Contractor Perspective on Factors for Evaluating Installation Options for Small-Diameter Utilities

Neil J. A. Woodroffe[1] and Samuel T. Ariaratnam, M.ASCE[2]

Abstract: Buried municipal infrastructure is rapidly expanding due to increased urbanization. Subsequently, engineers and contractors are faced with having to designate the most effective method of installing new buried infrastructure while being mindful of cost considerations. In order to determine the most feasible underground construction method, various risks and cost factors must be assessed and analyzed. A comprehensive survey was conducted to solicit input from 28 contractors in various geographical regions throughout the United States and Canada. The intent was to determine specific risk factors and their inherent impacts, as well as to better understand cost comparison between horizontal directional drilling and traditional open-cut construction methods. This paper is relevant to practitioners and researchers because it identifies and describes risks and cost factors from a contractor perspective that can be used for evaluating installation options for small diameter pipelines in an urban environment.

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Introduction

As the densities of urban and suburban neighborhoods increase, so does the congestion of underground infrastructure. This congestion makes open-cut construction methods increasingly difficult and costly due to added safety measures and restoration. In recent years, alternative construction methods have become more important for municipalities to consider. The goal for municipalities is to explore more feasible methods to reduce costs and maximize public safety. Horizontal directional drilling (HDD) is an applicable and alternative installation method that can be used in urban environments. Typically, HDD is employed in urban settings for pipe diameters less than 610 mm (24 in.), although the method is capable of installing diameters up to 1,350 mm (54 in.). The ability to maneuver around known existing utilities and subsurface objects makes the process desirable in areas with multiple utilities. With more and more utilities being installed in developed urban areas, underground infrastructure has realized increased costs and risks of digging up roadways, going under major pipelines, water channels, and underground utility corridors. The main influencing factor for owners and municipalities is the overall cost of a project; however, ecosocial effects, construction consideration factors, and risk factors are increasingly becoming important decision criteria for selecting the most viable construction method.

Urban growth has necessitated the installation of new underground utility networks to service this increased population. Subsequently, municipalities are faced with programming their budgets to accommodate this growth in sewer and water infrastructure. Currently, the most common method used for underground utility construction is traditional open-cut construction due to the simplistic approach of excavating soil. Generally, when open-cut is not acceptable or desirable, HDD practices can be used. In situations with high investments in surface infrastructure, congested existing utilities, and where social costs such as commuter traffic and businesses are affected, HDD is a more desirable choice (Lueke and Ariaratnam 2005). Low environmental and social impacts, safety issues, and soil conditions also make HDD a desirable method for underground construction. Further information on the process can be found in Knight et al. (2001) and Bennett et al. (2001). This paper presents a description of factors from a contractor perspective in determining the most appropriate method for installing small diameter pipelines in an urban environment between HDD and open-cut construction.

Literature Review

Previous research on installation of small diameter pipelines has focused on construction risks and factors to mitigate potential problems. Researchers have compared the benefits of various trenchless technology options with traditional open cut; however, there is limited information on comparing open-cut practices directly with horizontal directional drilling.

Barras and Mayo (1995) conducted a study that included a cost comparison for different types of construction sites using minidirectional drill rigs versus open trenching. He determined that additional factors would have to be investigated in order to make a more accurate comparison. One of the main considerations in the study was the cost differences between rural and urban settings to aid a local electrical utility company, Salt River Project (SRP), whose business is installing underground electrical distribution systems. Linear foot project costs for different diameter conduits were compared. Data from over 430 contractors were studied to obtain a better understanding of situations where

[1]Environmental Infrastructure Engineer, Stantec Consulting Inc., Phoenix, AZ 85044. E-mail: nwoodroffe@stantec.com

[2]Professor, Del E. Webb School of Construction, Ira A. Fulton School of Engineering, Arizona State Univ., Tempe, AZ 85287-0104 (corresponding author). E-mail: ariaratnam@asu.edu

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directional drilling would be advantageous. A limitation of the study is that information was only gathered in the Phoenix area, which questions the validity of the results when applied outside of the southwestern United States, especially in varied soil conditions. Over the past 10 years, the overall costs of the projects have grown significantly and the popularity of drill rigs has also grown immensely.

Another study suggested a procedure for comparing conventional trenching with trenchless construction using case histories. Clark and Browning (1992) used a benefit/cost analysis to help determine the most substantial savings for an underground construction project. The authors only examined the trenchless rehabilitation method of relining existing infrastructure as opposed to new installation methods. Analyzing two alternative methods with total cost information has merit because actual project costs were used. The authors identified and studied direct project costs for: (1) construction; (2) engineering; (3) service; (4) administrative; and (5) contingency. Some of the indirect costs that Clark and Browning investigated were business disruption and traffic effects. Although the study offers valuable information, it does not provide any comparison for employing horizontal directional drilling.

McKim (1997) proposed an alternative decision-making model to help identify essential aspects and strategic elements of a technology. His selection method used a hierarchy-based model to consider physical components of selected technologies. A limitation to the study was that it only examined pipe rehabilitation methods such as in-place liners, pipe bursting, deformed liners, grouted liners, and centrifugally spun liners. New construction technologies such as HDD were not examined. A breakdown of the requirements for each technique was identified; however, the economic element of each technique was not incorporated into the model. Furthermore, it was recommended that a complete decision process be developed and economic factors incorporated (McKim 1997).

A life-cycle cost comparison study between trenchless and open cut by Najafi and Kim (2004) considered factors that are involved with preconstruction, construction, and postconstruction costs. The analysis contained a breakdown of direct, indirect, and social costs involved within the construction criteria. Factors were then assigned a rating of "major," "minor," or "major to minor" depending on the severity of the issue. Having these ratings can aid in determining which method has more of a significant outcome; however, there is no indication of which method is more applicable for a given situation. The cost factors used in this study and developed by other researchers are helpful to indicate a basis of factors that should be considered when planning an underground utility project; however, they do not examine specific inherent installation risks.

