-up covers contractor overhead, contingencies and profit.

A Lotus spreadsheet routine, which performs these cost calculations, is included with an HDD design manual available from PRC *I*nternational (PRC*I*). The routine estimates costs involved with operating a typical horizontal drilling rig. Fig. 1 is the printout from an example estimate. The example analysis calculates an owner's cost estimate for a 24-in. river crossing with a drilled length of 2,500 ft in soft alluvial deposits—silts, sands and clays. Below is an explanation of how the routine operates.

Estimating parameters. With the spreadsheet, calculations can be performed using estimating parameters provided by the operator. Based on length, diameter and probable subsurface conditions, rates for pilot hole production, reaming and pull back penetration and mud flow can be selected from the tables included in this article.

The drilled segment length should be based on a preliminary design which takes into account standard horizontal drilling practices with respect to deflection angles and curvature radius. Four general classifications of subsurface conditions are listed in the tables. The general classification that is most descriptive of the anticipated conditions at the crossing should be used to select input parameters. Operational durations and drilling mud quantities are calculated by the routine using the input parameters. Calculations are organized according to three operation phases:

- Pilot hole
- Prereaming
- Pull back.

Pilot hole production rate is truly a production rate as opposed to a penetration rate. It takes into account time spent redrilling, surveying and adding pipe and is dependent on subsurface conditions and required pilot hole tolerance. Typical values are given in Tables 3 and 4.

Pilot hole duration is determined by

Table 3. Pilot hole production rate in feet per hour for pipe diameters less than 30 in.

Drilled length, ft	Silt, sand, clay	Gravel	Soft rock	Hard rock
<2,000	60	45	30	15
2,000 to 3,000	55	40	25	10
>3,000	50	35	20	questionable

Table 4. Pilot hole production rate in feet per hour for 30-in. diameters and greater

Drilled length, ft	Silt, sand, clay	Gravel	Soft rock	Hard rock
<2,000	50	40	25	10
2,000 to 3,000	45	35	20	questionable
>3,000	40	30	15	questionable

Table 5. Circulation loss factors used in HDD cost estimating routine

Soil type	Circulation loss factor
Silt, sand, clay	0.5
Gravel	0.8
Soft rock	0.2
Hard rock	0.2

ESTIMATING PARAMETERS

WORK SCHEDULE	10.0	Hours/Shift
	7.0	Shifts/Work
LENGTH	2,500	Foot
PILOT HOLE PROD RATE	55.0	Foot/Hour
DRILLING MUD FLOW RATE	5	bpm
PILOT HOLE DURATION	4.5	Shifts
CIRCULATION LOSS	50%	
PILOT HOLE MUD QTY	398	Sacks
PREREAM PASSES	1	Quanity
PREREAM TRAVEL SPEED	2.50	Foot/Min
PREREAM MUD FLOW RATE	10	bpm
PREREAMING DURATION	24.4	Hours
	2.4	Shifts
CIRCULATION LOSS	50%	
PREREAMING MUD QTY	500	Sacks
PULL BACK TRAVEL SPEED	8.00	Foot/Min
PULL BACK MUD FLOW RATE	10	bpm
PULLBACK DURATION	18.0	Hours
	1.8	Shifts
CIRCULATION LOSS	50%	
PULLBACK MUD QTY	158	Sacks
MUD COST	12.00	$/Sacks (100 lb)
TOTAL MUD QTY	1,154	Sacks (100 lb)

SHIFT COST SUMMARY

FUNCTIONAL TASK- (Crews Required)	NUMBER OF PERSONNEL	LABOR COST	EQUIPMENT COST	CREW TOTAL
MOBILIZATION (Drilling Crew)	9	3,800.00	5,170.00	8,970.00
RIG-UP (Drilling Crew)	9	3,800.00	5,170.00	8,970.00
PILOT HOLE (Drilling Crew)	9	3,800.00	5,170.00	8,970.00
REAM & PULL BACK - (Drilling & P.B. Support Crews)	19	7,650.00	7,340.00	14,990.00
RIG-DOWN (Drilling Crew)	9	3,800.00	5,170.00	8,970.00
DEMOBILIZATION (Drilling Crew)	9	3,800.00	5,170.00	8,970.00

