	TRENCHLESS TECHNOLOGIES RESOURCE CENTRE	
iSTT INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY	TRENCHLESS TECHNOLOGY OVERVIEWS	THIRD EDITION
	COSTS AND ENVIRONMENTAL IMPACT	LAST UPDATED JUNE 2009

1. INTRODUCTION

This section provides information on the costs of trenchless technology and the impact of the technology on society and its environment. "What is the Cost relative to conventional methods?" is the most frequently raised question by potential trenchless users, but unfortunately it is also the most difficult to answer. The total cost of a pipeline rehabilitation/renewal project can be divided into components as shown in the following table.

COST CATEGORY	COST PAID BY	Examples	
DIRECT	OWNER	CONTRACTOR COSTS	D1
		ENGINEERING	D2
		BIDDING COSTS	D3
		CONTRACT MANAGEMENT	D4
INDIRECT		COMPENSATION CLAIMS CUSTOMERS	I1
		COMPENSATION FOR CONTINGENT DAMAGE TO PROPERTY	I2
SOCIAL/ ENVIRONMENTAL QUANTIFIABLE	SOCIETY	TRAFFIC DELAY	S1
		BUSINESS DISRUPTION	S2
		ACCIDENT COSTS	S3
		POLLUTION	S4
SOCIAL /ENVIRONMENTAL NON QUANTIFIABLE		ENVIRONMENTAL IMPACT	S5
		QUALITY (OF LIFE)	S6

The main problem in discussing and comparing costs is to define which of these components has been included. The second problem is the time scale over which the costs are to be considered. The simplest and most commonly used approach is to consider only the owners costs on a short term current expenditure basis. However modern asset management practice strongly recommends Life Cycle Costing (LCC), in which costs are assessed over the expected lifetime of the asset. This approach can be used to select rehabilitation/renewal options by comparing the life cycle cost implications of each option, then selecting the one that gives the best Net Present Value (NPV) after applying an appropriate discount rate. However, if the aim is to make a fair comparison between open cut and trenchless options, the analysis **must** make proper allowance for social costs and environmental impacts. In practice, this level of sophistication is rarely achieved, and in most cases selection of rehab/renewal method is based on comparison of short term direct costs. Fortunately in markets with reasonable volumes of work even this comparison favours trenchless technologies in most circumstances.

Cost estimates for rehabilitation activities can be obtained from a wide range of sources including:

Rehabilitation Contractors	Contractors providing such preliminary cost estimates will always be concerned that such estimates will be used by the client as a firm benchmark for future bids. They inevitably reflect the contractor's particular technology preferences and past experiences
Consulting Engineers	Consulting Engineers obtain price data from a wide range of internal and external sources and the value and validity of such estimates depends on the quality of the information source
Experience of other owners on similar projects	Can be very valuable providing projects are truly comparable.
Published papers	Many papers presented at trenchless technology conferences contain details of both estimated and achieved costs
Published Cost surveys based on bid analysis	Examples are the annual review of North American bid and achieved cost data prepared by Louisiana Trenchless Technology and occasional surveys by Canadian research bodies.
Cost models from independent consultants/research bodies	Example is cost model provided to UK utilities by Water Research Centre (WrC)
Data from utility regulators etc	Example is benchmark data and cost report issue by UK water regulator OFWAT.

Further information on direct and indirect costs can be accessed using the Guidelines below, published papers and literature.

For more detailed Guidelines covering Direct and Indirect Costs click more>

Return to Overview ▲

2. SOCIAL COSTS AND ENVIRONMENTAL IMPACT

These are costs which arise as a direct consequence of the rehabilitation/renewal works but which are borne by society as a whole rather than the individual utility. Social costs arise from the impact of utility works on society and the environment, as illustrated in the table in the introduction section above. Various estimates of the overall cost of these impacts have been made with the most recent assessment of social costs in the UK being in the order of **twice the sum of the actual direct and indirect costs borne by the utility.**

Whilst most utilities agree that use of trenchless technologies can substantially reduce these social costs and environmental impacts, they frequently argue that it is impractical to include such social and environmental costs in the selection and bid evaluation process.

Social costs are just one aspect of the Environmental impact of pipeline installation and rehabilitation. The status of trenchless technologies in terms of Environmental Sustainability, Carbon Footprint (Impact on Global Warming) and related concepts are considered in detail below.

For more detailed Guidelines covering Social Costs click more>

Return to Overview ▲

iSTT INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY	TRENCHLESS TECHNOLOGIES RESOURCE CENTRE	
	TRENCHLESS TECHNOLOGY GUIDELINES	THIRD EDITION
	DIRECT AND INDIRECT COSTS-PUBLISHED INFORMATION	LAST UPDATED JUNE 2009

1. DIRECT COSTS

Direct Costs are borne by the utility owner and usually include:

A. Planning, Design and Supervision.
B. Payments to contractors and suppliers.
C. Diversion of flows and/or provision of temporary service.
D. Permanent reinstatement of excavations.

Direct costs are the most easily measured and compared component of overall costs, but there is still plenty of room for confusion over what is and is not included in a published cost. Table 1 (below) provides an example check list of activities which should be included in direct cost assessments for both sewer and water main rehabilitation.

Return to Overview ▲

2. INDIRECT COSTS

These generally include any additional costs associated with a contract which are borne by the utility and included in the final bid evaluation typical examples are:

A. Compensation for damages paid to other utilities and the owners of property and land.
B. Compensation paid to local businesses for loss of profits.
C. Compensation paid to customers for any excessive service interruptions.

These costs are sometimes difficult to assess in advance of the contract, but it is clear that all of these items should be significantly less in the case of trenchless technologies due to the reduction in collateral damage and disruption.

It should be noted that in many published papers, indirect costs are used to describe all additional costs which are not included in direct costs but which can be quantified. This may include some of the social costs described below.

TABLE1 – CHECK LIST OF DIRECT COST ITEMS IN REHABILITATION PROJECT

Activity	Tasks	Open cut Replacement	Trenchless off line	Trenchless on line	Renovation sewer	Renovation water mains –non structural	Renovation Water Mains- Structural
Project Planning and Design		√	√	√	√	√	√
Pipe condition assessment					√	√	√
Site and Route Investigation		√	√	√	√	√	√
Bid Preparation and Management		√	√	√	√	√	√
Contract Management		√	√	√	√	√	√
Preparation	Access Pit excavation		√	√		√	√
	Establish bypass			√	√		
	Establish temporary services			√		√	√
	Removal of fittings			√		√	√
	Cleaning and CCTV			√	√	√	√
Rehabilitation Process	Pipe/Liner supply and installation	√	√	√	√	√	√
Completion	End seals and fittings			√			√
	Reconnection	√	√	√		√	√
	Inspection and Test	√	√	√	√	√	√
	Backfill and Reinstatement	√	√	√		√	√
	Re-commission					√	√

Return to Overview ▲

3. SOURCES OF COST INFORMATION

The main sources of information on costs are summarised in the table in the Introduction section. The most common method used by utilities, is to ask an 'expert'. Unfortunately, the information provided by such experts, often reflects their preferences for a particular technology. In addition, rehabilitation/renewal contractors are always concerned that the price provided on the basis of limited information will be used by the client as a benchmark for future bids. The best source of all is the experience of other utilities that have performed similar work.

There are also a number of published documents available, via the web. A bibliography (available through ISTT, Email: info@istt.com), conference papers, and other published documents, which provide cost information.

Return to Overview ▲

4. EXAMPLES OF PUBLISHED COST DATA

The main problems in comparing costs between different regimes are related to activities such as engineering, planning and condition evaluation which may be carried out by the owner, but are not included in the contractor's perception of costs.