Tighe et al. (1999) studied costs associated with traffic delays due to pavement cuts and developed an approach for evaluating and quantifying savings associated with trenchless technology in utility construction. Traditional open trench versus trenchless scenarios were examined using three different traffic control plans to evaluate user delay costs. They found that user delay costs increase significantly with increase in traffic level through application of a case study. A limitation of this study is that it only examines traffic disruptions costs rather than contractor construction costs and risks.

Jung and Sinha (2007) developed an approach for quantitatively assessing direct, social, and environmental costs associated with municipal utility construction. Eight municipal projects in State College, Pa. were studied. Six of these involved the installation of polyvinyl chloride (PVC) pipe employing traditional open cut, while two projects involved the installation of high density polyethylene (HDPE) pipe using trenchless pipe replacement (or pipe bursting). The study recommended combining the three costs with direct capital costs when deciding between open cut and trenchless options for utility installation in urban areas. A limitation of this research is that the study is limited to local geology and construction costs. Furthermore, it does not examine horizontal directional drilling.

Previous research, although limited, has provided valuable insight into cost issues; however, it is important to also evaluate potential risk when considering alternative construction methods. Results from other researchers provide a mechanism for evaluating a systematic comparison applying cost and risk factors between HDD and open-cut construction.

Research Objectives and Methodology

The main objective of this research was to identify cost differences between HDD and open-cut construction from industry specialists and identify factors to assisting in selecting the most desirable construction method for a given small diameter utilities project in an urban environment. The focus involved investigating pipe and conduit installations ranging in size from 50 to 610 mm diameters (2–24 in.) as this is the typical range of application for urban utility projects. A survey questionnaire (Appendix) was created with input from contractors and engineering consultants in the underground infrastructure industry. The seven sectioned questionnaires were distributed to contractors across the United States and Canada to obtain diverse types of geographical (and geological) conditions. Follow up personal contact was made with each respondent to clarify any questions. A breakdown of the different factors selected for the survey questionnaire is presented in Fig. 1. These factors include: (1) company profile; (2) company information; (3) contracts and bidding estimates; (4) comparison of horizontal directional drilling to open cut; (5) ecosocial effects; (6) consideration factors; and (7) risk factors. The survey questionnaire concluded with a section soliciting the knowledge and awareness level of engineers and owners in the underground construction business.

Data Analysis

Demography

Survey questionnaires were distributed over a 9 month period in 2006 to 28 utility contractors with experience in horizontal directional drilling and open cut. Results were then obtained through follow-up personal interviews with contractors and their feedback was then analyzed. Table 1 presents geographical location information on the survey respondents. From the 28 contractors surveyed, 61% were located in the United States and 39% were based in Canada.

The range of annual revenues from contractors who participated in the survey was categorized and illustrated in Fig. 2. Approximately 21% of the companies surveyed had annual revenues less than $2 million. These companies can be categorized as smaller HDD subcontractors with approximately 2–13 permanent employees. Twenty-nine percent of the respondents identified themselves as having revenues between $2 and $4 million and generally employ 7–27 full time employees. Seven percent of

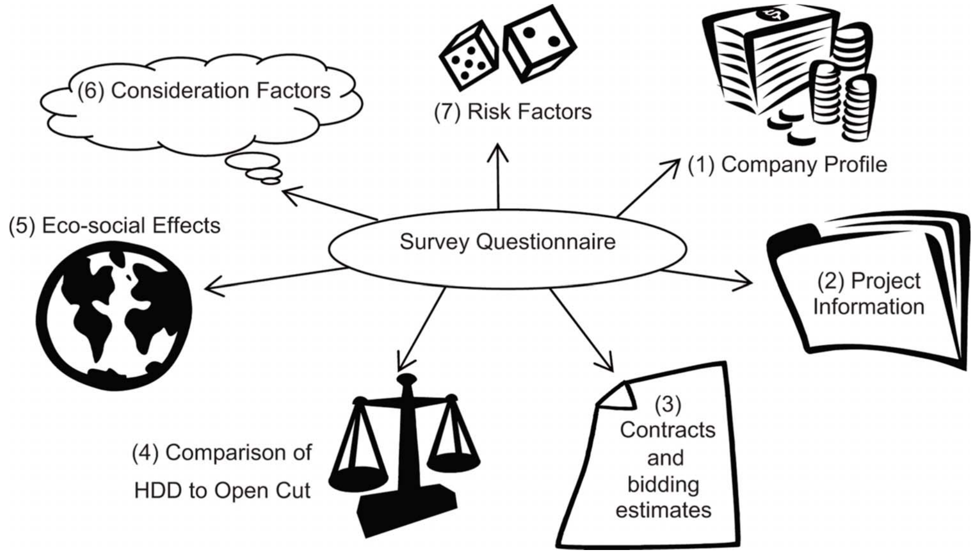

Fig. 1. Breakdown of survey questionnaire sections

the contractors surveyed had revenues ranging from \$4 to \$8 million and had 15–27 permanent workers. Companies between \$4 and \$8 million do not have a significant difference in the number of employees compared to companies ranging in size from \$2 to \$4 million. A large number of employees are evident with companies having revenues from \$8 to \$14 million with approximately 100–115 workers. This group of companies comprised 7% of the respondents. The largest category surveyed (36%) were those with annual revenues over \$14 million and having a permanent number of employees ranging up to 1,300. This large portion of companies ranging from \$14 million plus was not anticipated to be the majority of the respondents; however, a study conducted by Allouche et al. (2000) found that 23% of the contractors surveyed had annual revenues greater than \$14 million. These large companies can be categorized as national (as opposed to local/regional) or international dedicated directional drilling contractors or underground construction divisions of more diverse construction companies.

