Decision Support System for Microtunneling Applications

Tae Hwan Chung[1]; Dulcy M. Abraham[2]; and Sanjiv B. Gokhale[3]

Abstract: Microtunneling is a trenchless technology method used for installing new pipelines. The inherent advantages of this method over open-cut trenching have led to its increasing use since its first introduction into North America in the early 1980s. With this technology, surface disruption can be minimized, especially in urban areas, and high accuracy of installation (usually less than 2 cm over 100 m) can be achieved in both line and grade. But microtunneling machines are very expensive and few contractors have extensive experience with this technology. Microtunneling can also be risky when unexpected obstacles or soil changes occur. Careful constructability analysis is needed, and an appropriate microtunneling method should be selected in order to achieve successful completion of microtunneling projects. A computerized decision support system (DSS) for microtunneling was developed to support decision making for contractors who want to bid on microtunneling projects. This paper discusses the decision-making process for microtunneling and the development of the DSS. When the user enters basic information about the potential project such as drive length, installation depth, pipe diameter, and soil condition, the DSS evaluates whether microtunneling will be economically feasible and suggests appropriate types of microtunneling methods. The user can then select microtunneling machines, types of pipes, and types of shaft construction methods. This DSS is most beneficial when used at the preplanning stage by utility contractors.

DOI: 10.1061/(ASCE)0733-9364(2004)130:6(835)

CE Database subject headings: Microtunneling; Economic factors; Soil conditions; Decision support systems; Pipelines.

Introduction

Open-trench construction, which traditionally has been used for conduit construction, involves excavating a trench and installing conduit by using laborers. Open-cut trench construction has proven expensive, especially in congested urban areas, because it is associated with disruptions to surface activities. Other problems caused by open-cut methods include traffic disruption, interruption of local business, damage to existing utilities, and concerns for worker safety. This has resulted in a growing demand for trenchless technology as an alternative to traditional open-cut trench construction methods. According to the North America Society of Trenchless Technology (NASTT), trenchless construction is defined as "a family of methods, materials, and equipment capable of being used for the installation of new or replacement or rehabilitation of existing underground infrastructure with minimal disruption to surface traffic, business, and other activities." According to a recent survey of trenchless construction methods used by Canadian municipalities, the percentage of all municipal projects using trenchless construction methods has grown over the past 5 years by 180% (new installation) and 270% (rehabilitation) (Ariaratnam et al. 1999).

[1]Formerly, Graduate Student, School of Civil Engineering, Purdue Univ., West Lafayette, IN 47907.

[2]Associate Professor, School of Civil Engineering, Purdue Univ., West Lafayette, IN 47907.

[3]Associate Professor, Dept. of Civil and Environmental Engineering, Vanderbilt Univ., Nashville, TN 37235.

Note. Discussion open until May 1, 2005. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on January 23, 2001; approved on July 29, 2002. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 130, No. 6, December 1, 2004. ©ASCE, ISSN 0733-9364/2004/6-835–843/$18.00.

Microtunneling, one of the trenchless construction methods, has been increasingly used for installing new conduit construction. According to ASCE's *Standard Construction Guidelines for Microtunneling*, microtunneling can be defined as "a remotely controlled and guided pipe jacking technique that provides continuous support to the excavation face and does not require personnel entry into the tunnel" (ASCE 2001). In North America, the total installation lengths of microtunneling increased by 222% from 1990 to 1995.

There are many benefits of using the microtunneling method. Surface disruptions can be minimized and high accuracy of installation (usually less than 2 cm over 100 m) can be achieved in both line and grade. It can also be used for a wide range of diameters and for long drive lengths. Pipe diameters installed by the microtunneling method range from 8 in. (20 cm) to 10 ft (3.0 m), and lengths of up to 1,560 ft (475 m) have been achieved.

But microtunneling machines are very expensive and few contractors have extensive experience with this technology because of its relatively short history in North America. Microtunneling can also be risky when unexpected obstacles or soil changes occur. Hence, a careful constructability analysis is needed to achieve successful construction. A computerized decision support system (DSS) will be useful for assisting in the decision-making process by checking construction feasibility and selecting appropriate methods, equipment, and materials.

This paper discusses the different decision-making processes for microtunneling and the development of a DSS for microtunneling applications, and builds upon the work described in Ueki et al. (1999). The primary differences between the tool and the one developed by Ueki and his coauthors and this tool are that the DSS:

1. Considers site conditions an important part of the economic feasibility component;

J. Constr. Eng. Manage., 2004, 130(6): 835-843

Table 1. Comparison of Slurry and Auger Type Methods (Ueki et al. 1999)

Variable	Slurry type	Auger type
System	A slurry suspension is used to transport spoil directly to the surface.	An auger is used to transport spoil from the MTBM to the driving shaft.
Advantages	Available for wide range of soils, and diameters	System is simpler and less expensive
	Longer drives can be possible	Effective for smaller diameters (less than 120 cm) and shallow installations
	Available for soft rocks	
	Tunneling more than 3 m below groundwater table can be possible	
Disadvantages	System is more complex and expensive	Tunneling below water table is limited
		Limited pipe diameters
		Drive length is limited to around 105 m

2. Considers pipe properties an integral part of the DSS approach;
3. Also considers the selection of construction shaft methods; and
4. Provides estimates of project costs and durations.

This DSS is most beneficial when used by contractors at the preplanning and bid preparation stages. When the user enters basic information about the potential project, this DSS evaluates whether microtunneling operations will be economically feasible and suggests the appropriate type of microtunneling methods. The user can select microtunneling machines, type of pipes, and type of shaft construction methods. The DSS also provides users with approximate project durations and cost estimates.

The software selected to implement this tool is Microsoft Visual Basic 6.0. The data underlying the development of the DSS were obtained from many sources. In addition to literature sources, these include specifications from microtunneling machine and pipe manufacturers and interviews with manufacturers of microtunneling boring machines (MTBMs).