ESTIMATE RECAP

FUNCTIONAL TASK	SHIFTS	LABOR COST	EQUIPMENT COST	NON-SHIFT COST	TASK TOTAL
MOBILIZATION	2.0	7,600.00	10,340.00	20,000.00	37,940.00
RIG-UP	2.0	7,600.00	10,340.00	0.00	17,940.00
PILOT HOLE	4.5	17,272.73	23,500.00	0.00	40,772.73
REAM & PULL BACK	4.2	32,459.38	31,144.03	0.00	63,603.40
RIG-DOWN	2.0	7,600.00	10,340.00	0.00	17,940.00
DEMOBILIZATION	2.0	7,600.00	10,340.00	20,000.00	37,940.00
DRILLING MUD	N/A	N/A	N/A	13,847.73	13,847.73
TOTALS	16.8	$80,132.10	$96,004.03	$53,847.73	229,983.88

ESTIMATED COST

CONTRACTOR'S DIRECT JOB COST =	$229,984 U.S. DOLLARS
ESTIMATED MARK-UP @ 45%	$103,493 U.S. DOLLARS
ESTIMATED OWNER'S COST =	$333,477 U.S. DOLLARS

Fig. 1. Printout from an example Lotus spreadsheet analysis showing owner's cost estimate for horizontal directional drilling services only.

dividing the production rate into the drilled length to come up with total hours and converting total hours to shifts using the number of hours per shift.

Pilot hole mud flowrate is dependent on whether a jetting assembly or downhole motor is used. A jetting assembly flowrate of 5 bbl/min. is used for silts, sands and clays. A downhole motor flowrate of 10 bbl/min. is used for gravel, soft rock and hard rock.

The circulation loss factor adjusts drilling mud quantity calculations to account for mud which is not recovered for recirculation. For example, a circulation loss factor of 0.2 indicates that 20% of the fluid pumped downhole will be lost and 80% will be available for recirculation. The circulation loss factor primarily depends on subsurface conditions. It is difficult to predict and can range from near 0 to 1. Table 5 provides circulation loss factors that are used for estimating costs.

To determine pilot hole mud consumption multiply the circulation loss factor by the total quantity of mud pumped downhole during pilot hole drilling. Mud pumped downhole at this point is the product of the pilot hole mud flowrate, the pilot hole duration and a pumping factor. A pumping factor of 35 minutes per hour is used to account for time when drilling fluid is not being pumped. Pilot hole mud consumed in barrels is converted to 100-lb sacks of high-yield bentonite by dividing by a typical yield of 200 bbl of drilling mud per ton of dry bentonite.

Prereaming penetration rate is the speed at which the reamer is being pulled along the pilot hole. It is dependent on soil conditions and reamer diameter. Typical values are given in Table 6.

The number of prereaming passes depends on subsurface conditions and pipe diameter. For estimating purposes, it can be assumed that all crossings will be prereamed at least once. If the pipe diameter is between 30 and 42 in., a second prereaming pass is probable. If the pipe diameter is greater than 42 in., a third prereaming pass is probable. If the crossing is installed in soft or hard rock, two additional passes should be used in the estimate.

To establish the prereaming duration, divide the length by penetration rate to establish actual reaming time in minutes, adding two minutes per 30-ft drill pipe joint to break and make-up drill pipe, converting total minutes to shifts using the number of hours per shift, and adding an estimated rig-up time of one-half shift. This gives the duration for a single prereaming pass, which is then multiplied by the number of passes to give a total duration for the prereaming operation.

Prereaming mud flowrate primarily is a function of diameter and can be estimated from Table 7.

Circulation loss factors for prereaming are the same as for pilot hole drilling (Table 5).

Prereaming mud consumed is determined by multiplying the circulation loss factor by the total mud quantity pumped downhole during prereaming. Mud pumped downhole during prereaming is the product of the drilled length, the prereaming mud flowrate, and the number of prereaming passes, divided by the prereaming penetration rate. Prereaming mud consumed in barrels is converted to 100-lb sacks of high-yield bentonite by dividing by a typical yield of 200 bbl per ton of dry bentonite.

