- Confirm crew sizes and equipment from HDD contractors' feedback when preparing cost estimates during design. Although contractors may be hesitant or reluctant to divulge too much information regarding their means and methods, this type of information from contractors can play a key role in the accuracy of the cost estimates and the owner's budgeting process.

Project Status

Final design was completed in November of 2006, and the bid documents were advertised on December 5, 2006. Only one bid was received and opened on January 18, 2007. After a thorough bid evaluation process, the contract was awarded to Michels Directional Crossings. Construction is scheduled to begin in April 2007.

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Planning Methodology for Small Diameter Pipelines in an Urban Environment

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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 at Arizona State University to solicit input from twenty-eight 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 quantify cost comparison between Horizontal Directional Drilling (HDD) and traditional open cut construction methods. This paper identifies and describes risks and cost factors that were subsequently used to create a planning tool for small diameter pipelines in an urban environment.

Introduction
As the density of urban and suburban neighborhoods increase, so does the congestion of underground infrastructure making open cut construction methods more difficult and dangerous. In recent years, alternative construction methods have become more important for municipalities to consider. The goal of municipalities is to look for more feasible methods to reduce costs and improve safety. Horizontal Directional Drilling (HDD) is an applicable and alternative method that can be used in urban environments for pipe diameters less than 24 in. (600 mm). HDD is desirable because of its ability to maneuver around existing utilities and subsurface objects. With more utilities being installed in developed areas, underground infrastructure has further increased costs and risks of digging up roadways, going under major pipe lines, water channels and underground utility corridors. The main influential factor for owners and municipalities is the cost of a project; however, eco-social effects, construction consideration factors and risk factors are becoming increasingly more important for selecting the most viable construction method.

As with many construction projects, the difficulty lies with the economical reasoning for project funding. Municipalities invest considerable amounts of funding for sewer and water infrastructure as their communities mature. 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 and specific details on the HDD process can be found in Knight et al. (2001) and Kramer (1992). Through this research, it is expected that industry personnel a better method of choosing between HDD and open cut can be established, and those who are new to the industry can develop a better understanding of the many benefits HDD offers.

RESEARCH OBJECTIVES AND METHODOLOGY

The main objectives of this research were to identify and gather cost differences between HDD and open cut construction from industry specialists and identify factors that help indicate the most desirable construction method for a project. Our main focus was to investigate the installation of pipes and conduits ranging in size from 2 in. to 24 in. (50 mm - 600 mm) diameters. We distributed a survey to 28 contractors with experience in HDD and open cut construction. The seven-sectioned survey questionnaires were distributed across the United States and Canada to obtain diverse types of situations and conditions. Approximately 61% of the respondents were located in the United States and the remaining 39% were located in Canada. In the first two sections, questions relating to the contractors' business activities and project information, such as typical project sizes and project materials, were gathered. Section three of the survey asked contractors to provide the most common types of contracts and rank factors that significantly contribute in determining a bidding estimate and estimating a contingency, on a scale from one to ten. Section four of the survey addresses a comparison for cost factors, through percentages, found in underground utility projects that are able to be constructed using HDD or open cut. In section five of the survey, a direct comparison of eco-social factors for HDD and open cut was conducted. Section six pertains to consideration factors affecting the type of construction selection for a project that could be completed with either method. The final section of the survey was used to identify the five most important factors when considering HDD or open cut on a project. Respondents were asked to give their opinion on cost differences and myths that would prevent HDD from being used. Also included in the final section of the survey was a question regarding the knowledge level of owners and engineers in the underground construction industry.

DATA ANALYSIS

Profile of Contractors

Feedback from 28 contractors in the United States and Canada was analyzed. From the companies surveyed, approximately 71% performed both HDD and open cut construction. The remaining 29% performed only horizontal directional drilling.

Different types of construction that the contractors performed are displayed in Table 1. The most common type of construction is Water/Sewer/Storm at 89%. From these respondents, approximately 4% performed only Water/Sewer/Storm while the rest performed other types of services as well. The second most common type of construction is underground utility installation at 86% of the respondents.