Guidelines for Use of Microtunneling

Geotechnical Consideration

Geologic conditions are very important factors affecting the selection of microtunneling methods and equipment. A thorough subsurface investigation is required during the design phase to identify the geologic conditions along the pipeline. In order to select the appropriate microtunneling machine for each project, physical properties including the strength, grain size, moisture content, plasticity, compressibility, and permeability of the soil deposits should be carefully investigated. Groundwater conditions significantly influence ground behavior and the loss of ground support. Groundwater levels should be determined and the hydraulic conductivity estimated using pumping tests or other field tests to determine whether dewatering will be required.

Loss of ground support during tunneling operations results in surface settlement. This loss of ground may be related to soil conditions including soil squeezing, running, or flowing into the heading. The size of overcut and steering adjustments can also cause loss of ground. The magnitudes of losses will be mainly affected by factors such as ground conditions, groundwater conditions, size and depth of the pipe, equipment capacity, and skill of the operator in operating and steering the machine (Klein and Essex 1995).

Microtunneling Machine Consideration

Pressurized face MTBMs can be used to install pipelines in difficult and variable ground conditions because they can handle pipeline installation without excessive loss of ground and surface settlement. There are two types of microtunneling methods: slurry and auger. In a slurry type, a stabilizing pressure is applied to the tunnel face by using slurry (consisting of natural clay or bentonite mixed with water), while in an auger type, earth pressure resulting from the weight of excavated muck in a closed auger system is applied to maintain face stability. These methods result in preventing groundwater inflow.

Slurry-type machines can be used regardless of the groundwater level, while auger-type machines are mainly limited to less than 3 m below the groundwater level. Thus, slurry-type machines are preferable when the groundwater exists above the pipeline installation depth, but for pipeline installation above the groundwater table, auger types may have higher production and lower cost (Staheli and Hermanson 1996). Some machines are capable of crushing boulders and also boring through hard rock. These machines are usually equipped with drag bits, button cutters, or disc cutters (Klein and Essex 1995). Characteristics of both types of microtunneling methods are listed in Table 1.

Alignment Consideration

With a marginal increase in construction cost, pipelines can be installed at the deeper locations by microtunneling methods. Microtunneling can be advantageous when a deeper alignment can avoid existing utilities and also allow the sewer to run at grade without requiring lift stations. Straight alignments are preferable for microtunneling projects because they facilitate more accurate control of line and grade and more uniform distribution of force at pipe joints. The location of jacking and receiving pits should be determined by the maximum jacking distance of microtunneling techniques. For slurry-type machines, the maximum jacking distance without the intermediate jacking station typically ranges from 400 to 500 ft (120 to 150 m), while the maximum drive length of auger-type machines is limited to 350 ft (105 m) because of limitations of applicable torque.

Major factors affecting the maximum jacking distance will include the type of pipe materials, pipe size, soil conditions, thrust capacity of the main jacks, and use of bentonite lubrication. Intermediate jacking stations can be used for the extension of the drive length and are typically used for man-entry operations and when the pipe diameter is larger than 3 ft (0.9 m). For non-man-entry operations, the maximum jacking distance is determined by