Pullback penetration rate is the

Table 6. Prereaming penetration rate in ft/min

Pipe diameter, in.	Silt, sand, clay	Gravel	Soft Rock	Hard Rock
<24	3.0	2.0	1.0	0.5
24-32	2.5	1.5	0.5	questionable
>32	2.0	questionable	0.3	questionable

Table 7. Ream and pullback mud flowrate in bbl/min

Pipe diameter, in.	Silt, sand, clay	Gravel	Soft Rock	Hard Rock
<24	7	10	7	7
24-32	10	13	10	questionable
>32	15	questionable	15	questionable

Table 8. Pullback penetration rate in ft/min

Pipe diameter, in.	Rate
<24	10
24-32	8
>32	6

speed at which the pipe is being pulled into the reamed hole. It is dependent primarily on pipe diameter, but also can be affected by hole quality. Typical values are given in Table 8.

Pullback duration is determined by dividing the length by the penetration rate to establish the actual pullback time in minutes. Add two minutes per 30-ft joint for breaking and making up drill pipe. Then, convert total minutes to shifts using the number of hours per shift, and adding estimated rig-up time of one shift.

Drilling mud flow rates used during pullback are essentially the same as those used in prereaming (Table 7). Circulation loss factors used for pullback are the same as those for pilot hole drilling (Table 5).

To develop a figure for mud consumption during pullback, multiply the circulation loss factor by the total mud quantity pumped downhole during pullback. Mud pumped downhole during pullback is the product of the drilled length and the pullback mud flowrate, divided by the pullback penetration rate. Pullback mud consumed in barrels is converted to 100-lb sacks of high-yield bentonite by dividing a typical yield of 200 bbl of drilling mud per ton of dry bentonite.

Drilling program calculations conclude by determining total mud consumed. The total is the sum of the consumed amounts calculated for each operational phase plus 1,000 bbl. The 1,000 bbl accounts for the drilling mud system "line fill." For pricing convenience, mud consumed in barrels is converted to 100-lb sacks of high-yield bentonite by dividing by a typical yield of 200 bbl of drilling mud per ton of dry bentonite.

Shift-cost summary. For clarity, the computer routine calculates total direct job cost by breaking the job into a series of functional tasks. These tasks are:

Mobilization. Transporting workers and equipment to jobsite.

Rig-up. Erecting the drilling rig at the jobsite, ready for pilot hole drilling.

Pilot hole. Directionally drilling the small-diameter pilot hole, complete for reaming and pulling back.

Ream and pullback. Reaming the pilot hole and pulling the prefabricated pull section back through to the drill rig.

Rig-down. Disassembling the drilling rig at the jobsite ready for demobilization.

Demobilization. Transporting workers and equipment from the jobsite.

Drilling mud. Cost of drilling mud used in the crossing installation.

Additional tasks not addressed in the routine but which may require estimating are defined below. These tasks do not involve specialized drilling activities and can be accomplished using standard pipe line construction methods.

Site preparation. Cleaning and grading the jobsite on each river bank in preparation for construction.

Pull section fabrication. Stringing, welding, coating and pretesting the pull section and preparing the section for installation.

Final hydrostatic test. Final hydrostatic test of the in-place pull section.

Site restoration. Worksite cleanup.

Labor and equipment cost per shift are determined by identifying individual laborers and equipment necessary to complete a specific task and assigning hourly or per-shift rates to each laborer and equipment item. The labor and equipment costs per shift for a specific task can then be calculated.

The routine uses two standard crews, a horizontal drilling crew and a pullback support crew. The horizontal drilling crew performs HDD activities, while the pullback support crew handles the pull section during installation. Shift costs for these crews are detailed in Tables 9 and 10. Allocating crew costs to the defined tasks is presented in the routine under the heading: "Shift Cost Summary."

Estimate recap. The routine presents calculated direct costs, broken down by task, under the heading: "Estimate Recap." Calculated direct costs are a combination of shift costs, determined by multiplying the number of shifts by the single-shift cost, and non-shift costs, which are not tied to duration.

Non-shift costs included in the routine are drilling mud and transportation. Drilling mud cost is calculated in the drilling program using a per-sack price of $12. A $20,000 lump sum for transportation is included in both the mobilization and demobilization tasks. Pilot-hole and ream/pullback durations are calculated in the drilling program. Durations for rig-up/rig-down and mobilization/demobilization are set at a constant two days each.