Table 1. Percent of Respondents by Geographical Location

Location of respondents	Percent of respondents (%)
Central United States	32
Eastern United States	25
Western United States	18
Western Canada	18
Eastern Canada	11
Southern United States	7

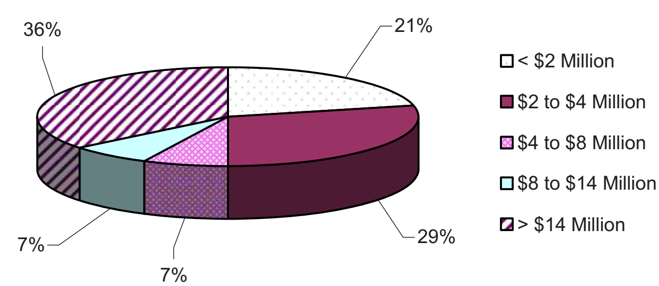

Fig. 2. Percent of respondents in each range of company's annual revenues (in US\$ millions)

Profile of Contractors

From the companies surveyed, approximately 71% performed both HDD and open-cut construction. The remaining 29% performed only HDD construction methods. None of the companies surveyed practiced just traditional open-cut construction.

Different areas of specialized work performed by the surveyed contractors are presented in Table 2. The most common area of specialization is water/sewer/storm at 89% of the overall respondents. From these respondents, approximately 4% performed only water/sewer/storm, while the remaining also performed installation of other types of utilities. Underground utility installation was a close second at 86%; this includes dry utilities such as natural gas, electrical, and telecommunication installation.

Section two of the survey investigated the breakdown of work obtained through competitive bidding by percentage. As shown in Table 3, 39% of the contractors surveyed indicated that 75–100% of their annual work was acquired through competitive bidding. Most HDD projects are competitively bid; however, private work such as telecommunication and electrical is often negotiated.

A list of seven price ranges for projects by percentage was conducted to identify the most common dollar value of projects constructed in 2005–2006. The most common price range for underground construction projects indicated by the contractors surveyed was from \$180,000 to \$350,000, representing 24% of the

Table 2. Percent of Respondents for Areas of Specialized Work

Types of specialized work	Percent of respondents (%)
Water/sewer/storm	89
Underground utility installation	86
Pipeline (oil, natural gas)	61
Environmental remediation	36
Horizontal sampling	21

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Table 3. Percent Breakdown of Annual Work Obtained by Contractors through Competitive Bidding

Percent of work obtained through competitive bidding (%)	Number of contractors	Percent obtained (%)
<25	2	7
25–49	7	25
50–74	8	29
75–100	11	39
Total	28	100

respondents. This is fairly indicative of small diameter utility projects in an urban setting. The overall percent breakdown for the prices of projects was found to be fairly uniformly distributed throughout the ranges as shown in Table 4.

The survey examined product material types to determine a breakdown of the most common pipe product used in underground construction. The results from Table 5 revealed the most common pipe product to be HDPE with 49%. PVC and steel were the second and third most common material used by 23 and 22% of contractors, respectively. Ductile iron was found to be the least common product material used in only 6% of the projects by the contractors interviewed. HDPE being the most common pipe material used is consistent with underground utility and water/sewer/storm projects comprising the majority of areas of specialization. This supports the findings of a HDD industry survey conducted by Carpenter (2007). Steel pipe is the most common material used in the oil and gas industry, which again is reflective of 61% of the area of specialization being oil and natural gas pipelines.

Questions regarding contracts and bidding estimates in section three of the survey were intended to better understand the most common types of contracts used by the respondents (see Table 6).

Table 4. Percentage of Respondents within Each Average Project Cost Range

Project dollar value	Percentage of respondents (%)
<$7,000	1
$7,000–$18,000	16
$18,001–$35,000	8
$35,001–$70,000	12
$70,001–$80,000	16
$180,001–$350,000	24
>$350,001	14
Total	100

Table 5. Pipe Product Breakdown Used by Contractors

Product material	Percentage of contractors (%)
HDPE	49
PVC	23
Steel	22
Ductile iron	6

Table 6. Percent of Respondents That Utilize Each Type of Contract

Type of contracts	Number of respondents	Percentage of respondents (%)
Unit price (rate per foot)	28	100
Lump sum	22	79
Lump sum with schedule of unit prices	17	61
Per diem (daily rate)	16	57
Hourly	16	57
Cost plus percentage fee	9	32
Cost plus fixed fee	3	11

Unit price was cited as the most popular contracting method used. One hundred percent of the respondents indicated using unit price contracts in their business, followed by a lump sum at 79%. This is not surprising given the horizontal/linear nature of underground utility infrastructure projects. Also the majority of dry utility (i.e., telecommunications, natural gas, and electrical) projects are awarded by unit cost contracts. Currently, these comprise approximately 56% of the overall HDD market (Carpenter 2007).

Contingency Plans

The final question within section three asked the contractors to rank, on a scale from 1 to 10, factors they considered to be the most important when estimating a contingency plan for underground infrastructure projects (1 being least important and 10 being most important). The results are presented in descending order of priority in Table 7. Previous experience was by far the most important factor when estimating a contingency plan. As with any underground construction project, previous experience is always a critical aspect to the technical and financial success of a project (Allouche et al. 2000). As contractors become more experienced using specific equipment for various environments, productivity should increase and contingency/risk should be reduced. Availability of soil data was another important contingency factor identified by the contractors. Information on geological conditions and tooling selection enables contractors to select appropriate tooling and better predict productivity. Overall bid price would be reduced if quality project information and knowledge of the site conditions were provided to the contractor. Other factors that were received from respondents included: seasons/weather; design restrictions; drill setup area; pipe layout locations; and prevailing prices for the current market.