J. Constr. Eng. Manage., 2004, 130(6): 835-843

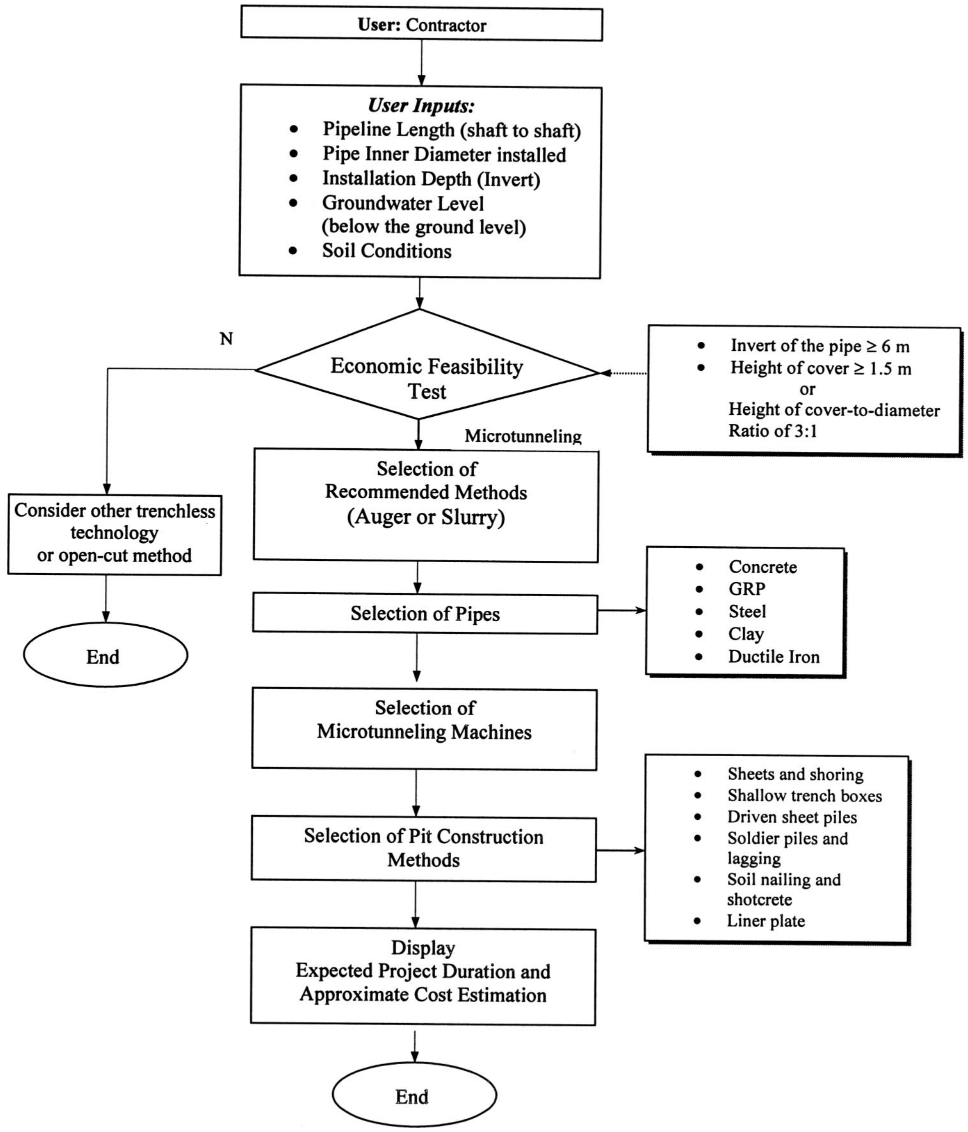

Fig. 1. Flowchart showing selection of microtunneling method

the jacking capacity from the drive shaft. This is due to the fact that the interjack equipment cannot be used since it cannot be retrieved for non-man-entry operations (Klein and Essex 1995). The inner diameter for pipes used in microtunneling ranges from 8 in. to 10 ft (200 to 3,000 mm). Most of the slurry-type machines are applicable within this range, but, auger-type machines are usually limited to the maximum inner diameter of 4 ft (1.2 m).

Development of the Decision Support System (DSS)

The DSS consists of seven stages, as shown in Fig. 1. The seven stages are user input data, economic feasibility test, method selection, pipe selection, machine selection, shaft construction method selection, and determination of approximate project duration and cost. The user needs to enter basic project data including lengths of pipeline to be installed, inner diameter of pipe, installation depth, groundwater level, and soil conditions. An economic feasibility test is performed to determine if microtunneling is economically feasible based on the installation depth. If not, some other trenchless technology or open-cut method should be considered. The method selection determines which type of microtunneling (auger or slurry) will be more applicable to the project. In the machine selection process, one can choose specific microtunneling machines currently used in North America. The pit selection process selects the construction method of pits. At the final stage of the decision-making process, the DSS tool shows estimates of project duration and cost. These processes are discussed in detail in the following sections.

Economic Feasibility Test

Microtunneling is not always the optimum choice for every project. Generally it is economical when the invert of the pipe is 20 ft (6 m) deep or more, since the use of the traditional dig-and-fill method at these depths would require extensive trench shoring and considerations of confined space entry, which slows down productivity, hampers safety, and adds to the cost of construction. A minimum of 5 ft (1.5 m) of cover or a height of cover to diameter ratio of 3 is usually recommended for microtunneling to avoid heave or settlement of the surface (Staheli and Hermanson

J. Constr. Eng. Manage., 2004, 130(6): 835-843

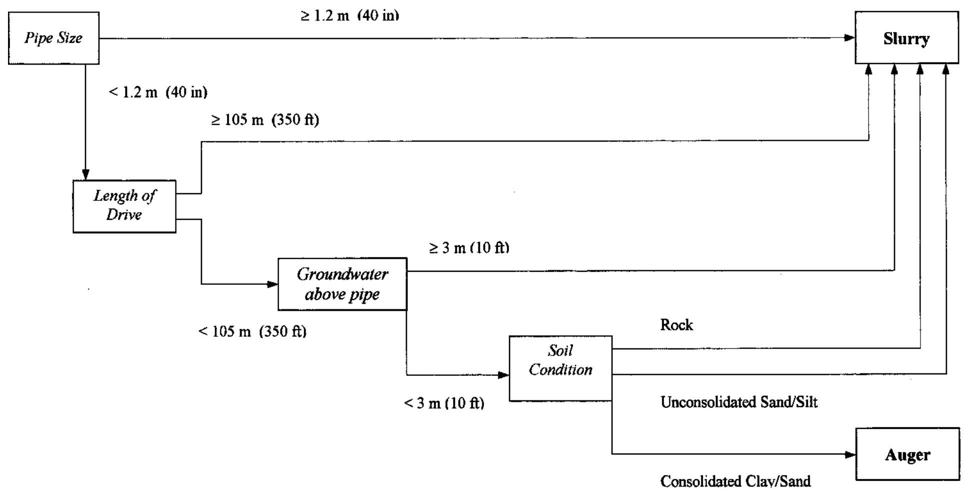

Fig. 2. Selection of microtunneling methods (slurry or auger type) (adapted from ASCE *Standard Construction Guidelines for Microtunneling*)

1996). When the average depth to pipe invert exceeds 6 m, microtunneling is considered economical and the user can go to the next step. If the installation depth is less than 6 m, the DSS compares a height of cover or cover-to-diameter ratio with minimum height of cover (1.5 m) or cover-to-diameter ratio (3:1), respectively. If these conditions are met, microtunneling is technically feasible, but if not, this system recommends that the user investigate using other trenchless technology or open-cut methods.

Selection of Recommended Method

In an auger microtunneling operation, the diameter of pipe installed is usually less than 120 cm, while the slurry type is available for a wider range of pipe diameters. On the other hand, in the auger type, the length of the drive will be limited by available machine torque. Although motors can be installed in the cutter head to provide torque to the cutting face, the length of the drive will be limited by the torque required to rotate the auger string. Maximum lengths for drives with auger types are typically around 105 m (350 ft), but longer drives can be achievable in a slurry type (Staheli and Hermanson 1996).

Slurry microtunneling can be used regardless of the groundwater level, while auger microtunneling is usually limited to less than 3 m below groundwater level. If the groundwater level is below the tunnel elevation, auger types might be used to avoid the problem of hydrofracture. Auger types have less mechanical complexity and potentially higher production rates in soils above groundwater (Staheli and Hermanson 1996).