This has led to the concept of Standard Costs which are prepared using an agreed protocol and a common set of assumptions, and are frequently used to benchmark utility companies in terms of relative performance. One of the most extensive and widely publicised examples of this approach can be found in the publications of OFWAT, the organisation responsible for the regulation of the UK privatised water industry.

4.1 OFWAT STANDARD COSTS

OFWAT has developed a standard cost and benchmarking process to monitor the maintenance and rehabilitation performance of the water companies in England and Wales. Standard Costing procedures for a wide range of activities have been agreed with the Companies, which then report the costs to OFWAT on an annual basis.

The histogram below shows a typical set of costs after adjustment by OFWAT and typically exhibiting a 2:1 ratio between the highest and lowest. The benchmark cost is determined by OFWAT, and is a cost which should be achievable by all the companies if they work efficiently.
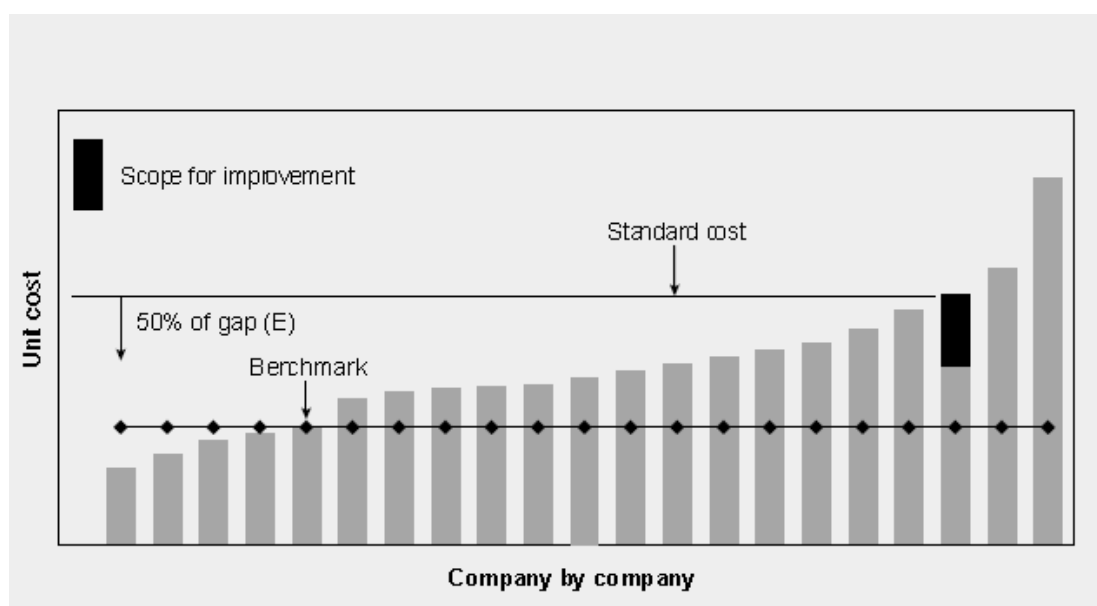
The Table below lists benchmark costs for a range of diameters and rehabilitation/renewal methods, including open cut replacement in grass verge, suburban highway and urban highway locations. The table also shows the cost differences between HDD and open cut in all three locations, and between the other rehab/renewal technologies and urban open cut. It can be seen that the trenchless methods are cost competitive in most situations.

	OFWAT BENCHMARK COSTS UKP/METRE					
DIAMETER mm	100	150	200	300	450	600
open cut grass(ocg)	28	36	41	62	132	179
hdd grass	35	47	66			
cost inc/dec %	20%	23%	38%			
open cut suburb	77	89	102	140	197	262
hdd subrb	40	52	71			
	-93%	-71%	-44%			
open cut urban	91	101	114	153	232	314
hdd urban	41	53	73			
	-122%	-91%	-56%			
epoxy spray lining	38	45	36	44		
	-58%	-55%	-68%	-71%		
close fit sliplining	52	63	53			
	-43%	-38%	-54%			
pipe bursting	41	49	51			
	-55%	-51%	-55%			
sliplining (insertion)	33	40	52	66	120	
	-64%	-60%	-54%	-57%	-48%	

Detailed study of the OFWAT Benchmark costs provides an interesting insight into the variability of costs within and between utilities, contractors and locations. The absolute values are, of course, specific to the purposes of OFWAT, but the relationship between the costs of Open Cut Replacement, and the various trenchless technologies are probably of wider validity.

DIAM	cement mortar lining	Epoxy Spray Lining (PU Lining costs similar)		pipe bursting		Sliplining	
MM	Apr-98	Apr-98	Mar-01	Apr-98	Mar-01	Apr-98	Mar-01
80	51	38	34.69	47	44.81	44	50.64
100	52	39	38.58	52	49.83	47	56.32
150	53	43	46.8	63	60.45	55	68.32
200	55	46	53.67	78	69.33	65	78.35
250	56	50	59.69	96	77.1	76	87.14
300	58	54	65.11			90	95.05
350	59	58	70.07			105	102.29
400	61	63	74.67			124	109
450	63					146	115.29

Return to Overview ▲

4.2 COSTS BASED ON ANALYSIS OF BIDS

In both the UK and USA, cost models based on analysis of project bid data are available. In the UK these are produced by the Water Research Centre (WRc) and are issued privately to the utilities. Many utilities then modify the basic model to suit their own circumstances. A typical set of costs is listed in the table below, and, as might be expected, these are comparable with, but not identical, to the OFWAT costs.

In the USA, bids submitted by contractors for public tenders are published, and are easily accessible. The Trenchless Technology Centre at Louisiana Tech (LATECH) publishes a regular analysis of all the bids related to municipal pipelines. The data is presented in graphical form, by plotting each bid against the diameter of the pipe, for each technology. A curve fit is then performed on the data, and the best fit equation is then derived. In each case, the analysis is performed for all bids, and also for those bids which won the contracts. Some typical costs for open cut and some trenchless technologies are tabulated together below with the parameters of the curve fit in each case. The data used is from the 2003 survey, and more recent data is directly available from LATECH.

The curve fit equations are of the form:

UNIT COST = $KD^{M.} + C$

Where D = Diameter in inches and K, M, and C are curve fit constants

	K	M	C	D MIN	D MAX	6	12	24	36	48
OPEN CUT	0.6	1.5	76	4	96	85	101	147	207	278
CIPP	0.77	1.5	25.9	6	108	37	58	116	193	282
SLIPLINE	0.71	1.5	40.1	6	120	51	70	124	194	278
HDD	0.31	2	32.9	2	42	44	78	211	435	
FOLD AND FORM	0.48	1.5	39.6	6	16	47	60			
DEFORM REFORM	0.38	1.5	20.4	8	12	36				
SPIRAL WIND	0.34	1.5	57	14	18					
BURST HYDRAULIC						26	82	171		
BURST PNEUMATIC	2.63	1.25	30.3	6	24	55	89	170		
BURST STATIC	0.67	1.25	79.52	6	20	85	93	114		
SPRAYED	5.16	0.75	13.6	8	20000	48	57	80	99	117