Table 7. Relative Importance of Factors in Estimating Contingency Plan

Factors for a contingency plan	Score
Previous experience	8.3
Availability of soil data	7.9
Type of contract	6.8
Location (urban/rural)	6.8
Project size	6.5
Owner/client	6.5
Proximity to home base	5.6

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Table 8. Relative Importance of Factors in Estimating Bid Price

Factors affecting bid price	Score
Construction method	7.8
Experience	7.7
Quality of your cost estimate	7.7
Current work load	7.5
Owner/client	6.5
Number of competitors	5.8

Price of Project

To determine the cost for a typical project, six factors were examined in order to identify the most important component of the overall price. Table 8 presents results of factors that affect the bid price of a project. Construction method was found to be the most important factor in determining bid price. It refers to the organization and ways a construction project is delivered. Previous experience and quality of the cost estimate were both a close second. Experienced contractors can better assess a project to determine price. Current work load of a contractor was also found to have an influence on bid price. As with most projects, the bid price will likely be higher when contractors are busy with other work and not as dependent on winning new work. The number of competitors did not seem to have a significant effect on the overall price of the project, which suggests that contractors are providing competitive bids to owners. Other factors that were received from the survey but were too few to include are: seasons/weather; proximity to office; and the engineering firm. Once again, only a few respondents mentioned these additional factors. As a result it was assumed they were not as important as those listed in the survey questionnaire.

Information on typical costs for an underground construction project was solicited in section four of the survey. Establishing a cost comparison method that captures a variety of different environments and settings is challenging when using direct dollar amounts. Some contractors claimed that it was not possible to directly compare costs of HDD with open cut, while others seemed to respond with encouraging feedback when using percent ratios rather than firm costs. The cost comparison results between HDD and open cut are illustrated in Fig. 3 and show various cost factors that the surveyed contractors considered as savings for horizontal directional drilling, designated by a positive percentage. Conversely, a negative percentage indicates a savings realized by open cut. Two thirds of the factors observed in the survey were identified as being a savings when utilizing HDD. Even though the upfront acquisition costs of HDD are lower than those of open-cut equipment, the maintenance and replacement cost for the tooling tends to be more expensive. Additionally, HDD equipment is used continuously throughout a project, while equipment used during open-cut construction tends to be used periodically during a project. For example, an excavator would create a trench and then remain idle until backfilling is performed. The duration on a HDD project was found to have a time savings of 16% over open cut. Time savings can be a significant factor on a project, especially if groundwater or saturated soils are evident. Additional profit on a project was found to be approximately 12% in favor of HDD. Surface restoration costs are the most significant cost savings that HDD offers. The savings in restoration indicated for paving alone was nearly 70% and approximately 53% for restoration costs other than paving. HDD's major cost savings related to surface restoration refers to removing and replacing sidewalk, roadways, and vegetation near the construction site. Job site management and the operational cost of labor have a slight savings for HDD; however, both factors are less than 10% savings.

Three of the cost factors considered revealed open cut to have a slight savings over horizontal directional drilling. The averages of the respondents indicate that contractors spend approximately 9% more on equipment operational costs for HDD than on open cut. This additional expense to HDD is attributed to the higher maintenance costs as previously mentioned. Material costs for HDD were also found to be nearly 3% higher. Material costs for HDD were cited as being higher than open cut due to the increased costs associated with pipe preparation prior to pipe installation (i.e., fusion, restraint joint). The engineering service costs on a project are expected to be similar for HDD and open cut.

Ecosocial Impacts

Nine ecosocial factors were examined in section five of the survey by using a Likert scale ranging from 1 to 10. Results from

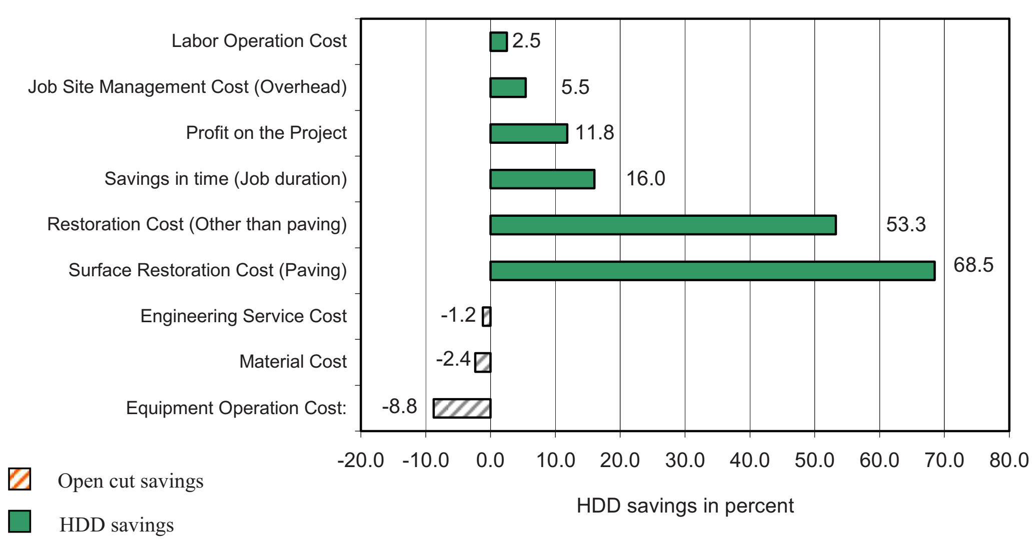

Fig. 3. Percent comparison of cost factors between HDD versus traditional open cut (negative percent indicates savings realized by open cut)