Another factor to be considered is compatibility with soil type. For cohesive soils, the auger type is better suited than the slurry type, but slurry types can cover a wider range of soil types and are especially well suited for granular soils. They can also be used for rock excavation, with appropriate disc cutter heads (Staheli and Hermanson 1996). The steps in the selection process are shown in Fig. 2.

Selection of Pipe

The size of the pipe and the type of pipe material are important factors to consider in the microtunneling operation. Other factors affecting the selection of the pipe material are the pipeline's final use, the environmental soil conditions, and compatibility of the material with the microtunneling method (Myers et al. 1999).

The pipe must be designed to withstand the axial forces applied to it during installation. These axial forces can be substantial, approaching 1,000 tons or more for larger pipes (Klein 1995). These axial forces are determined based on soil type, depth of excavation, use of lubrication system, steering corrections, length of tunnel segment, and excavation overcuts (Myers et al. 1999).

Jacking pipes should have tight joints and consistent inside and outside diameters. Jacking pipes currently used in microtunneling methods include (Klein 1995)

- Glass-fiber reinforced thermosetting resin pipe (GRP),
- Reinforced concrete pipe (RCP),
- Steel casings,
- Vitrified clay pipe (VCP), and
- Ductile iron pipe.

Concrete is one of the materials commonly used as a primary lining for microtunneling with a range of diameters from about 12 in. (300 mm) and upwards. Concrete pipes are normally manufactured from 3 to 10 ft. (1–3 m) long with internal diameters of 12 in. (300 mm) to 144 in.(3,600 mm).

Compared to RCP, GRP has a number of advantages. These include lighter weight and ease of handling, smoother exterior and better dimensional control resulting in lower pipe friction, higher tensile and compressive strengths, and better corrosion resistance. One disadvantage of GRP is its higher costs compared to other pipe materials, especially when supplied in short lengths (Klein 1995). The available diameter of GRP ranges from 12 in. (300 mm) to 108 in. (2,700 mm). Sections may be as long as 20 ft (6 m), with 10 ft (3 m) to 20 ft (6 m) preferred.

VCP has some of the same advantages as GRP in terms of strength, smoothness, and corrosion resistance (Klein 1995). The internal diameter of vitrified clay pipes ranges from 6 to 24 in. (150 to 600 mm), and diameters up to 48 in. (1,200 mm) for larger diameter pipes are also offered. Pipe lengths usually range from 3 to 4 ft (0.9 to 1.2 m) for smaller diameters.

Steel pipes of various lengths are used for the sleeves for the installation of gas, oil, and water pipelines where fine tolerances in line and level are not required. Steel pipes have outstanding strength and good weldability but relatively low resistance to corrosion; hence they traditionally were not used in the sewage sector (Stein et al. 1989). Factors such as welding time and pipe size should be considered when determining the length of each individual pipe.

J. Constr. Eng. Manage., 2004, 130(6): 835-843

Table 2. Available Sizes of Each Pipe Type for Microtunneling

Type of pipe	Available diameter	Pipe section length
Reinforced concrete pipe (RCP)	12 to 144 in. (300 to 3,600 mm)	3 to 10 ft (0.9 to 3 m)
Glass-fiber reinforced thermosetting resin pipe (GRP)	12 to 108 in. (300 to 2,700 mm)	10 to 20 ft (3 to 6 m)
Vitrified clay pipe	6 to 24 in. (150 to 600 mm) Up to 48 in.	3 to 4 ft (0.9 to 1.2 m) Up to 10 ft
Ductile iron pipe	4 to 24 in. (100 to 600 mm)	Up to 20 ft (6 m)
Steel pipe	3 to 144 in. (75 to 3,600 mm)	8 to 40 ft (2.4 to 12 m)

Ductile iron pipes can be used for the microtunneling operation. Ductile iron pipes are offered in diameters ranging from 4 to 24 in. (100 to 600 mm) with available lengths up to 20 ft (6 m).

Applicable sizes of each pipe material are shown in Table 2 and Fig. 3, and features of each pipe material are compared in Table 3. GRP and VCP have been preferred to other pipe materials due to their resistance to corrosion, leak-free joints, and smooth interior surface.

Selection of Machine

In the machine selection process, the user can choose the appropriate machine from the microtunneling machine databases. These databases include currently available data from major microtunneling machine manufacturers including Iseki, Akkerman, Soltau, and Herrenknecht. Sample machine data are shown in Table 4.

The decision support tool displays the machines available, based on the size of the pipe, and the user selects the machine. The tool compares the maximum jacking capacity of each machine with the predicted jacking force calculated by the decision support tool. If the maximum jacking capacity of the machine is greater than the predicted one, the user can choose that machine and go to the next step. Note that only pipe material is selected at this stage while pipe thickness is not considered; pipe thickness varies depending on pipe materials and pipe sizes.

The jacking force is an important factor to consider because it limits drive length and determines pipe strength. It is not easy to predict jacking force because many factors (e.g., soil conditions, pipe materials, and lubrication) that affect the jacking force are interrelated. One approach to predict jacking forces is to consider the surface area of the pipe and the force per unit area or frictional forces. Using this method, the jacking force is calculated as follows (Lys and Garrett 1995):

$$JF = \pi \times OD \times L \times F_r \tag{1}$$

where JF = total jacking force (tons); OD = pipe outer diameter (m); L = drive length (m); and F_r = friction factor (tons/m^2).