The data is presented as a ratio between the unit cost of the various technologies, and the cost of Open Cut, at the same diameter. Once again, it is apparent that trenchless techniques are directly competitive with Open Cut in most circumstances.
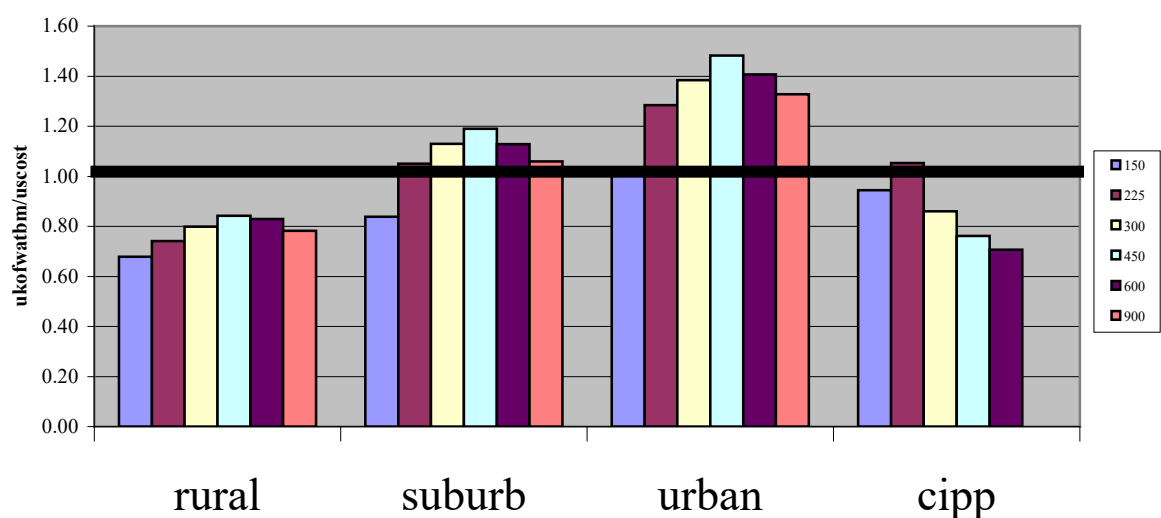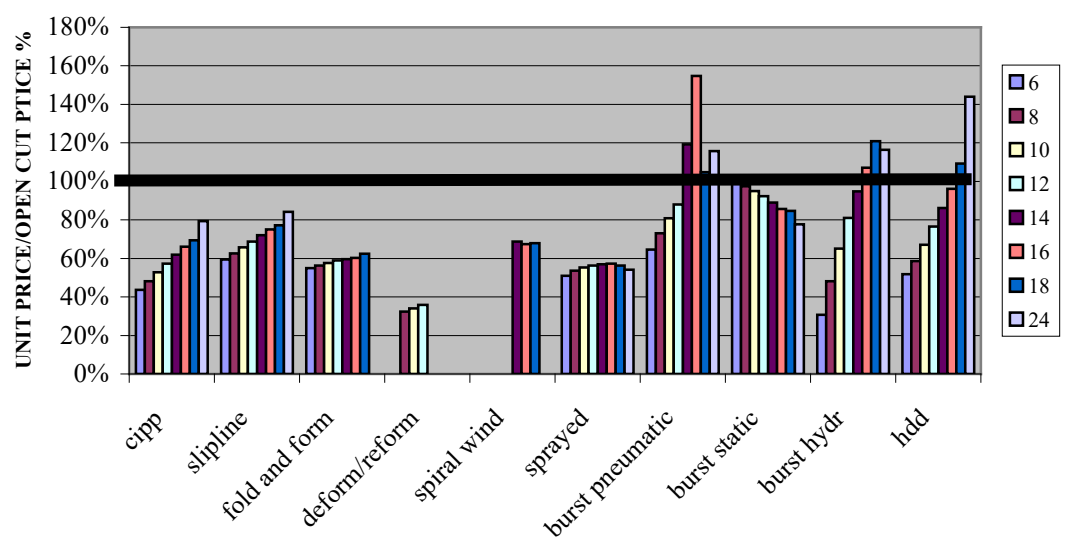
Return To Overview ▲

5. COMPARISON OF COSTS

It is interesting to compare the costs, from OFWAT and LATECH. Care is needed, because the majority of the OFWAT costs are related to water mains, whereas, the LATECH costs are mainly for sewers. The only area of direct overlap is between the OFWAT open cut, and CIPP sewer costs, and the equivalent costs from LATECH. The US costs, have been converted from $/ft, to GBP (£)/metre, using an exchange rate of 1.82. The results are shown below, which compares the ratio between the costs for different technologies and diameters. Surprisingly, the costs are very similar, although, in view of the many variables involved, this is almost certainly, a coincidence. More normally, comparison of costs between different countries is of little significance.
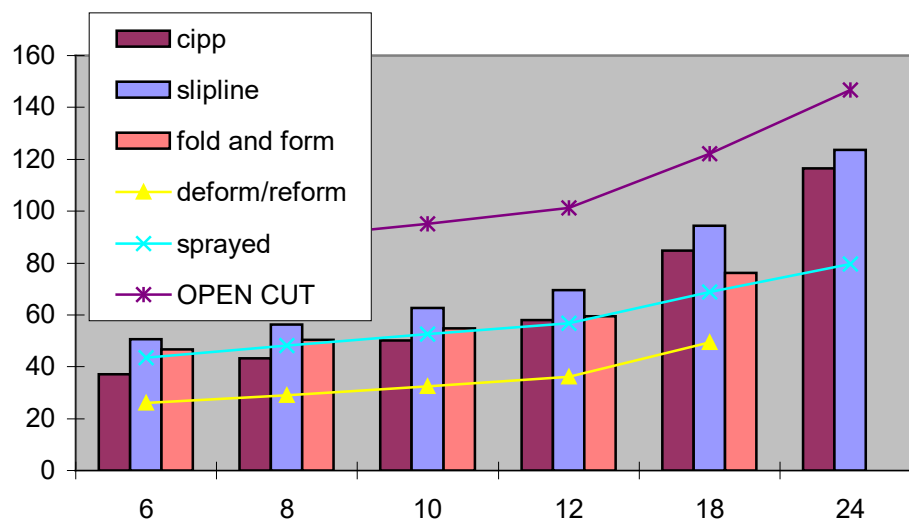
LATECH BID DATA 6 TO 24 IN

A number of recent papers comparing the costs of various rehabilitation options can be found in (Nashville 2006), (Rome 2007), (San Diego 2007) and (Moscow 2008)

Return to Overview ▲

	TRENCHLESS TECHNOLOGIES RESOURCE CENTRE	
iSTT INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY	TRENCHLESS TECHNOLOGY GUIDELINES	THIRD EDITION
	SOCIAL COSTS AND ENVIRONMENTAL IMPACT AND SUSTAINABILITY	LAST UPDATED JUNE 2009

1. INTRODUCTION

It has long been accepted that the open trench approach to the installation of utility infrastructure is capable of causing major disruption to commerce and the general public. Indeed, this was one of the motivating factors for Ted Flaxman when he chaired those historic meetings in London in 1985 that heralded the birth of the ISTT. No doubt he believed that the new Society would rapidly find a means of assessing the financial impact of such disruption, so that it could be incorporated in the bid process. However, 21 years later, as these guidelines were being drafted, the following comment was made in a paper by Pucker, Allouche, and Sterling delivered at the 2006 North American, No Dig Conference in Nashville,

"For the most part, social costs are not considered during a construction project's planning, design and bid evaluation stages, because they cannot be calculated using standard estimating methods. In recent years efforts have been made to introduce approaches for predicting social costs associated with utility construction projects. Nevertheless, unit cost data needed for the verification of such prediction methods is lacking."