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Table 9. Relative Importance of Ecosocial Impacts to Construction Methods

Ecosocial impacts	Score HDD	Score Open cut	Score Difference
Dust pollution	2.4	7.2	−4.8
Travel effect on general public	3.4	7.7	−4.3
Effect on the ecological system	3.2	6.8	−3.6
Vibration	3.2	6.3	−3.2
Effect on business sales	4.3	6.4	−2.1
Noise pollution	4.9	6.6	−1.7
Operational costs by contractor	5.4	6.4	−1
Maintenance costs by contractor	6.9	6.1	0.8
Disposal of waste material	6.6	4.6	2

Table 9 indicate that horizontal directional drilling significantly reduces a project's environmental impacts. For example, dust pollution on an open-cut project was found to be almost three times the impact as on a HDD project. The survey results indicate numerous advantages when HDD is used relating to decreased traffic disruption, less effect on business sales, and decreased impact on the ecological system. HDD scored higher than open cut for removal of waste materials. This is due mainly to the challenge in locating a designated area to discharge used drilling fluid. On open-cut projects, if soils are removed from the site, disposal of waste materials is usually nonproblematic as long as the soil is not deemed to be contaminated.

Consideration Factors

Similar to the ecosocial section of the survey, consideration factors were compared directly between HDD and open cut. Table 10 presents results from the comparison and indicates the importance of having a detailed understanding of anticipated soil conditions. Having reliable information and quantity of existing utilities in the proposed construction area is as critical in open cut as in HDD. Unfortunately, both methods pose the risk of striking existing utilities if this pertinent information is not provided or is inaccurate. As would be expected, groundwater table and weather conditions have a greater impact on open-cut projects due to added dewatering considerations. The impact of surface obstructions is critical in determining if open cut can even be utilized on a given project. Horizontal directional drilling is a more feasible option for installing utilities under buildings, critical roadways, and waterways because of the high cost of support required during open cut. Unforeseen buried obstructions such as timber and concrete can have implications on HDD projects as these can cause deviations in the drilling process due to deflections of line and grade. Safety issues for both types of construction were surprisingly similar, even though HDD does not create an open trench, thereby reducing the likelihood of fatalities due to collapsed trenches.

Table 10. Relative Importance of Project Consideration Factors to Construction Methods

Project consideration factors	Score HDD	Score Open cut	Score Difference
Surface obstructions	5.1	8.6	−3.5
Groundwater table	5.2	8.5	−3.3
Weather conditions (rain/snow/heat)	4.8	7.3	−2.5
Traffic restrictions	5.7	7.8	−2.1
Safety issues	7.4	8.0	−0.6
Density of existing utilities	8.5	8.3	0.2
Availability of existing utilities info.	8.7	8.0	0.7
Buried obstructions (i.e., timber, concrete, etc.)	7.6	6.5	1.1
Soil condition/properties	8.5	6.9	1.5

Table 11. Contractors' Five Factors for Utilizing HDD

HDD factors		Percent selected by respondents (%)
1.	Soil conditions	68
2.	Site access	46
3.	Traffic	39
4.	Project details	32
5.	Client specifications	32

Potential Risk Factors

Table 11 presents the top five most significant factors to consider prior to construction of a horizontal directional drilling project. As shown in Table 12, responses from the surveyed contractors were categorized into 13 subheadings to solicit the most popular factors influencing the decision of employing HDD versus open-cut construction. Approximately 68% of the respondents indicated soil conditions to be the most important consideration factor prior to selecting HDD as a viable method. This result is not surprising because encountering soils such as gravels and cobbles is extremely challenging (Ariaratnam et al. 2004). The second most important factor was site access at 46%. Having adequate site access can help reduce wasted time spent on material handling and equipment maintenance and mobilization. The social cost implication of traffic issues (i.e., restriction, control) was cited as another important consideration factor.

A similar list of the top five most significant factors for open cut is presented in Table 13. The differences between the factors for open cut and HDD are location of existing utilities and the impact of restoration. Existing utilities are a major concern for traditional open cut because once the utility location is identified it must be exposed and crossed. Open-cut equipment runs the risk of damaging existing utilities during the excavating process. On the other hand, any contact with a known utility when HDD is employed can be avoided by either navigating below the utility or through steering precision. Sixty-one percent of respondents deemed that soil condition was the most important consideration factor for open-cut construction with 35% specifically indicating groundwater table as being their key soil condition issue. Wet, saturated soils may require dewatering prior to installation of a utility.

Common Myths Involving HDD

Lack of knowledge by engineers sometimes creates myths regarding the applicability of HDD for a given project. For example, a common misconception cited by the surveyed contractors was a

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Table 12. Contractors' Top Risk Factors Influencing Construction Method

Obstructions	Soil conditions	Site access
Public obstructions	Subsurface structure	Storage areas
Surface obstructions	Facing out	Site layout
Subsurface obstructions	Groundwater table	Location of site
	Backfill (material/requirements)	Setup area
Project details	**Client specifications**	**Existing utilities**
Depth of cut/slope (grade)	Ease of permits	Location of existing utilities
Size of (bore/project)	Owner/client	Number of utilities
Duration	Customer credibility	Logistics of tie-in
Confined work area	Bid/unit price	Utility density
Location of project/bore	Current work load	Subsurface area
Length of bore	Project engineer	
Work (hours/restrictions)	Availability of contractors	
Accuracy of line and grade	Time to complete	
Environmental impact	**Restoration**	**Product specifications**
Fluid requirements	Pavement replacement	Size of pipe
Environmental areas	Surface restoration	Type of pipe
Contamination/containments	Landscaping	
Drilling fluid disposal		
Spoil deposit		

Safety	Costs	Weather	Traffic issues
Site safety	General costs	Incremental conditions	Traffic control
	Restoration costs		Traffic restrictions

concern that HDD is not applicable for installation in rock. This is untrue as proper identification of the presence of rock will allow the contractor to select the appropriate tooling (i.e., drill bits and reamers) and drill rig to cut through the formation. As previously mentioned, cobbles and gravels are the most difficult ground conditions for HDD contractors to navigate. Another myth involves the ability to install on-grade by HDD. The technique is capable of on-grade sewer installations; however, it is not recommended to attempt grades less than 1% due to the difficulty in maintaining the slope. Although such installations have been successfully completed, it is more common to use HDD for on-grade utility installations of 1.5% or steeper.