Using data obtained from previous microtunneling jobs, including pipe diameter, drive length, and jacking force for the maximum force that occurred on the job, Lys and Garrett (1995) indicated that the maximum frictional forces vary from 0.03 to 0.07 tons/ft^2 (0.29–0.68 tons/m^2). The Lys and Garrett approach does not consider the effects of depth, groundwater levels, soil conditions, overcut, and steering. In spite of these limitations, this method for predicting jacking forces is widely used. In this DSS, an average friction force of 0.05 tons/ft^2 (0.49 tons/m^2) is used to calculate the predicted jacking force.

Selection of Shaft Construction Method

The most common way of excavating a shaft is to use a backhoe. For stiff soils and medium hard rock, ripping might be required, or blasting for very hard rock conditions. The size of the shaft and the groundwater level determine the required support methods for shafts. For shallow shafts, cantilevered supports are preferred because the cross bracing will not interfere with the installation of the microtunneling machine and pipe sections. Lateral bracing will be needed when the depth of shaft is more than 10 to 15 ft (3 to 4.5 m), while no support may be needed in rock and shallow soil conditions (Abramson, unpublished paper, 1998).

Sheets and shoring are commonly used for supporting narrow and shallow trenches. The main materials for sheets are wood, corrugated metal, or sheet piles. The sheets are driven into the ground or slipped down simultaneously with the excavation. Walers hold the sheets in place using expanding jacks. Because jacks are often needed every 5 to 10 ft (1.5 to 3 m), they are very cumbersome to use in microtunneling operations except for small-diameter installations (Abramson, unpublished paper, 1998).

Shallow trench boxes are prefabricated trench boxes and usually rectangular in shape. The trench box has cutting edges at the bottom and is placed over the shaft location. As the excavation is made, the trench box is lowered into the hole. Due to its own weight, the trench box tends to sink into the excavation (Stein et al. 1989). Trench boxes are simpler to install and have fewer cross braces than sheets and shoring. This method can be used for ex-

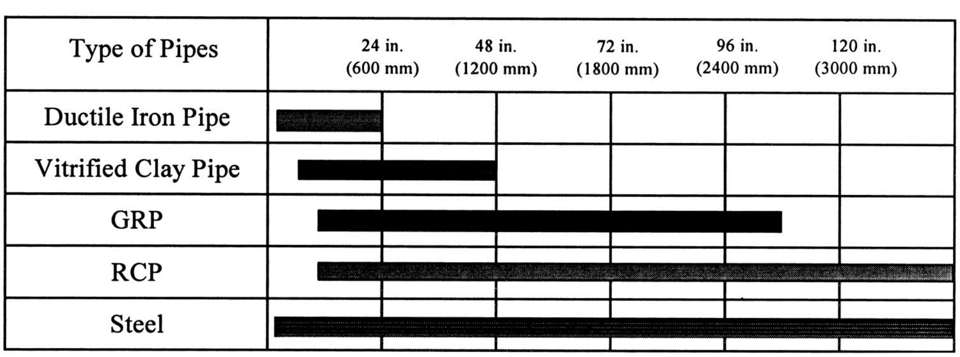

Fig. 3. Range comparison of each pipe size (diameter)

J. Constr. Eng. Manage., 2004, 130(6): 835-843

Table 3. Comparison of Features of Each Pipe Material (Hobas)

Features	RCP	GRP	Vitrified clay pipe	Benefits
Corrosion resistance	No	Yes	Yes	Long service even in corrosive environments
				Hydraulics nearly unchanged with time
Leak-free joints	No	Yes	Yes	No exfiltration in environmentally sensitive areas
				No time and expense to find and seal leaks
				Excellent hydraulic characteristics
Smooth interior surface	No	Yes	Yes	High flow capacity

cavation sizes up to 10 by 20 ft (3 by 6 m). For excavations larger than about 10 by 20 ft (3 by 6 m), other support methods should be used (Abramson, unpublished paper, 1998).

Driven sheet piles may be suitable for shallow excavation [typically less than 15 ft (4.5 m)] without any bracing and walers, while for deeper excavations, cross bracing and walers are needed. In this method, heavy sheets are interlocked and cantilevered from the bottom of the excavation. Sheets are driven into place by pushing and pounding them with a backhoe bucket or conventional pile driver. After all sheets are installed, the excavation is started and bracing is installed when the required level of excavation is reached. Sheet piles will limit groundwater inflow to a large extent (Abramson, unpublished paper, 1998).

Soil nailing and shotcrete can be used as an alternative to soldier piles and lagging or sheet piles. The excavation is done in 5 to 10 ft (1.5 to 3 m) lift increments. After each lift is excavated, shotcrete is applied and one row of soil nails is installed. Generally, the shotcrete is 3 to 6 in. (7.6 to 15.2 cm) thick and the nails are composed of No. 8 to 10 bars cement grouted into place. The bar lengths are 50 to 70% of the excavation height. Shotcrete will reduce but not prevent groundwater inflow into the excavation (Abramson, unpublished paper, 1998).

Linear plates are primarily used for large circular excavations below the groundwater table because they have favorable load-bearing features and can be handled easily at the construction site. In this method, segmental steel plates are bolted together at the site. When multiple tunnels are bored from one shaft, a circular shaft is advantageous. However, this method is labor intensive and expensive to install (Stein et al. 1989).

Table 5 compares shaft construction methods. The criteria considered for the comparison include applicable sizes, depths, applicability to wet ground conditions, and need for watertight construction. All construction methods mentioned above are applicable in dry ground conditions. Depending on installation depth, ground condition, and a need for watertight construction, the decision support tool evaluates and displays available construction methods for shafts. Depending on the depth to pipe invert, the DSS calculates the approximate depth of shafts. An additional 4 ft (1.2 m) is added to include the depth of the bottom of the shaft. Users need to choose the ground condition (dry or wet ground) and determine a need for watertight construction. The final decision is made by the users based on their past experience or familiarity with specific construction methods.

Project Duration and Cost

Production rates, which will determine project durations, and installation costs of microtunneling are of great interest to owners, contractors, and designers. There are a few research studies analyzing production rates and installation costs based on analysis of past microtunneling projects.