The efforts referred to in this extract, are chronicled in numerous papers presented over the years at No-Dig Conferences, and listed in papers and the Bibliography available from ISTT (Email: info@istt.com). As will be seen later, social costs are now seen as just one component of the overall environmental impact of utility works. Fig 6.1 summarises some of the main impacts, and it can be seen, that in addition to the immediate impacts associated with the works, there are some broader issues. These are generally considered in an overall assessment of the ENVIRONMENTAL SUSTAINABILITY of a product, or process, which is considered in a subsequent section of this document.

Return to Overview ▲

HISTORY

The first serious attempt to assess the magnitude of the disruption associated with open cut utility installation was made by Thomson et al, in conjunction with the UK Transport and Road Research Laboratory [TRRL]. Based on observations of a number of contracts, it was concluded that social costs could be more than double the direct costs of an installation, and that the cost to society in the UK, was at least GBP (£) 2.1 billion per annum. This figure has been frequently quoted, although, some argue it is a gross exaggeration. This project was intended to be the catalyst for a mass of new legislation aimed at encouraging the use of trenchless methods. This included such innovations as charging contractors for road occupancy, and for the extent of open trench used. Unfortunately it coincided with the privatisation of the UK Water Industry, and the legislation became a victim of politics.

In spite of all the detailed research carried out in the ensuing twenty years, there is still considerable controversy in the UK and many other countries. The benefits of trenchless methods in reducing

disruption are widely accepted. However, there is still no agreement over the magnitude of social costs, and the best means of incorporating them in the bid process.

The paper quoted earlier, provides an excellent summary of the status of this endeavour, and is partially summarised below.
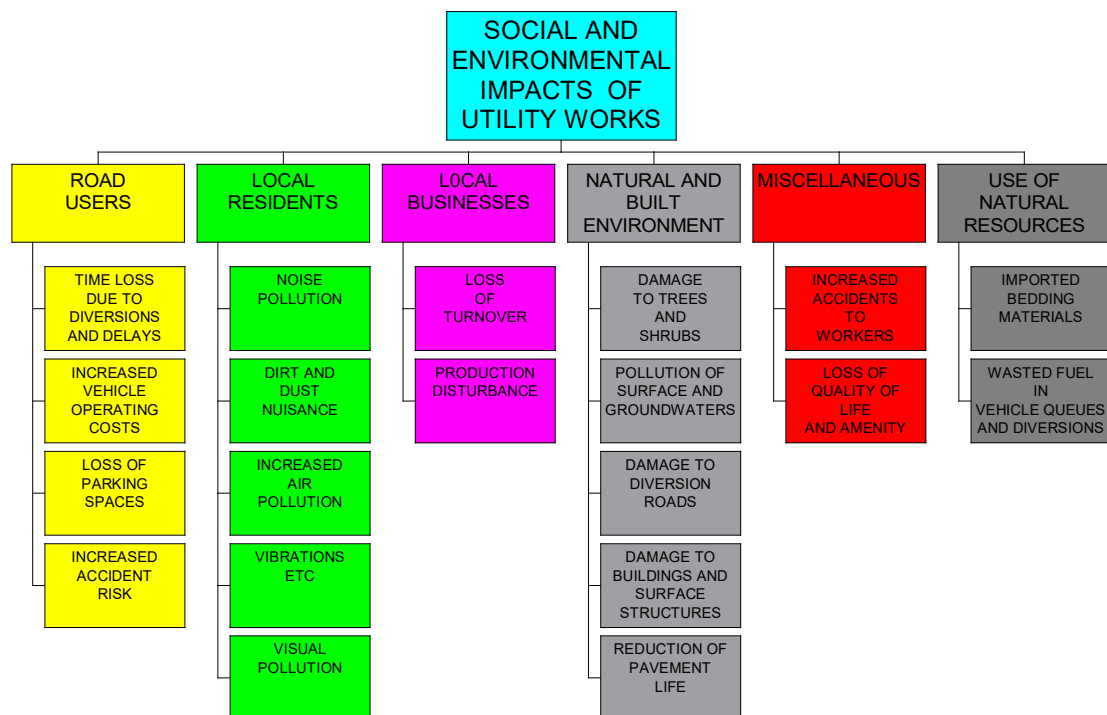
SOCIAL COST CATEGORIES

Social cost categories related to construction work are numerous. The case histories reported in the paper considered the following eight social cost categories:

1. *Travel delay*: Utility construction work can cause significant traffic delay due to lane closures or complete road closures. Pedestrians also can be forced to detour because of lane closure and other construction activities.
2. *Vehicle operating costs*: Longer travel distances and stop-and-go traffic induce higher vehicle operating costs. For example 1,000 speed changes from 50 mph to 15 mph and back to 50 mph cause an additional fuel consumption of 12.2 gallons for light duty vehicles. (Budhu and Isely, 1994).
3. *Decreased road surface value*: Open excavations can result in pavement deformations and asphalt cracking at the edges of the trench, which leads to an accelerated degradation of the pavement. Reduction in useful pavement life to due an open-cut excavation is estimated to be as high as 30% (Tithe, et al, 2002).
4. *Loss of trade*: Construction zones can decrease the accessibility to businesses due to congested traffic conditions, blocked parking spaces and barriers from the construction site itself. On one hand businesses lose customers, who prefer to go to more convenient places, while on the other hand businesses depending on deliveries may have problems with their supplies.
5. *Loss of parking spaces*: Loss of parking spaces leads to a decreased parking meter revenue for the city and lower revenues from parking fines.
6. *Cost of dust control*: Open excavations result in a significant amount of dust in their surrounding. Cleaning needs, and thus costs, increase. Also the quality of life for people living near the construction zone decreases.
7. *Noise pollution costs*: The use of heavy construction equipment results in a higher noise level in the vicinity of the work area. In addition construction work may lead to a higher noise pollution due to changing traffic conditions compared to the 'normal' situation.
8. *Worker safety*: Open trenches pose a higher risk to workers and pedestrians than trenchless technologies. Accidents related to trenching are about 112% higher than the average value for construction work in general. Each year more than 60 workers are killed in trenching accidents (Jung and Sinha, 2004).

FIG 6.1

SOCIAL AND ENVIRONMENTAL IMPACTS OF UTILITY WORKS

ROAD USERS	LOCAL RESIDENTS	LOCAL BUSINESSES	NATURAL AND BUILT ENVIRONMENT	MISCELLANEOUS	USE OF NATURAL RESOURCES
TIME LOSS DUE TO DIVERSIONS AND DELAYS	NOISE POLLUTION	LOSS OF TURNOVER	DAMAGE TO TREES AND SHRUBS	INCREASED ACCIDENTS TO WORKERS	IMPORTED BEDDING MATERIALS
INCREASED VEHICLE OPERATING COSTS	DIRT AND DUST NUISANCE	PRODUCTION DISTURBANCE	POLLUTION OF SURFACE AND GROUNDWATERS	LOSS OF QUALITY OF LIFE AND AMENITY	WASTED FUEL IN VEHICLE QUEUES AND DIVERSIONS
LOSS OF PARKING SPACES	INCREASED AIR POLLUTION		DAMAGE TO DIVERSION ROADS		
INCREASED ACCIDENT RISK	VIBRATIONS ETC		DAMAGE TO BUILDINGS AND SURFACE STRUCTURES		
	VISUAL POLLUTION		REDUCTION OF PAVEMENT LIFE		

Other factors that could be considered as being a Social Cost by nature include:

a)   The use of material and energy resources to extract the base material used.
b)   The use of energy to convert the materials to their final form.
c)   Pollution and safety hazards arising from these activities.
d)   Quantity and disposal of waste.
e)   Impact of the use of the product or process on all aspects of the human, natural and built environment (The issues normally included in social costs).
f)   Impacts arising from the operation of the product or process over its working life.
g)   Impacts arising from disposal – recyclabiliy.