Knowledge and Awareness Level

In the last section of the survey, contractors were asked to rate the knowledge level of engineers and owners involved in typical underground construction. Those surveyed scored the knowledge level of engineers a 4.8 out of 10. This low score was not surprising because of the perceived lack of education in underground construction practices. Currently, engineering courses specializing in underground utility construction, specifically horizontal directional drilling, are not readily available at universities. The average knowledge level of an owner was 3.9 out of 10, which again was not surprising, for the same reason cited for engineers. The increase in the availability of training courses over the past few years should result in a better level of knowledge and awareness in the future. Various industry associations including the North American Society for Trenchless Technology, American Society of Civil Engineers, National Utility Contractors Association, and the Distribution Contractors Association are actively promoting an educational program for contractors and engineers on trenchless methods such as HDD.

Table 13. Contractors' Five Factors for Utilizing Traditional Open Cut

Open-cut factors		Percent selected by respondents (%)
1.	Soil conditions	61
2.	Traffic	46
3.	Existing utilities	39
4.	Project details	25
5.	Restoration	21

Software Planning Tool

The results of the research were used to develop a Visual Basic software tool to assist contractors and engineers in evaluating HDD versus open-cut options for a given project. Underground Jobsite Analysis is a commercially available software tool that navigates the user through a series of screens (Fig. 4) to help in assessing various project factors and associated risks and recommending the most appropriate method for installing an underground utility. A cost module is also incorporated to enable the user to either input project cost estimates or use default values. The software is available for free through ⟨www.vermeer.com⟩.

Conclusions and Recommendations

Owners are realizing the importance of using the most feasible construction method for installing small diameter utilities as their

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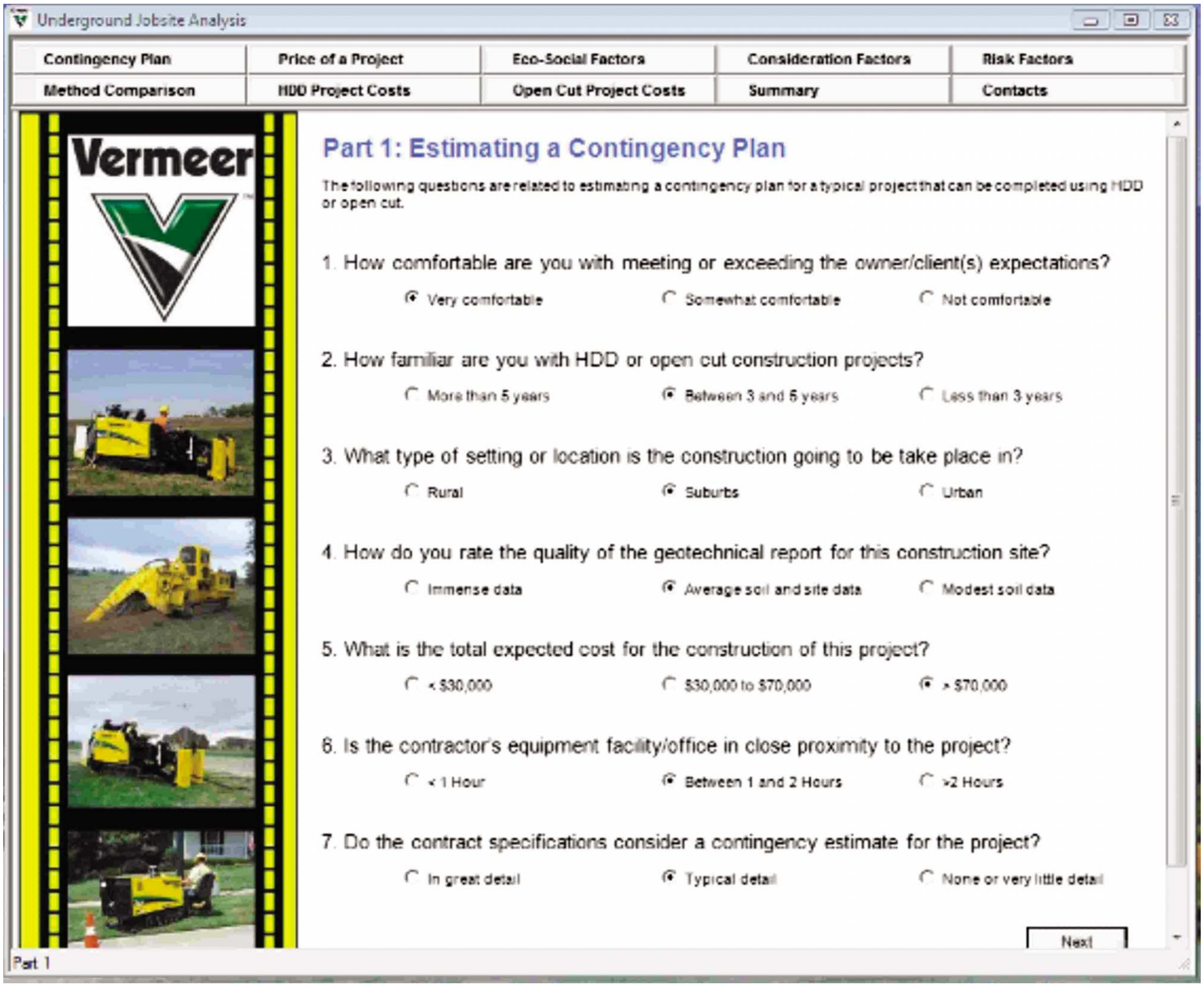