Project Duration

According to Klein and Essex (1995), the average production rate ranges from about 4 to 8 ft (1.2 to 2.4 m) per hour. These ranges are based on several microtunneling projects completed from 1987 to 1995. Hourly production rates obtained from some projects in the 1987–1995 time frame are shown in Fig. 4. Higher production rates have been achieved with smaller pipe sizes. Because many other factors, including pipe diameter, pipe length, pipe material, and soil conditions, affect the production rates, the data must be used judiciously.

As shown in Fig. 4, higher production rates have been achieved with fiberglass pipe than with concrete pipe. This might be due to the fact that fiberglass pipes are smoother, lighter, and easier to handle, and each fiberglass pipe section is longer compared to other pipe materials. Both vitrified clay and fiberglass pipes are generally manufactured to very tight tolerances, which help to reduce jacking loads and result in faster installations. However, in terms of price, concrete pipes are generally the most economical.

Interviews were conducted with manufacturers of microtunneling equipment in North America to obtain more data related to production rates. These interviews indicated that the production

Table 4. Sample Machine Data

Company	Product name	Product ID	Type	Jacking force (tons)	Maximum machine diameter (mm)	Retention length (m)
Herrenknecht	AVN	300	Slurry	86.0	410	100
Herrenknecht	AVN	400	Slurry	86.0	565	100
Herrenknecht	AVN	500	Slurry	140.6	665	120
Herrenknecht	AVN	600	Slurry	140.6	780	140
Herrenknecht	AVN	700	Slurry	259.0	875	140
Herrenknecht	AVN	800 B	Slurry	346.2	975	150

J. Constr. Eng. Manage., 2004, 130(6): 835-843

Table 5. Comparison of Each Construction Method for Shafts (Abramson 1998)

Type of method	Size and shape	Depth	Wet ground	Watertight
Sheets and shoring	Any	Up to 20 ft (6 m)	Not recommended	No
Shallow trench boxes	Up to 10 by 20 ft (3 to 6 m)	Up to 30 ft (10 m)	Suitable	Yes
Driven sheet piles	Any	Up to 50 ft (15 m)	Applicable	Yes
Soldier piles and lagging	Any	Up to 50 ft (15 m)	Applicable	No
Soil nailing and shotcrete	Any	Surface level	Not applicable	Yes
Liner plate	>8 ft (2.4 m) diameter	Unlimited	Applicable	Yes

rate is influenced primarily by the ground type and the length of the pipe sections being installed. The actual pipe jacking speed while tunneling ranges from 12 in. (300 mm) per hour in hard rock to 10 ft (3 m) pipe installation in 15 min in sand. These rates do not include the connection time. The target connection time is 30 min, although 30 to 60 min is the average range. The average production rate including connection time is 50 ft (15 m) per shift, and this production rate is considered a target production rate by many microtunneling contractors. This rate is quite close to the average rate per shift from the study conducted by Klein and Essex (1995) [(48 ft (14.4 m) per shift based on the average production rate of 6 ft (1.8 m) per hour)]. Setup and mobilization time were not included in this rate. The average production rate on a project including setup and mobilization times is 20 to 30 ft (6 to 9 m) per day. If the drives and pipe section lengths are longer, a higher average production rate is achievable.

For the development of the DSS, the range of the average production rate from 4 to 8 ft (1.2 to 2.4 m) per hour was selected for the calculation of the project duration. Based on the average production rate range, the decision support tool calculates and displays the approximate project duration range. The predicted project duration provides a good estimate of the project duration during the initial planning stage of the microtunneling project.

Project Cost

A study of the trenchless technology cost trend conducted by Thomson et al. (1998) compared the jacked sewer installation costs in Europe and North America in 1988 and 1998. These costs for North America are shown in Fig. 5 and were obtained from a wide range of jobs. The cost of the pipe itself is included in the installation cost, but the costs of driving and receiving shafts are not because these costs usually vary with the installation depth.

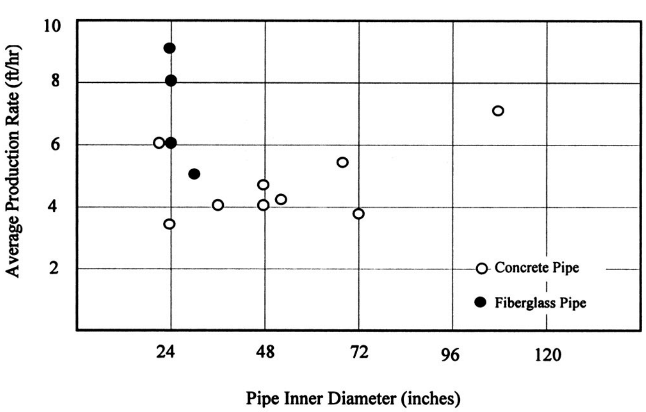

Fig. 4. Average hourly production rate for microtunneling projects (Klein and Essex 1995)

Based on the costs shown in Fig. 5, the DSS determines the estimated project cost (pipe jacking+pipe). For instance, if the pipe diameter and the total drive length of pipeline to be installed are 900 mm (36 in.) and 150 m (500 ft), respectively, the estimated project cost will be $300,000 (based on the unit cost of $2,000/m, as shown in Fig. 5). The cost of shaft construction is not included.

Case Studies for Validation

The prototype DSS was validated by comparing the results obtained by using the DSS with the decisions made on past projects.

J. Edward Drain Interceptor Sewer Project

The J. Edward Drain Interceptor Sewer Project site was located at the Town of Westfield, Indiana, north of Indianapolis, and included open-cut construction of 7,260 ft (2,213 m) of sewer main and microtunneling of 3,058 ft (932 m) of 24 in. (600 mm) sewer installation. One alignment on this project had the sewer going under the golf course. Microtunneling was selected for this route because microtunneling was the least disruptive and potentially the most economical alternative for this segment of the sewer. The low bidder presented the low bid of $2,196,200 for the entire job. This bidder was also the low bidder for the microtunneling segment at $983,147 ($321/lf).