Return to Overview ▲

In 2000, the ISTT began collaboration with UNEP (United Nations Environmental Program). The background to this is summarised below using information extracted from various UNEP documents

1. **ABOUT UNEP/IETC…**
    a. IETC is part of the UNEP Division of Technology Industry and Economics (DTIE)
    b. IETC's mandate is the promotion and transfer of Environmentally Sound Technologies (ESTs) to developing countries and those with economies in transition

2. **UNEP/IETC ASSISTS DECISION MAKERS BY:**
    a. Identifying and helping to solve water and urban related environmental problems
    b. Developing tools and techniques to assist in the identification, selection and use of appropriate ESTs
    c. Promoting implementation of environmentally sound technologies (ESTs) and better practices
    d. Activities focus on water and urban environmental issues

3. **THE NEED FOR NEW APPROACHES**
   a. Past environmental problems have arisen primarily because of inappropriate management and a lack of understanding of the impact of management practices upon the environment.
   b. New management methods and tools must be developed and applied.

4. **SUSTAINABLE DEVELOPMENT**
   a. Part of an integrated management and governance framework which addresses:
   b. The needs of the present without compromising the ability of future generations to meet their own needs (WCED 1987);
   c. Improving the quality of human life within the limits of supporting ecosystems (IUCN/UNEP/WWF 1991).

5. **THIS MEANS INTEGRATING:**
   a. Ecological imperative - living within the limits of global biophysical carrying capacity and biodiversity;
   b. Social imperative - ensuring that basic needs are met through democratic systems of governance and equity;
   c. Economic imperative - ensuring a vibrant economy based on eco-efficiency and sustainability.

6. **ENVIRONMENTALLY SOUND TECHNOLOGYESTS**
   a. Definition of Environmentally Sound Technologies (ESTs) is based on Agenda 21.
   b. … Arising from the 1992 United Nations Conference on Environment and Development (UNCED), also known as the Earth Summit.

7. **AGENDA 21 DEFINES ESTS AS TECHNOLOGIES WHICH:**
   a. Protect the environment;
   b. Are less polluting;
   c. Use all resources in a more sustainable manner;
   d. Recycle more of their wastes and products;
   e. Handle residual wastes in a more acceptable manner than the technologies for which they are substitutes.

8. **INHERENT TO THIS IS:**
   a. The improvement of technology currently used
   b. Its replacement with more appropriate environmentally sound technology, and
   c. Its consideration within the ecological and socio-economic context.

9. **ESTS AND SUSTAINABLE DEVELOPMENT IN THE CONTEXT OF POLLUTION ESTS ARE PROCESSES AND TECHNOLOGIES THAT:**
   a. Generate little or no waste
   b. Prevent or avoid pollution
   c. Control or treat pollution after it has been generated.

10. **NOT JUST INDIVIDUAL TECHNOLOGIES ESTS ARE ALSO TOTAL SYSTEMS THAT INCLUDE:**
    a. Know-how,
    b. Operating procedures,
    c. Goods and services, and
    d. Equipment, as well as
    e. Organisational and managerial procedures.

11. HENCE, THE TERM EST:
      a. Applies to all technology and its transition in becoming more environmentally sound
      b. Covers the full spectrum from basic technologies adjunct to the production system, to fully integrated technologies where the EST is the production technology itself
      c. Captures the full life cycle flow of the material, energy and water in the production and consumption system.

UNEP CHECKLIST OF CRITERIA FOR ENVIRONMENTAL SUSTAINABILITY

EST Criteria

Criteria are principles or standards against which something is judged. Appropriate criteria are needed to help guide the identification and selection of ESTs in a manner consistent with sustainable development objectives. Figures 4 and 5 each provide a checklist of selected generic criteria and indicators that can be used in assessing and evaluating ESTs. These checklists were developed by the UNEP/IETC Expert Group on Environmentally Sound Technologies as an initial working template in an effort to define the essential criteria and indicators for identifying and selecting ESTs. The checklist in Figure 4 provides environmental criteria and related indicators. Figure 5 provides a limited perspective on some of the relevant socio-economic indicators. IETC's immediate interest is to examine the relevance of the environmental criteria and indicators.

Figure 4:   *Proposed Checklist of Environmental Indicators for ESTs*
(Prepared by UNEP/IETC Expert Group on Environmentally Sound Technologies)

Criteria	Indicators	Yes	No	Quantitative Indicators (i.e., amount saved/spent and/or reduced/ increased)	Qualitative Indicators (i.e., based on potential local, regional and global impacts)
Technical Suitability	• Addresses fundamental scientific and engineering principles (i.e., laws of thermodynamics and reactivity) • Production or process yield • Contaminant removal rates or treatment efficiency • Potential for generation of secondary pollutants/by-products • Noise • Thermal losses and radiation emissions • Performance at different settings and different locations • Sensitivity to specific operating conditions • Reliability • Replicability • Potential for system failure • Profiling of risks and uncertainties				
Compliance with Regulations and Standards	• Quantity of waste generated (water, air and solids) • Quantity of waste controlled by environmental permits • Compliance with local and regional standards • Compliance with MEAs (i.e., POPs, Biosafety, etc.) and other internationally recognised standards (i.e., ISO, etc.) • Availability of reliable data • Part of a 3rd party assessment programme (i.e., Ecolabelling, ETV, etc.)				

Eco-Efficiency and Conservation of Biodiversity	• Useful life (in accordance with optimal performance specifications) • Efficiency of energy, water and materials use relative to the service provided • Lifecycle performance (i.e., overall GHG emissions throughout lifecycle) • Use of renewable resources • Incorporation of closed loop processes • Design for the environment • Cumulative air, water and waste emissions • Impact on ecosystems health & integrity (including biodiversity and ecological footprint)				
Protection of Water Resources	• Water use • Conservation of water • % use of recycled water • Wastewater treatment requirements • Level of treatment (primary, secondary, tertiary) • Overall water efficiency				
Optimisation of Materials and Energy Use	• Use of fuels and energy resources • Quantity of renewable resources • Quantity of non-renewable resources • % of recyclable and reused materials in the production process • Use of environmentally friendly materials • Use of locally sustainable resources • Duration of product use or useful life • Energy efficiency and savings • Overall efficiency of resource use				
Minimisation of Toxic Materials and Waste	• Quantity of waste (air, water and solids) • Quantity of toxic and hazardous waste used and generated • % of waste materials used as raw materials for other industries (i.e., based on industrial ecology and CASE principles) • Quantity of by-product recovered • Cost of pollution control abatement technology • Need for waste treatment and disposal • Ultimate disposal costs of unmarketable by-products and waste • Overall operations and maintenance cost				
Protection of Terrestrial Resources	• Space required for construction • Compatibility with immediate or adjoining facilities and systems • Transportation and materials flow requirements • Potential for soil contamination • Potential for geomorphology, landscape and ecohydrological impacts				
Protection of the Atmosphere	• Air emissions • Potential for long range transport of atmospheric pollutants • Potential for climate change impacts				

Figure 5: Proposed Checklist of Socio-Economic Indicators for ESTs
(Prepared by UNEP/IETC Expert Group on Environmentally Sound Technologies)