Fig. 4. Underground Jobsite Analysis screen shot

infrastructure develops. Increased public awareness of disruption and environmental concerns has resulted in the necessity to evaluate different factors when engaging in utility projects in an urban environment. The historical way of selecting the lowest cost option is now being replaced with other intrinsic considerations being factored into the overall selection process. Today, ecosocial effects, construction consideration factors, and risk factors have become critical in selecting the preferred construction method.

Surveys were distributed to utility contractors with a broad range of annual revenues and company sizes across the United States and Canada. From the surveys gathered, an analysis was performed to compare types of risk factors and costs inherent in HDD and traditional open-cut construction. Previous experience was found to be the most important factor in estimating a contingency plan utilizing HDD. This is not surprising as experience with any new technology is invaluable in overcoming unforeseen obstacles on a project. The contractors indicated that the most important factor affecting their bid price on a project was construction method, followed by experience, and quality of the cost estimate. In terms of a direct comparison of the two underground construction methods, two thirds of cost-related factors studied indicated savings when employing HDD. The greatest savings for HDD were found to be in restoration costs, while open-cut realized savings from equipment operation costs. When contractors encounter difficult geological conditions, they can expect a higher level of maintenance required when using HDD methods due to retooling requirements such as drill bits and reamers. As would be expected, subsurface conditions play a major role in determining the choice of construction methods. For example, an abundance of existing utilities would generally lead to adopting HDD practices, while cobbles and gravels would favor open-cut practices. The nature of HDD enables contractors to drill beneath existing utilities thereby avoiding the requirement for supporting these utilities during open-cut excavation.

A proper selection method can be established by investigating and identifying the various risks and factors that are inherent in underground utility projects in an urban environment. Traditional open-cut construction and horizontal directional drilling are each viable methods for installing buried utilities; however, after investigating the results of the surveys, it is possible to distinguish the different risks and factors that contribute to a more feasible and viable method of construction.

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Appendix. Survey Questionnaire

IRA A. FULTON SCHOOL OF ENGINEERING
ARIZONA STATE UNIVERSITY, TEMPE, AZ

SURVEY OF COST DIFFERENCES BETWEEN
HORIZONTAL DIRECTIONAL DRILLING VS. TRADITIONAL OPEN CUT CONSTRUCTION

CONFIDENTIAL

Please complete the following Questionnaire, which will be followed up by a phone interview from Dr. Samuel T. Ariaratnam or Neil Woodroffe.

This questionnaire is somewhat detailed and should take approximately 15 minutes. Your name and Company information will be kept confidential and used for research purposes at Arizona State University only.

The goal of this survey is to help the Trenchless Technology Industry get a better understanding of the cost difference between Horizontal Directional Drilling (HDD) vs. Open Cut and grow the development of HDD.

SECTION 1 - COMPANY PROFILE:

1. Regions of operation (Please check all that apply):
   - Region I (ME, VT, MA, NH, RI, CT)…………………………………………… ☐
   - Region II (NY, NJ)……………………………………………………........ ☐
   - Region III (PA, VA, WV, MD, DE)…………………………………………….. ☐
   - Region IV (KY, TN, NC, SC, GA, AL, MS, FL)…………………………….. ☐
   - Region V (OH, IN, IL, MI, WI, MN)…………………………………………… ☐
   - Region VII (IA, NE, KS, MO)………………………………………......... ☐
   - Region VIII (ND, SC, MT, WY, CO, UT)…………………………………… ☐
   - Region IX (CA, NV, AZ, HI) …………………………………………………. ☐
   - Region X (WA, ID, OR, AK) …………………………………………………. ☐
   - Region XI (TX, OK, LA, AR, NM)…………………………………………….. ☐
   - Canada………………………………………………………………………… ☐

2. Company's annual revenues (in Millions of U.S dollars):
   - < 2 ……….…………………………………………………………………… ☐
   - 2 to 4 …...………………………………………………………........................ ☐
   - 4 to 8…………………………………………………………………………. ☐
   - 8 to 14 …………………………………………………………………………... ☐
   - > 14 ……………………………………………………………………………... ☐

3. Approximate number of permanent employees ………………………………… _______

4. Approximate number of temporary employees …………………………….…..... _______

5. Which of the following types of projects do you undertake?
   - Underground utility installation (cables, phone, fiber optics, electrical) ……... ☐
   - Pipeline (oil, natural gas) …………………………………………………... ☐
   - Water / Sewer / Drainage ....………………………………………………... ☐
   - Environmental Remediation ………………………………………………….. ☐
   - Horizontal Sampling ……………………………………………………...... ☐
   - Other:____ ……. ☐

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SECTION 2 – PROJECT INFORMATION:

1. Percentage of annual work obtained through competitive bidding:
   - None ………………………………………………………………………......... ☐
   - < 25 % …………………………………………………………………….…... ☐
   - 25 – 49 % ………………………………………………………………………. ☐
   - 50 – 74 % ………………………………………………………………………. ☐
   - 75 – 100 % ……………………………………………………………………... ☐