Table 1. Percent of respondents for areas of specialized work

Types of Specialized Work	Percent of Respondents (%)
Water / Sewer / Storm	89
Underground installation (phone, fiber optics, electrical, etc.)	86
Pipeline (oil, natural gas)	61
Environmental Remediation	36
Horizontal Sampling	21

A range of annual revenues for contractors who participated in the survey have been categorized and are shown in Figure 1. Approximately 21% of the companies surveyed had annual revenues less than $2 Million (M). These companies can be categorized as smaller HDD subcontractors with approximately 2 to 13 permanent employees. Twenty-nine percent of the respondents identified themselves with revenues between $2 and $4 M and these companies generally have 7 to 27 full time employees. Seven percent of the contractors surveyed had revenues ranging from $4 to $8 M and had 15 to 27 permanent workers. Companies between $4 and $8 M do not have a significant difference in the number of employees compared to companies ranging in size of $2 to $4 M. A large number of employees are evident with companies ranging at $8 to $14 M with approximately 100 to 115 workers; this group of companies comprised 7% of the respondents. The largest category surveyed was those with annual revenues over $14 M, and the permanent number of employees was drastically larger, ranging from approximately 45 to 1,300. This large portion of companies ranging from $14 M plus was not anticipated to be the majority (36%) of the respondents. However, a survey conducted by Allouche et al. (2000) found that 23% of the contractors surveyed had annual revenues greater than $14 M. These large companies can be categorized as national or international dedicated directional drilling contractors or underground construction divisions of more diverse construction companies.

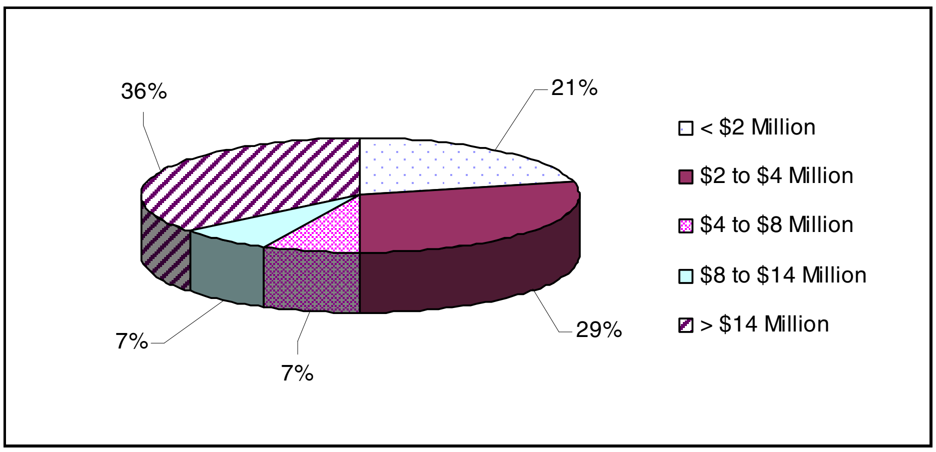

Figure 1. Percent of respondents in each range of company's annual revenues (in millions of U.S dollars)

Section two of the survey, investigates the breakdown of work obtained through competitive bidding by percentage. The results of the survey indicated that approximately 39% had between 75-100% of their annual work acquired from competitive bidding. Table 2 indicates the rest of the results regarding work obtained from competitive bidding.

Table 2. 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

A breakdown of the price range for projects by percentage was conducted to see what kind of project sizes were being constructed in 2005-06. The most common price range for underground construction projects of the contractors surveyed was from $180,000 to $350,000, making up 24% of the respondents. Overall the percentage breakdown for the prices of projects is found to be fairly consistent throughout the ranges as seen in Table 3.

Table 3. 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

Contingency Plans

The final question within section three, asked the contractors to rank on a scale from 1 to 10, factors they consider to be the most important when estimating an underground utility project (1 being least important and 10 being most important). These results are displayed in Table 4, in descending order of priority. The contractors' previous experience was by far the most important factor when estimating a contingency plan. As with any underground construction, previous experience is always a critical aspect to the technical and financial success of a project (Allouche et al., 2000). As contractors become experienced with their drill rig or backhoe capabilities under various environments; productivity will increase and contingency needs will be reduced. Availability of soil data was another important contingency factor identified by the surveyed contractors. With more information on soil conditions, a reduction in the overall bid prices will occur. Other factors that were received from a few survey respondents but not included in the results were: seasons; design restrictions; drill setup; pipe layout locations and prevailing prices for the market. These additional factors would give more specific information regarding a contingency plan if they were included in the survey; however, most respondents did not identify them.