Criteria	Indicators	Yes	No	Quantitative Indicators (i.e., amount saved/spent and/or reduced/ increased)	Qualitative Indicators (i.e., based on potential local, regional and global impacts)
Financial Viability	• Capital investment • Return on investment • Payback period				
Operations & Maintenance Viability	• Management and labour costs • Expertise and skills requirements for operation and maintenance • Utilities cost (water and energy) • Cost of other consumables • Cost of pollution prevention and control • Cost of residuals management and solid waste disposal • Cost of environmental remediation and restoration • Cost of natural capital • Cost of environmental health and safety liabilities • Frequency of maintenance • Parts and service cost • Overall cost effectiveness				
Responsive to Local Needs and Benefits	• Public acceptance • Public health & safety risk • Social benefits • Cultural value • Employment • Use of local resources • Capacity building requirements				
Quality of Information	• Reliability of data • Existence of a QA/QC programme • Available comparisons to existing systems • Transparency of data collection and reporting • 3rd party substantiation				

The concept of Sustainability in Trenchless Construction is further explored and developed by (Ariatnam et al, Moscow 2008). Traditional performance indicators of construction projects have concentrated on Cost, Quality and Time. However sustainability assessment focuses on three issues

A Minimising Environmental Impact
B Maximising economic benefits
C Minimising Socio-cultural Impact

The relationship between these issues and the more traditional performance indicators is illustrated in Fig 1 below in which the authors define the Triple Bottom Line approach.
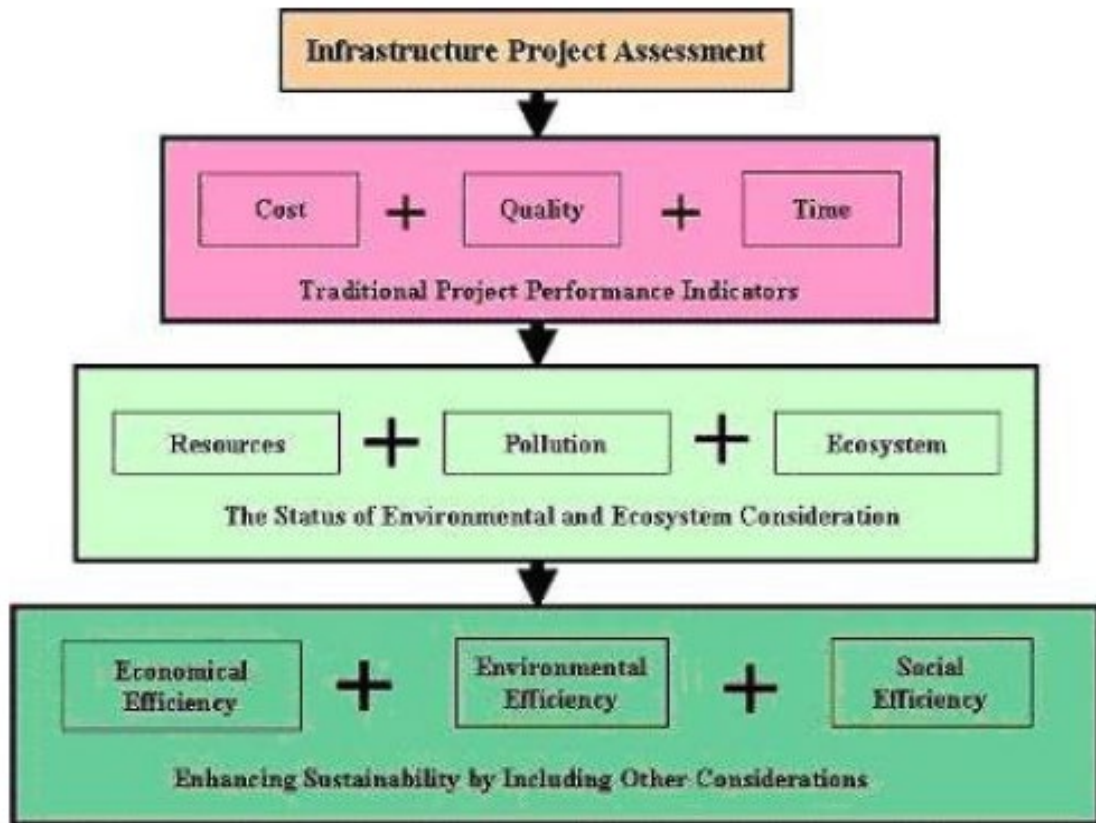
Figure 1: Triple Bottom Line Approach

The paper demonstrates the applicability of the sustainability concept using a case study of a water main replacement project with three available construction options:

A   OPEN CUT
B   PIPEBURSTING
C   HORIZONTAL DIRECTIONAL DRILLING (HDD)