2. Typical project sizes each year (the $ value in % falls under each category):
   - < $7,000 ………………………………………………………………… ____%
   - $7,000 - $18,000 …………………………………………………………… ____%
   - $18,001 - $35,000 ………………………………………………………...... ____%
   - $35,001 - $70,000 ………………………………………………………...... ____%
   - $70,001 - $ 180,000 ……………………………………………………....... ____%
   - $180,001 - $350,000 …………………………………………………........ ____%
   - > $350,001 ……………………………………………………………… ____%

3. Percentage of pipe material installed for all types of utilities using HDD:
   - PVC ……………………………………………………………………… ____%
   - HDPE …………………………………………………………………… ____%
   - Steel ……………………………………………………………………... ____%
   - Ductile Iron ……………………………………………………………… ____%
   - Other: ____ ……………… ____%

SECTION 3 – CONTRACTS AND BIDDING ESTIMATES:

1. Types of contracts undertaken (Please check all that apply):
   - Unit Price (rate per foot) ……………………………………………….….... ☐
   - Per Diem (daily rate) …………………………………………………………… ☐
   - Hourly …………………………………………………………………….…... ☐
   - Lump Sum ……………………………………………………………………. ☐
   - Lump Sum with Schedule of Unit Prices ………………………………………. ☐
   - Cost Plus Percentage Fee ……………………………………………………. ☐
   - Cost Plus Fixed Fee …………………………………………………………..... ☐
   - Other: ___________________________________ ………............................... ☐

2. How important are the following factors to consider in estimating contingency?
(1 being least important and 10 being most important)

Owner/Client	1 2 3 4 5 6 7 8 9 10
Previous Experience	1 2 3 4 5 6 7 8 9 10
Location (Urban/ Rural)	1 2 3 4 5 6 7 8 9 10
Availability of soil data	1 2 3 4 5 6 7 8 9 10
Project Size	1 2 3 4 5 6 7 8 9 10
Proximity to home base	1 2 3 4 5 6 7 8 9 10
Type of Contract	1 2 3 4 5 6 7 8 9 10
Others:_______________	1 2 3 4 5 6 7 8 9 10

3. How important are the following factors in determining the price of your bid for a typical project?

Owner/Client	1 2 3 4 5 6 7 8 9 10
Number of competitors	1 2 3 4 5 6 7 8 9 10
Experience	1 2 3 4 5 6 7 8 9 10
Quality of your cost estimate (innovations in your design)	1 2 3 4 5 6 7 8 9 10
Construction Method	1 2 3 4 5 6 7 8 9 10
Current work load	1 2 3 4 5 6 7 8 9 10
Others:_______________	1 2 3 4 5 6 7 8 9 10

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SECTION 4 - COMPARISON OF HDD TO OPEN CUT:

1. Below is a list of factors that contribute to the overall cost on a typical underground construction project. Indicate the cost difference in percentage for a project that could be completed using either HDD to Open Cut?

HDD Equipment Operation Cost	___% Lower	or	___% Higher
HDD Labor Operation Cost	___% Lower	or	___% Higher
HDD Material Cost	___% Lower	or	___% Higher
HDD Job Site Management Cost (Overhead)	___% Lower	or	___% Higher
HDD Engineering Service Cost	___% Lower	or	___% Higher
HDD Profit on the Project	___% Lower	or	___% Higher
HDD Paving Restoration Cost	___% Lower	or	___% Higher
HDD Restoration Cost other than paving	___% Lower	or	___% Higher
HDD Savings in time (Job duration)	___% Lower	or	___% Higher

SECTION 5 - ECO-SOCIAL EFFECTS FOR A PROJECT:

1. The following eco-social effects listed below are associated in the construction of the installation method of underground pipelines. On a scale from 1 to 10, circle a range for each effect on both a HDD project and an Open Cut project. (1 being the lowest and 10 being the most severe)

Impact on a Project	HDD	Open Cut
Dust Pollution	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Noise Pollution	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Vibration	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Operational costs by contractor (fuel, wage for workers, etc)	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Maintenance costs by contractor (tires, tooling, etc)	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Effect on business sales	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Travel effect on general public (traffic delay)	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Effect on the ecological system (air pollution, hazardous material exposure, etc)	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Disposal of waste material	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10

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SECTION 6 - CONSIDERATION FACTORS FOR A PROJECT:

1. Numerous considerations factors are listed below that are generally used for determining a method that is best for a typical project. Circle a number for each of the factors on a range from 1 to 10 for HDD and for Open Cut. (1 being the least significant and 10 being most important)

	HDD	Open Cut
Soil Condition / Properties	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Availability of Existing Utilities Info.	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Density of Existing Utilities	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Ground Water Table	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Weather Conditions (Rain/Snow/Heat)	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Safety Issues	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Buried Obstructions (i.e. timber, concrete, etc)	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Surface Obstructions (i.e. buildings, vegetation, etc)	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Traffic Restrictions	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10

SECTION 7 - RISK FACTORS:

1. List below, the viability of the top 5 most significant factors that your firm considers when determining HDD vs. Open Cut on a specific project. Some examples could be weather conditions, environmental restrictions, ground water table, safety, traffic, etc…

	HDD	Open Cut
1		
2		
3		
4		
5		

2. What is your overall impression on the cost differences of HDD vs. Open Cut, please comment?

3. What do you think are the most important selling features in HDD?

4. Sometimes HDD is considered to be a non-viable method. What are some of the reasons, excuses or myths that you have heard in this regard?

5. Where would you place the knowledge level of engineers and owners on a scale of 1 to 10 regarding the HDD process for underground utility installation? (1 being the lowest and 10 being the highest)

Engineers (i.e. Consultants)	1 2 3 4 5 6 7 8 9 10
Owners (i.e. Municipalities)	1 2 3 4 5 6 7 8 9 10

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