Table 4. Relative importance of factors in estimating a 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

Price of a Project

In order to determine the cost for a typical project, six factors were examined in order to identify the most important part of the overall price. Table 5 presents survey results of factors that affect the bid price of a project. The type of construction method was found to be the most important factor in determining the bid price for a project. Contractor's previous experience and quality of the cost estimate was a close second. The number of competitors did not seem to have a large affect on the overall price of the project, which implies that contractors must be giving competitive bids to the owners. Some other factors received from survey respondents include: seasons; proximity to office; and the engineering firm. Once again, only a few respondents mentioned these additional factors. As a result, we assumed they were not as important as the ones listed in the survey.

Table 5. Relative importance of factors in estimating a bid price

Factors Effecting 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

Section four of the survey was created to determine typical costs for an underground construction project. This was by far the most difficult part of the study. Some contractors claimed that it was not possible to compare costs of HDD with open cut, while others seemed to respond with encouraging feedback when comparing with percentages. The cost comparison results between HDD and open cut are displayed in Figure 2. This figure shows various cost factors that contractors considered a savings for HDD, designated by a positive percentage. A negative percentage indicates a savings realized by open cut. Two-thirds of the factors observed in the survey were identified to be a savings for HDD. From these results, we were surprised to see that equipment operation costs for HDD were not considered to be a savings factor. The factor with the most notable controversy between respondents was equipment operation cost. Some of the respondents claimed that only the initial upfront cost of a drill rig is the biggest expense. Another reason for HDD's higher equipment cost is the maintenance after drilling through difficult conditions. Duration on an HDD project was found to have a time savings of 16% over open cut. Time savings can be a significant factor on a project if ground water or saturated soils are evident. Additional profit on an HDD project was found to be approximately 12%. Surface restoration costs are the most significant cost savings that HDD offers. The savings in restoration for paving alone was near 70%. 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 indicated open cut to be have a slight savings over HDD. The averages of the respondents indicate that contractors spend approximately 9% more on equipment operational costs for HDD than open cut. Material costs for HDD were also found to be nearly 3% higher. The engineering service costs on a project are expected to be similar for HDD and open cut.

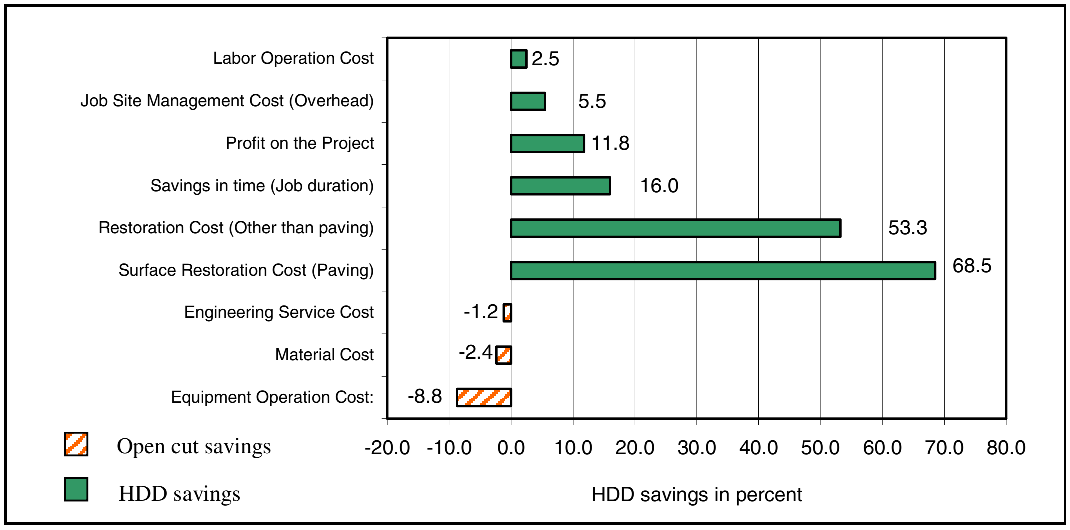

Figure 2. Percent comparison of cost factors between HDD versus traditional open cut (negative percent indicates savings realized by open cut)

Eco-Social Impacts

Eco-social factors were examined in section five of the survey by using a scale ranging from 1 to 10. Results indicate that HDD significantly reduces a project's environmental impacts (Table 6). Dust pollution on an open cut project was found to be almost three times the impact than on an HDD project. There are numerous advantages when HDD is used relating to decreased traffic disruption, less effect on business sales, and the decreased impact on the ecological system. Also, HDD scored higher for removal of waste materials. This is due in large part to the difficulty of finding a designated area to discharge the drilling fluid. On open cut projects, if soils are removed from the site, disposal of waste materials is usually non-problematic if the soil is not contaminated.