Owner's cost. Cost estimate for the owner is calculated by adding a markup to total direct costs. This markup covers contractor overhead, profit and risk contingencies. The overhead and profit components are held constant at 10% and 15%, respectively. The risk component must be evaluated for each crossing, taking into account possible problems posed by installation length, pipe diameter and subsurface conditions.

Risk may be evaluated logically by estimating the cost and frequency of possible operational problems. For example, encountering a single random boulder while drilling the pilot hole may force the contractor to redrill a portion to avoid the boulder. This redrill may add two days to the duration, resulting in an increase in direct cost of $17,940, twice the HDD crew's shift cost. Through experience in a given region or subsurface material, the contractor may know that a boulder, or some type of obstruction requiring a two-day redrill, will be encountered every 2,000 ft drilled. A logical contingency cost for encountering an obstruction during pilot hole drilling then may be calculated for a specific job by dividing the designed drilled length by 2,000 ft and multiplying the result times $17,940. These calculations illustrate a logical method for evaluating one risk scenario.

However, operational problem scenarios and costs vary and are difficult to predict.

Consider, for example, that the contractor encounters a boulder and redrills around it. The redrilled path just misses another boulder. During prereaming, the boulder is encountered, but it is displaced slightly and the reaming tool "walks" around it. The boulder next is encountered during pullback. This time, the rigid line pipe will not "walk" around the boulder and the pipe becomes stuck. Five days are needed to free the pipe before it twists off in front of the reamer. At this point, the contractor cannot free the line and must abandon it beneath the waterway. Now, the entire operational budget probably has been spent, reaming tools and some drill pipe have been lost, and the contractor owes the owner for the abandoned pipe line section. Further, a new pilot hole has to be drilled along a different path, new pipe must be purchased and fabricated into a pull section, and the ream and pullback process has to be started again. The contractor's risks have not diminished. The geology has not changed and the effort may fail again.

Typical markups for contractor risk associated with length and diameter in varying soil conditions are presented in Tables 11 and 12. These values are added to the previously mentioned 25% (10% overhead plus 15% profit) to determine the markup.

Table 9. Horizontal drilling crew cost per 10-hour shift

Description	Quantity	Unit/shift	Total/shift
Superintendent	1	$600	$600
Driller	1	500	500
Surveyor	1	500	500
Mud man	1	500	500
Crane operator	1	500	500
Ramp laborer	2	300	600
Mud laborer	2	300	600
Labor total	9		$3,800
Horizontal drilling spread	1	$2,500	$2,500
(fuel and maintenance)		500	500
Downhole survey system	1	1,500	1,500
Crane	1	250	250
(fuel and maintenance)		25	25
Backhoe loader	1	250	250
(fuel and maintenance)		25	25
Pickup trucks	2	50	100
(fuel and maintenance)		10	20
Equipment total			$5,170
		Crew total	$8,970

Table 10. Pullback support crew cost per 10-hour shift

Description	Quantity	Unit/shift	Total/shift
Foreman	1	$550	$550
Sideboom operator	2	500	1,000
Backhoe operator	1	500	500
Common laborer	6	300	1,800
Labor total	10		$3,850
Sideboom tractor	2	$500	$1,000
(fuel and maintenance)		200	400
Track-mounted backhoe	1	300	300
(fuel and maintenance)		150	150
Roller stands	1 set	200	200
Pickup trucks	2	50	100
(fuel and maintenance)		10	20
Equipment total			$2,170
		Crew total	$6,020

Table 11. Markup for contractor's risk associated with drilled length

Drilled length, ft	Silt, sand, clay	Gravel	Soft Rock	Hard Rock
<2,000	0%	20%	10%	30%
2,000 to 3,000	10%	40%	20%	50%
>3,000	20%	60%	30%	questionable

Table 12. Markup for contractor's risk associated with pipe diameter

Pipe diameter, in.	Silt, sand clay	Gravel	Soft Rock	Hard Rock
<24	0%	30%	20%	50%
24 to 32	10%	50%	30%	questionable
>32	20%	questionable	40%	questionable

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