The results of test borings showed that fine to coarse sands and silt predominated at depths in excess of 20 ft (6 m) below ground surface, and the depth of the sewer invert varied from 30 to 55 ft (9.1 to 16.8 m) below ground surface. The complete sewer had nine 60-in. (1.5-m) diameter manholes spaced approximately 400 ft (122 m) on center. Four 12-ft (3.6-m) diameter jacking shafts and three 8-ft (2.4-m) diameter receiving shafts were located at manholes for the jacking operation. The pipe was jacked from each jacking shaft in two directions to the adjoining receiving shaft. For the purpose of comparison with the output of the DSS, the 400-ft (122-m) microtunneling run and the average depth to invert of 42 ft (12.8 m) were chosen for the project input data. Because the average groundwater depth was not available for this project, it was assumed to be 20 ft (6 m).

Outputs of the DSS were compared with actual project data, as shown in Table 6. The slurry-type method was selected because of the soil condition and long drive length. The DSS recommends three microtunneling machines, and one of them was used at the actual project. The DSS also recommends two types of pipe after considering pipe diameter and corrosion resistance requirements. A 24-in. ID vitrified clay pipe was used for this job. The DSS estimates a project cost of $164,700 based on a unit cost of $1,350 per linear meter, while the actual unit cost of this project was $1,054 per linear meter.

J. Constr. Eng. Manage., 2004, 130(6): 835-843

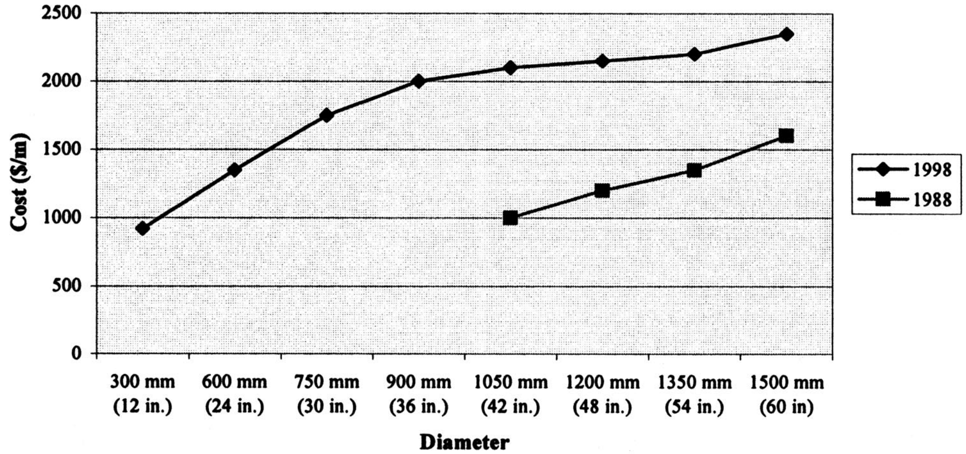

Fig. 5. Jacked sewer installation costs 1988–1998 [Thomson et al. (1998), used with permission of Benjamin Media, Peninsula, Ohio]

Holes Creek Tunnel Project

The Holes Creek Tunnel Project was located in Montgomery County, Ohio, and included the installation of 1,083 ft (330 m) of 38-in. (965-mm) OD and 3,330 ft (1,015 m) of 51-in. (1,300-mm) OD sanitary sewer pipe by microtunneling and 160 ft (48 m) of 30 in. (760 mm) OD sanitary sewer pipe by the conventional open-trench method. This project was initiated by an administrative order of the Ohio Environmental Protection Agency because of the problem of combined sewer overflows in the Holes Creek drainage area. The selected sewer goes through a residential area and under Holes Creek. This was the second microtunneling project for the contractor who undertook the project. The result of soil tests showed that the soil at the invert elevation was mainly clays with sand, gravel, and weathered shale with limestone seams. The groundwater was found to be at an average of 5 ft (1.5 m) above invert elevation. The installation depth ranges from 15 to 30 ft (4.5 to 9 m). The microtunneling project consisted of 10 drives and lengths of each drive varied, ranging from 206 to 688 ft (63 to 210 m) (Nido, unpublished research study, 1999). For the purpose of the comparison with the output of the DSS, the 688-ft (210-m) microtunneling run and the average depth to invert of 23 ft (6.9 m) were considered.

The output of the DSS was compared with actual project data, as shown in Table 7. Slurry-type microtunneling was selected because of the pipe diameter, long drive length (over 105 m), and soil conditions. The DSS suggested three microtunneling machines, one of which (Soltau RVS 600-AS) was used at the actual project. The DSS suggests two types of pipe after considering pipe diameter and corrosion resistance requirement. A 48-in. ID fiberglass pipe was used for this job. The DSS estimated a project cost of $451,500 based on a unit cost of $2,150 per linear meter. In this DSS, the average production rate range of 1.2 to 2.4 m/h was used while the actual production was 1.8 m/h (6 ft/h). For further verification, production rates for each drive on this project were also obtained and compared, as shown in Table 8. The average production rates for each drive ranged from 1.28 to 2.13 m/h (4.2 to 7.0 ft/h). This result shows that the range of average production rates selected by this DSS seems reliable.

