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TRENCHLESS TECHNOLOGIES AND THEIR IMPACT ON URBAN UTILITY SYSTEMS[1]

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INTRODUCTION

In the last two to three decades, many new underground utility construction and repair technologies have emerged that are grouped under the term *trenchless technology*. The term is used to describe those technologies that allow the installation, replacement or repair of underground utilities or conduits without the need for the excavation of a continuous trench from the surface. While the term *trenchless* certainly applies to larger bored tunnels also, the term is typically used to refer to urban-utility-scale-technologies rather than rail, metro, or road tunnel installations. The development of these technologies provides new solutions for installing and maintaining urban utility systems but also introduces new issues into the planning, design and operation of these systems. These new issues have impacts on the engineers who plan and design the systems, impacts on the conduct of site investigations for utility work, and impacts on the long-term arrangements of urban utility systems as the techniques are used more extensively.

Descriptions of various trenchless technologies can be found in a few books and reports [1,2,3,4,5] and a number of conference proceedings [6], journals, e.g. [7], and magazines [8,9]. Much of the information about the technologies, however, is still obtained directly from the specialist installation contractors, and manufacturers or suppliers of the equipment and products involved -- either directly or through trade associations. Trenchless technologies have been classified in different ways but can be considered to fall into four main categories:

- **New pipe installation using pipes jacked from a jacking pit as the excavation lining and, if necessary, the thrusting force for a boring head.** Various methods of removing the soil from the face of the pipe are used according to the nature of the soil, relationship to the water table, length of the project, etc. Specific methods are referred to as *pipe jacking*, *auger boring*, *microtunnelling*, *pipe ramming*, etc. Microtunnelling machines are the most sophisticated of these and can allow non-man entry tunnelling for lengths of several hundred meters with close control on line and grade (typically +/- 25 mm).

- **New pipe, cable or conduit installation using *horizontal directional drilling* (HDD).** These techniques utilize rotating drill strings or oil field downhole mud motor technologies to advance the hole. The direction of the drill hole advance can be controlled and this is used in conjunction with methods of locating the current position of the drill bit and the attitude of the drill bit to follow a prescribed path through soil or rock. The drill hole can be held open using drilling mud and, if necessary, a temporary casing and then the permanent pipe or cable pulled in using a back reaming operation while withdrawing the temporary casing (if used). While the principles are the similar, the equipment and project conditions divide the use of these technologies into two main divisions: small, highly portable drilling equipment (mini-HDD) used for shorter, shallower installation of small conduits, and larger drilling

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equipment used for major river crossings (e.g. pipes up to 1.2 m diameter and over 1 km in length). Short installations, such as for utility house connections, may also use impact moles that have limited or no steering capabilities. HDD techniques are also being used in environmental clean-up applications.

- ***Pipe and manhole rehabilitation techniques* that can be carried out from within the existing structure**. These techniques usually involve remote inspection systems to assess the condition of the lining and any other structural or operational problems. The repairs may be done by robotic methods for local problems, installing simple slip linings, installing temporarily distorted linings that are restored to their original shape in place, and installing cured-in-place pipe linings (CIPP). Lining systems inevitably reduce the internal diameter of the pipe but improved flow characteristics may compensate for this loss.

- ***Trenchless pipe replacement* techniques that involve breaking of an existing pipe in place and then displacement of the broken pipe segments into the surrounding soil as a new pipe is pulled along the same line as the old pipe.** The pipe breaking operation is done by simply pulling or pushing a cone shaped head through the old pipe and may be coupled with cutting blades to assist in the splitting of the old pipe. New pipes may be of the same diameter or a larger diameter than the old pipe thus allowing an increase in service capacity as well as avoiding the creation of a new utility location in the public right-of-way. An allied technique involves a microtunneling-type machine that grinds up the existing pipe rather than breaking and displacing pipe fragments.

While man-entry tunneling techniques pre-date Roman times and pipe jacking techniques were introduced around the turn of the last century, the rapid development of trenchless technologies has occurred in the last two decades. The increasing problems of both new installation and repair of urban utility systems have provided the impetus for innovation, and the relatively small scale but large number of projects has allowed a wide range of innovations to be tried on an incremental basis by small as well as large companies. Techniques have been developed in different areas of the world depending on local needs and innovations. Once developed, however, the techniques can be readily exported to other countries due to their significant reliance on know-how and experience in use and the relatively small-scale of many equipment items.