The paper identifies six underlying issues which must be addressed as illustrated below The authors then describe a methodology for the assessment of the sustainability of under ground infrastructure practices using the Sustainability Assessment Model(SAM) which is also illustrated below
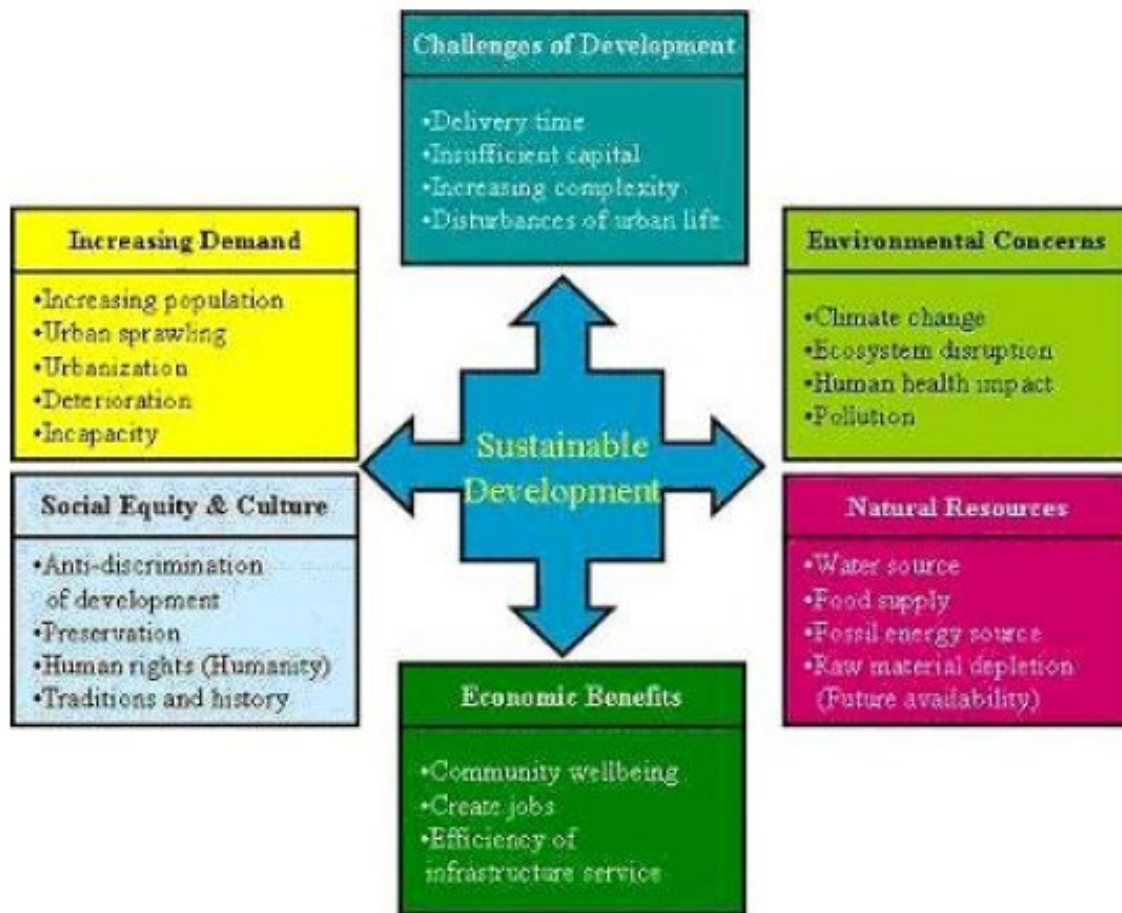
Figure 2: Issues in Sustainable Development
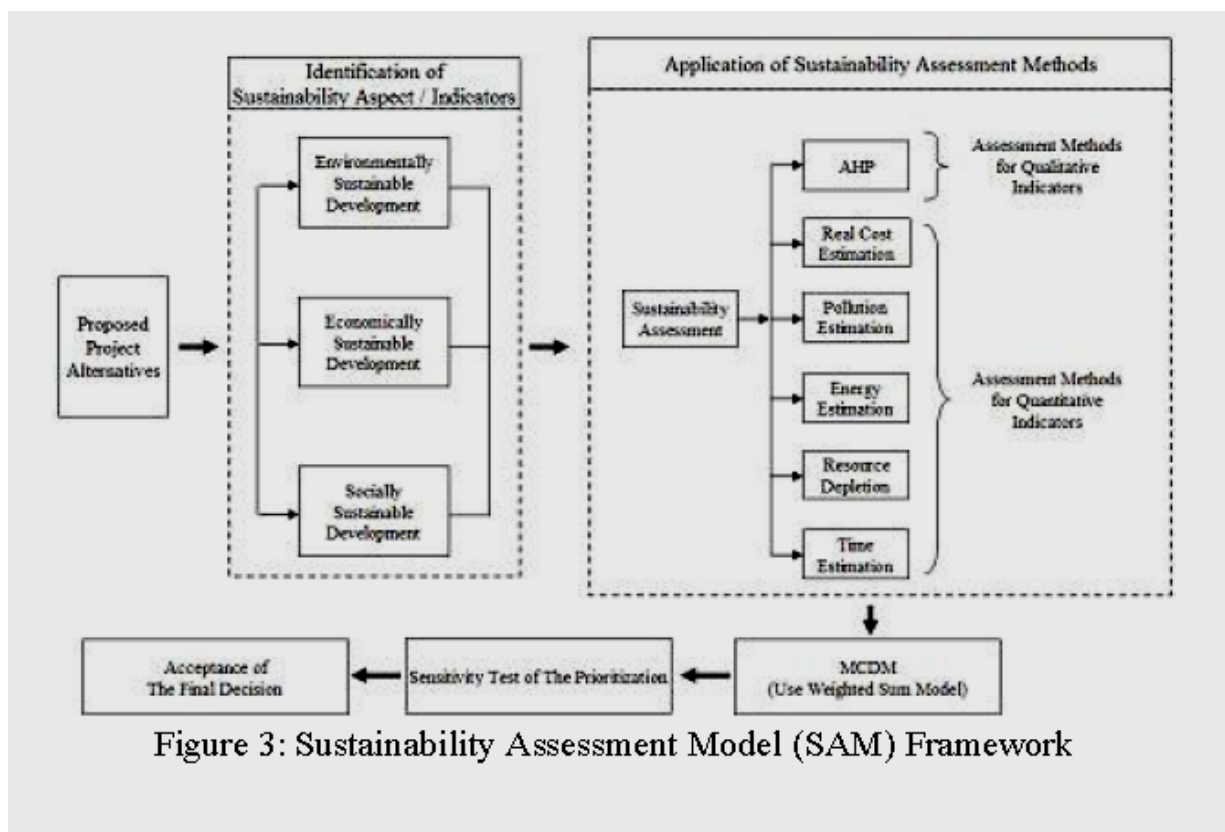
Figure 3: Sustainability Assessment Model (SAM) Framework

Description of Case Study and Options

807.7 m of existing 200 mm Diameter Asbestos Cement Water Main System is under capacity and needs replacement. The three alternatives considered are

1. New installation of Ductile Iron Pipe using conventional open cut methods
2. Replacement with HDPE pipe using Pipe Bursting
3. New installation of fusible PVC pipe using the HDD method

Pipe Bursting and HDD require significantly less excavation disruption and completion time than the open cut method

The assessment process consists of six modules namely

1. Analytic Hierarchy Process (AHP)
2. Real Cost Estimation
3. Pollution Estimation
4. Energy Estimation
5. Time Estimation
6. Natural Resource Depletion Impact analysis

AHP is a procedure in which relative weights are assigned to selected sustainability indicators to which quantitative assessments are then made for each criterion and installation option. The results are then aggregated to give an overall sustainability comparison of the options.

The Real Cost estimation is based on Life Cycle Costs for direct construction and indirect costs such as restoration, social costs and environmental remediation costs. The estimates made in this case study are tabulated below

COST ITEMS	ALT 1 (OPEN CUT	ALT II PIPE BURSTING	ALT III HDD
CONSTRUCTION MATERIALS (PIPE COST ONLY)	$53,000 ($65.6/m)	$62500 ($77.1/m)	$71550 ($88.6/m)
CONSTRUCTION METHOD installation, backfill, compaction	$159000 ($196.9/m)	$17250($213.3/m)	£265000 ($328.1/m)
RESTORATION (only asphalt concrete replacement	$36800 ($30/m)	$3000 ($30/m2)	$2500 ($30/m2)
RELOCATION AND ROW	n/a	n/a	n/a
SECURITY	n/a	n/a	n/a
MAINTENANCE,OPERATION ,REHABILITATION	n/a	n/a	n/a
ENVIRONMENTAL REMEDIATION	n/a	n/a	n/a
COST TOTAL	$248800	$237,750	$339,050

TIME ESTIMATION
The Construction schedule has a direct correlation with sustainability because it determines factors such as fuel consumption, air emissions and local disruption. This is a key factor when comparing open cut with trenchless technologies because the construction schedule of the latter is significantly shorter The life span of the completed infrastructure is also important because it determines return on investment

RESOURCE DEPLETION

Resource depletion analysis focuses only on non renewable natural resource consumption and its estimated depletion rate. The two plastic pipes in the case study, HDPE and PVC are made from petroleum feedstock . PVC consumes less petroleum feedstock than HDPE because 50% of the PVC product is chlorine which is derived from salt, a plentiful natural material. Ductile iron is made from raw iron which is readily recyclable and in plentiful supply and therefore has the least impact in terms of resource depletion. However this is not a significant factor in the present project due to the relatively small quantities of materials used.

ENERGY AND POLLUTION ESTIMATION

Assessment of energy consumption and pollution generation are both dependant on fossil energy consumption which is in turn dependent on the amount of work, production capacity and operational work hours for heavy equipment. The case study assumes that the only energy source for heavy equipment is diesel fuel and this is converted into an equivalent energy unit. Energy is also consumed in the extraction, transport, processing and use of construction materials and this is added to the fuel element to give the total energy requirement. Trenchless techniques consume far less energy than open cut due to the reduction in soil excavation and movement, backfill and compaction activities.