Summary

Since its first introduction into North America in 1984, microtunneling has been successfully used as an alternative to the traditional open-cut methods. With this technology, surface disruption can be substantially reduced compared with open-cut methods, and very highly accurate installations in line and grade can be achieved. In spite of the many benefits of microtunneling, some contractors are still reluctant to accept this technology, the main barriers being the need to purchase/lease expensive microtunneling machines and the lack of experience. Few contractors have extensive experience with this technology because of its short history, especially in North America. They face many uncertainties when they consider using this technology, including those associated with soil conditions, method selection, machine selection, and economics of microtunneling. Proper selection of methods and equipment based on thorough site investigation will be a key factor in successful completion of microtunneling operations.

To help contractors who want to bid on microtunneling

Table 6. Comparison of Results of DSS with Actual Project Data (Westfield Project)

Category	Outputs of DSS	Actual project
Type of method	Slurry	Slurry
Type of pipe	Vitrified clay pipe Fiberglass pipe	Vitrified clay pipe
Type of machine	Soltau RVS 250-AS Herrenknecht AVN 600 Iseki TCC 600	Soltau RVS 250-AS
Type of shaft construction method	Liner plate Driven sheet piles	Liner plate
Cost	$1,350/m (total: $164,700)	$1,054/m (total: $128,588)

J. Constr. Eng. Manage., 2004, 130(6): 835-843

Table 7. Comparison of Results of DSS with Actual Project Data (Holes Creek Project)

Category	Outputs of DSS	Actual project
Type of method	Slurry	Slurry
Type of pipe	Fiberglass pipe Vitrified clay pipe	Fiberglass pipe
Type of machine	Soltau RVS 600-AS Herrenknecht AVN 1200 Iseki TCC 1200	Soltau RVS 600-AS
Type of shaft construction method	Liner plate Driven sheet piles Shallow trench boxes	Liner plate
Production rate	1.2 to 2.4 m/h	1.8 m/h

projects, a computerized decision support system (DSS) for microtunneling was developed. This paper discussed the process of the DSS development and its application. This DSS can be used for decision making at the preproject planning stage, and its main benefit includes its ease of use as a decision aid. When the user enters basic information about the potential project such as drive length, installation depth, pipe diameter, and soil conditions, this DSS evaluates whether microtunneling will be economically feasible and recommends an appropriate microtunneling method. The user can select microtunneling machines, type of pipes, and type of shaft construction methods with the aid of this DSS, which also provides users with project duration and cost estimates based on the average production rate and the average unit cost of microtunneling installations.

Table 8. Soil Conditions and Productions for Each Drive at the Holes Creek Tunnel Project

Drive number	Soil conditions	Average production (ft/h)	Average production (m/h)
1	Lean clay/mostly sand and gravel	5.1	1.55
2	Lean clay/mostly sand and gravel	5.1	1.55
3	Lean clay with cobbles	5.3	1.62
4	Laminated limestone and shale bands	4.5	1.37
5	Laminated limestone and shale bands	6.0	1.83
6	Laminated limestone and shale bands	4.7	1.43
8	Lean clay with cobbles	6.8	2.07
9	Lean clay with cobbles	7.0	2.13
10	Laminated limestone and shale bands	4.2	1.28

Note: Source of table is an unpublished research paper by Nido (1999).

This DSS was developed only for microtunneling projects. Similar DSSs can be developed for other trenchless technologies such as pipe jacking, directional drilling, and pipe bursting. If an integrated DSS for some or all trenchless technologies is developed, it will assist decision makers in selecting appropriate methods, equipment, and material by providing appropriate information about the risks associated with each technology.

Internet Sites

AMERICAN MT Pipe, Inc. ⟨http://www.acipco.com⟩ (July 2000).
Canclay Pipe, Inc. ⟨http://www.canclay.com⟩ (April 2000).
Herrenknecht, Inc. ⟨http://www.herrenknecht.de/en/dyn_frameset.php3⟩ (April 2000).
Hobas Pipe, Inc. ⟨http://www.hobaspipeusa.com⟩ (April 2000).
Kerr Construction, Inc. ⟨http://www.kerrconstruction.com⟩ (May 2000).
Microtunneling, Inc. ⟨http://www.microtunneling.com⟩ (June 2000).

References

Ariaratnam, S. T., Lueke, J. S., and Allouche, E. N. (1999). "Utilization of trenchless construction methods by Canadian municipalities." *J. Constr. Eng. Manage.*, 125(2), 76–86.

ASCE. (2001). *Standard construction guidelines for microtunneling*. Committee Ballot, Revision 7, 1998, Reston, Va.

Klein, S. J. (1995). "Design aspects of microtunneling projects." *No-Dig Eng.*, 2(2), 9–12.

Klein, S. J., and Essex, R. J. (1995). "Microtunneling design considerations" *Proc., 2nd Int. Conf., Advances in Underground Pipeline Engineering*, ASCE, Reston, Va., 603–614.

Lys, R., Jr., and Garrett, T. M. (1995). "Microtunneling forces: The pipe's perspective." *Proc., 2nd Int. Conf., Advances in Underground Pipeline Engineering*, ASCE, Reston, Va., 627–634.

Myers, M. B., Stickrod, T. W., Abraham, D. M., and Iseley, T. (1999). "Microtunneling technology for conduit construction." *Pract. Period. Struct. Des. Constr.*, 4(2), 56–63.

Staheli, K., and Hermanson, G. E. (1996). "Microtunneling: When, where, and how to use it." *Water Envir. Tech.*, 8(3), 31–36.

Stein, D., Mollers, K., and Bielecki, R. (1989). *Microtunneling: Installation and renewal of nonman-size supply and sewage lines by the trenchless construction method*, Ernst and Sohn, Berlin.

Thomson, J., Sangster, T., and Kramer, S. (1998). "An overview of the economics of trenchless technology." *No-Dig Eng.*, 5(2), 23–27.

Ueki, M., Haas, C. T., and Seo, J. (1999). "Decision tool for microtunneling method selection." *J. Constr. Eng. Manage.*, 125(2), 123–131.

J. Constr. Eng. Manage., 2004, 130(6): 835-843