Table 6. Relative importance of eco-social impacts to construction methods

Eco-Social Impacts	Score		
	HDD	Open Cut	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

Consideration Factors

Similar to the eco-social section of the survey, consideration factors were compared directly between HDD and open cut on a scale of 1 to 10. Results from the comparison are shown in Table 7, which indicates the importance of having a detailed understanding of the soil conditions. Having the proper information and quantity of existing utilities in the construction area is as critical in open cut as it is in HDD. As would be expected, the ground water table and the weather conditions are much more critical on an open cut project. The impact of surface obstructions for open cut is much more important. However buried obstructions such as timber and concrete have an importance for HDD. Safety issues for both types of construction were surprisingly similar, even though HDD was expected to have a lower rating due to a significant reduction of open trenching and a reduction of fatalities.

Table 7. Relative importance of project consideration factors to method

Project Consideration Factors	Score		
	HDD	Open Cut	Difference
Surface Obstructions	5.1	8.6	-3.5
Ground Water 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

Potential Risk Factors

Table 8 shows the top five most significant factors to consider prior to construction of a HDD project. All responses were categorized into 13 different sub-headings and each heading was then accumulated. Approximately 68% of the respondents indicated soil conditions were the most important factor to consider before HDD is selected as a viable method. This result was not surprising because the most challenging situations that contractors encounter during HDD are gravels and cobbles (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. Traffic, which can also be classified as a social factor, was another important consideration on a project.

Table 8. Contractors' Top Five Factors for HDD

	HDD Factors	% Selected by Respondents
1.	Soil Conditions	68
2.	Site Access	46
3.	Traffic	39
4.	Project Details	32
5.	Client Specifications	32

A similar list of the top five most significant factors for open cut is shown in Table 9. The differences between the decision factors for open cut and HDD are location of existing utilities and the impact restoration. Existing utilities are a major concern for traditional open cut because once the utility location is identified it must be exposed and crossed. For HDD, after the location of the existing utility has been identified, any contact with the utility can be avoided through steering the drill head. Sixty-one per cent of respondents deemed that soil conditions were the most important factor for open cut construction and 35% of these specifically indicated ground water table as being their issue with soil conditions. Existing utilities is notably the most surprising because in section five of the survey, contractors identified existing utilities as being more important for HDD than open cut construction.

Table 9. Contractors' Top Five Factors for Traditional Open Cut

Open Cut Factors	% Selected by Respondents
1. Soil Conditions	61
2. Traffic	46
3. Existing Utilities	39
4. Project Details	25
5. Restoration	21

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. From those surveyed, the knowledge level for engineers was 4.8 out of 10. We were not surprised by this low score because of the lack of education in underground construction. The average knowledge level for an owner was 3.9 out of 10.

CONCLUSIONS AND RECOMMENDATIONS

Selection of the most feasible construction method is becoming increasingly more important as municipalities and their infrastructure develop. Construction solutions are usually solved with the lowest cost method; however, with an increase in public concerns regarding environmental issues, other factors should also be considered. Eco-social effects, construction consideration factors and risk factors have become critical in selecting the preferred construction method.

Surveys were distributed to contractors with a broad range of annual revenues across the United States and Canada. From the surveys gathered, an analysis was performed to compare types of risk factors and costs found in HDD and open cut construction. According to the results gathered from section three of the survey, previous experience is the most important factor in estimating a contingency plan. The contractors indicated that the most important factor affecting the bid price of a project was the type of construction method, followed by the contractor's experience and the quality of the cost estimate. In terms of a direct comparison of the two underground construction methods, two-thirds of the factors studied had a savings for HDD. The greatest savings for HDD were the restoration costs, while the greatest savings for open cut was equipment operation costs. The greatest comparable difference existing between HDD and open cut are dust pollution and traffic restrictions. The survey asked contractors for the top five influencing factors on a HDD and open cut project. In both lists, the top factor cited was soil conditions.

Results of the survey suggest that using HDD in urban environments not only has an economical advantage but also a reduction in risk factors that contribute to a successful project. Subsequently, owners that perform a comprehensive analysis on their projects will be able to determine the best construction method that will meet the owner's function, budget and safety needs.