IMPLICATIONS OF TRENCHLESS TECHNOLOGY DEVELOPMENT

Social costs

An urban area requires the provision of many services to businesses, homes and public facilities. These services may include water, sewer, electricity, gas, telephone, other cable services, district heating and district cooling. Most of these services are placed underground and most beneath public streets and highways. Placement of these utilities underground offers the provision of large service networks more or less invisibly across the urban area and provides physical and environmental protection for the services.

Problems with underground services appear when further work is required on the system in order to make new connections, provide a system expansion, or carry out utility repair, replacement or renovation. The need for street access for installation and repair of utilities provides a continuing interplay between the needs for utilities to be installed and maintained and other public interests in:

- the minimization of the total societal costs of utility work
- the effective management of the public space beneath public rights of way
- the mitigation of traffic congestion
- the management of total life-cycle costs of street and highway pavements

The difficulty of excavating around existing utilities and the societal impacts (traffic congestion, loss of business, noise, etc.) of open-cut work in busy streets are fueling the interest in trenchless alternatives [10] and the continual improvement in the technologies themselves and their relative cost add to their growth [11]. Trenchless techniques typically do not have as strong a relationship of cost to depth of installation and hence become competitive on a first cost basis as the depth of installation increases. When the societal impacts of open-cut work are properly costed, they become the technique of choice in many more situations [12,13].

Thus, in order to lower the overall cost to the public of maintaining both utilities and road pavements, it is necessary to have a means of estimating the cost of different levels of street or highway occupance for the utility work and the statistical impact of a road cut on the life cycle cost of a pavement. When calculated or established, these indirect costs can be applied to utility construction or repair decisions in the same way as congestion costs and accident costs are applied to current highway alignment decisions -- the savings to society are included in the decision-making process for the selection of alternatives even though the costs are not directly paid by the agency making the decision. The procedures for doing such analyses are well established but, for some of the indirect costs, the database currently is insufficient to establish the necessary correlations between differences in construction or repair procedures and specific indirect costs.

Urban Underground Space Planning

If underground facilities are to provide the most valuable long-term benefits possible, then effective planning of the underground resource must be conducted [14]. Unfortunately, it is already too late for the near-surface zones beneath public rights-of-way in older cities around the world. The tangled web of utilities commonly found is due to a lack of coordination and the historical evolution in utility provision and transit system development. The underground has several characteristics that make good planning especially problematical:

- Once underground excavations are made, the ground is permanently altered. Underground structures are not as easily dismantled as surface buildings.
- An underground excavation may effectively reserve a larger zone of ground required for the stability of the excavation.
- The underground geologic structure greatly affects the types, sizes, and costs of facilities that can be constructed, but the knowledge of a region's subsurface can only be inferred from a limited number of site investigation borings and previous records.

- Large underground projects may require massive investments with relatively high risks of construction problems, delays, and cost overruns.
- Traditional planning techniques have focused on two-dimensional representations of regions and urban areas. This is generally adequate for surface and aboveground construction but it is not adequate for the complex three-dimensional geology and built structures often found underground. Representation of this three-dimensional information in a form that can readily be interpreted for planning and evaluation is very difficult.

Utility planning issues related to trenchless technologies

There are potential problems that may derive from the widespread adoption of trenchless techniques. These are mostly long-term and avoidable with good planning. For example, trenchless installation techniques for cables and conduits allow new systems to be installed relatively easily by passing beneath existing systems and, for safety reasons, it is often prudent to allow significant clearance to existing systems. This will lead to a tendency for utility systems to gradually occupy larger and larger zones of the urban underground and to follow curved rather than straight alignments. The privatization and duplication of utility systems that is occurring in many countries also increases the pressure on available underground space and could accelerate this trend.

Over time, this spreading use and less predictable location will affect the cost and feasibility of installing later utilities or other urban systems such as transit and road tunnel systems or urban underground space for commercial or service purposes. To avoid these problems and to take full advantage of the characteristics of trenchless installation and repair will require more comprehensive planning of how underground utility systems are to be provided in urban areas than has been the case in the past. For example:

- Deeper microtunneled sewers may reduce the capital and operating cost of more frequent pumping stations.
- Trenchless installations may allow alternate and shorter alignments for utility lines with fewer manholes caused by directional changes.
- Many operational problems with utility systems come from the main line/lateral connection layout of most utilities. Although initial costs may be higher, alternate layouts such as the "Berlin" system [1] (where connections are made only from manholes along the main line) allow full trenchless construction, reduce the incidence of problems in the system and allow trenchless repairs/replacements to be made without excavation at each lateral connection.
- Grinder pumps and pressure/vacuum sewers allow non-gravity systems and allow a wider variety of trenchless installation techniques to be considered.
- Stronger planning guidelines are needed to avoid unnecessary and haphazard use of underground space in urban areas -- space reservation for future facilities and better record keeping is necessary.
- Utility installation and repair projects need to be designed on the basis of the overall cost of doing the work -- not just the cost to the unit or utility doing the work.