SUMMARY OF SUSTAINABILITY ASSESSMENT RESULTS

ASSESSMENT RESULTS	ALT1 (OPEN CUT)	ALT.II (PIPE BURSTING	ALT.III (HDD)
AHP	0.23	0.40	0.37
REAL COSTS ($)	$248,800	$237750	$339050
ENERGY CONSUMPTION GJ	1008	416	536
POLLUTION EMISSION KG			
NOX	111.2	67	135
SOX	343	55	146
C02	45793	28521	32978
CONSTRUCTION SCHEDULE (days)	56	10	10
RATE OF NATURA L RESOURCE DEPLETION	183	663	219

The eight assessment results given above are incomparable attributes which can only be treated individually so a multi-criteria Decision Making (MCDM) technique must be used in order to integrate the independent attributes into a single attribute for final prioritisation. In this case a Weighted Sum Model (WSM) was used to obtain the results tabulated below which confirm pipe bursting as the most sustainable option.

SUMMARYOF WEIGHTED SUM MODEL (WSM) RESULTS FOR FINAL SUSTAINABILITY PRIOITISATION

ASSESSMENT RESULT ITEMS	WEIGHT FACTOR	ALT I (OPEN CUT)	ALTII (PIPE BURSTING)	ALT III (HDD)
AHP	0.35	0.08	0.140	0.131
REAL COSTS ($)	0.25	0.118	0.132	0.000
ENERGY CONSUMPTION	0.10	0.000	0.056	0.044
POLLUTANTS EMISSION	0.10	0.010	0.065	0.025
CONSTRUCTIONSCHEDULE	0.10	0.000	0.050	0.050
RATE OF NATURAL RESOURCE DEPLETION	0.10	0.052	0.000	0.048
SUMMATION	1.000	0.260	0.442	0.298
PRIORITISATION		3	1	2

CARBON FOOTPRINT EVALUATION

It is now generally accepted that carbon dioxide emission is the principal cause of climate change/global warming. This has lead to the widespread adoption of carbon dioxide generation as one of the key indicators of the environmental impact of modern technologies. This is expressed in the Parameter "Carbon Footprint" which compares the total quantity of carbon dioxide emitted by all processes involved in the practice of different technologies. In general carbon dioxide emission is associated with the use of carbon based fossil fuels such as coal and oil.

In the case of pipeline rehabilitation the consumption of fossil fuels and hence the Carbon Footprint is determined by the following activities:

a) Extraction and transport of raw materials and conversion into pipes/linings
b) Fuel consumed by excavators, cranes, trucks etc in excavation of trenches/ pits and removal and disposal of surplus materials
c) As b) for the importation and use of specialist backfill materials including reinstatement of paved areas
d) Extra fuel consumed by vehicles due to diversions, speed restrictions and other factors associated with road closures/traffic restrictions etc.

All of these activities have recently been incorporated in computer software developed by the University of Waterloo on behalf of the British Colombia Section of NASTT and available for Download from the NASTT-BC website. The software evaluates the carbon footprint of the Following rehabilitation options

1. Installation of replacement pipe using conventional open cut methods
2. Installation of replacement pipe using trenchless methods such as HDD and Microtunneling
3. Installation of replacement pipe within the original (Pipe Bursting and Splitting and conventional sliplining)
4. Rehabilitation of existing pipe by installation of a close fit lining such as CIPP or CFTPP

The program allows the input of a wide range of parameters including pipe diameter and type, soil type and cover depth, , surface material, traffic management arrangements including closures and diversions, Traffic conditions (volume, average speed etc), transport distances for material supply and disposal etc.

Typical results for a model pipeline rehabilitation project involving the rehab of 1000 ft of 12 in diameter water main is tabulated below. It can be seen that the use of trenchless technologies causes a

dramatic reduction in carbon emission compared to open cut methods this reduction is of major significance to Governments attempting to achieve carbon neutrality and also demonstrates a significant reduction in the use of a non-renewable resource i.e fuel oil.

The cost implications of this reduction are also tabulated below.

The quantity of carbon dioxide released is directly associated with the use of fossil fuels in a pipe Rehabilitation project the main usage of fuel is diesel oil used to power site equipment such as Excavators, Cranes and dump trucks, haulage equipment to transport materials, spoil and backfill and fuel consumed by third party vehicles during, delays and diversions associated with traffic management. The cost of fuel for the site and haulage equipment will normally be included in the direct costs of the contract and will be paid by the contractor. The fuel costs associated with Traffic Management delays and diversions will be paid by the operators/owners of the delayed vehicles and hence form a component of social cost.

In addition to the direct costs of fuels the emission of carbon dioxide generates a cost associated with the methods used to subsequently remove it from the atmosphere. This is termed Carbon Social Cost and depends on the carbon emission targets and strategies in each country. In the UK this cost is currently around \$45/metric tonne of CO_2 and is another component of social costs.

The costs in the table below have been estimated using data from USEPA on the quantity of CO_2 emitted during the combustion of diesel and other fossilised fuels. For simplicity it is assumed that all the emitted CO_2 is associated with the combustion of diesel oil. In practice part of the emission would be associated with other sources.

CARBON FO0TPRINT DATA FOR MODEL PROJECT USING NASTT SOFTWARE						
REHABILITATION METHOD	CO2 EMISSION	DIESEL FUEL EQUIVALENT	COST OF DIESEL FUEL EQUIVALENT	CARBON SOCIAL COST	TOTAL COST	TOTAL COST
	METRIC TONNES	USGALLONS (000)	\$(000)	\$(000)	\$(000)	\$/METRE
OPEN CUT	708.5	70.15	156.43	31.56	187.99	601.58
HORIZONTAL DIRECTIONAL DRILLING	35.4	3.50	7.82	1.58	9.39	30.06
%	5.00%					
SLIPLINING OR PIPEBURSTING	70.8	7.01	15.63	3.15	18.79	60.12
%	9.99%					
CURED- IN -PLACE PIPE LINING	14.1	1.40	3.11	0.63	3.74	11.97
	1.99%		0.00			
AVERAGE TRENCHLESS	40.1	3.97	8.85	1.79	10.64	34.05
	5.66%					

CARBON FOOTPRINT COMPARISON FOR THREE PROJECTS IN CANADA USING NASTT SOFTWARE										
PROJECT TITLE	DIAMETER MM	LENGTH METRES	CARBON EMMISION TONNES	DIESEL FUEL EQUIVALENT LITRES (000)	COST OF DIESEL $(000)	CARBON SOCIAL COST $(000)	TOTAL COST $(000)	TOTAL COST $METRE	PROJECT COST $ (000)	PROJECT COST $/METRE
OPEN CUT										
SURREY WATER MAIN	150/100	5500	1450	543.39	320.11	64.60	384.71	69.95	2300.00	418.18
BURNABYFORCE MAIN	150	800	364	136.41	80.36	16.22	96.58	120.72	275.00	343.75
DELTAWATER MAIN	350	440	426	159.64	94.05	18.98	113.03	256.88	200.00	454.55
TRENCHLESS										
SURREY WATER MAIN	150/100	5500	70	26.23	15.45	3.12	18.57	3.38	1700.00	309.09
BURNABYFORCE MAIN	150	800	36	13.49	7.95	1.60	9.55	11.94	178.00	222.50
DELTAWATER MAIN	350	440	42	15.74	9.27	1.87	11.14	25.33	145.00	329.55
OPEN CUT - TRENCLESS										
SURREY WATER MAIN	150/100	5500	1380				366.14		600.00	109.09
	%		4.8%				4.8%		73.9%	
BURNABYFORCE MAIN	150	800	328				87.02		97.00	121.25
	%		9.9%				9.9%		64.7%	
DELTAWATER MAIN	350	440	384				101.88		55.00	125.00
	%		9.9%				9.9%		72.5%	

Bibliography: The Bibliography may be accessed via the TRC Home page. If none is currently available on-line, please contact ISTT – info@istt.com for further information.

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