Utility planning issues related to the value of space beneath public-rights-of-way

Use of the underground in the past has been based mostly on a first-come, first-served basis with principal attention focused on minimizing the cost of that increment of underground development. Space allocation for shallow utilities beneath roadways is practiced (e.g. [15]), but examples of more comprehensive utility planning are more difficult to find.

Does the fact that public agencies and utilities do not have to pay for utilizing the public space beneath rights-of-way mean that the space should be administered as if it has no value and no impact on the long-term development of the urban area? In effect, this is what often happens at present -- current projects to be placed beneath streets are laid out and constructed on the basis of avoiding existing utilities, maintaining access for future repair, minimizing damage to boulevard trees, and where possible following utility layout corridors which have been set up to reduce future utility conflicts and accidental damage due to unknown location. It is desirable to build underground facilities as cheaply as possible so that they can be used economically to solve urban problems. If no value is assigned to space underground, however, there are none of the normal economic pressures to help rationalize the appropriate use of the underground and minimize the volume of this resource usurped by individual uses [16]. These issues present difficult problems to resolve, especially in older portions of cities with narrower streets and a longer history of utility development. The nature of the decisions currently made however do not consider substantially alternate uses of the space which may be desirable later in the growth of the urban area.

Land in most countries of the world is available for private ownership. Also, in most countries, ownership of the land surface carries with it ownership of the underground region beneath and ownership of the air space above the specified surface land area. A survey of the legal and administrative controls on the use of underground space carried out by the International Tunnelling Association found that, with a few notable exceptions, most countries had similar laws governing the ownership and regulation of underground space [17].

Although such issues surrounding property rights for underground space are important, the principal issue of concern in this paper is whether underground space beneath public rights-of-way has its own intrinsic value which should be taken account of in decisions about how such space should be used for the public "good."

The monetary value of most land and other resources in free market economies is determined by the price at which the resource will trade. The value is affected by the desirability of a particular location, the economic potential of the land or its location and the effect of any government restrictions or incentives which may affect the use of the land. Since the public land used for street and highway right-of-ways is seldom traded, its value is usually not as readily determined. However, one can assume, in general, that as the value of tradeable land increases, the intrinsic value of adjacent public or non-tradeable land also increases (this relationship being modified by the extent to which the public land is necessary for access, service or amenity to allow the private land to hold its value) [13].

In dealing with the efficient use of surface land resources, the World Bank [18] has noted:

- "Land price increases in a growing city with fixed land area are necessary for the efficient allocation of space."
- "The waste of space or land in inefficient allocation carries with it a loss of "opportunity cost."
- "The critical attribute of land that distinguishes it from most other resources is that, with minor exceptions, it is non-reproducible..... Hence there is the desiderata that land should be employed in its most valuable use."

Likewise, if the value of underground space is not considered in cost-benefit analyses involving underground facilities, the analyses may not provide the optimal solution among several alternatives or the correct answer to whether a project has a net benefit or cost. Of particular relevance to utility placement is that more of the resource of underground space may be consumed than is justified when there are competing technologies or configurations available which use less underground space overall or less valuable underground space at greater depths. In the absence of strict planning controls, the treating of underground space as a "free good" can and has resulted in a chaotic use of the underground. In Tokyo, city planners are looking to layers of underground space at depths of 50 m or more to find zones which are clear enough from existing structures to allow substantial new infrastructure facilities to be built. Perhaps, as in all major cities, this need to go deep for new facilities could be mitigated with better long-range planning and better accounting of the value of the resource usurped by earlier structures.

CONCLUSIONS

The growth in the use of trenchless technologies in utility construction and repair and the variety of urban underground facilities poses a number of important issues for planning of the urban underground. The future implementation of better utility planning practices will require the acceptance of these concerns and principles for social cost evaluation by utility engineers and those responsible for the care and use of streets and highways. More data is needed in some instances to fully apply the methods for valuation of social costs and underground space value, e.g. the impact of utility work on the life-cycle cost of a road pavement, but, in general, the principles and contracting practices necessary to incorporate such factors into decision-making already are established.

These issues should be addressed now before the tangled maze of utilities now present beneath just beneath our streets extends to much greater depths beneath our urban areas.

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