Application of Micro-Trenching for Fiber to the Home

by

Hediyeh Vaseli

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Abstract

Demand for high speed data transmission has grown considerably and required bandwidth has increased which can no longer be supported by traditional copper networks due to its limited data transmission capacity. Hence, providing broadband access through fiber optic (FO) cables to overcome this restriction has become essential for internet carriers There are various FO deployment methods with different advantages and disadvantageous. Open-cut trenching method has been the traditional approach for installing FO cables. However, there are several challenges associated with this method which increase the importance of considering an alternative for fiber optic deployment. Micro-trenching is an innovative installation method which minimizes surface scaring and potential negative social and environmental impacts. Considering the fact that this method has been rarely used in cold regions such as Alberta and also due to lack of practical information in this area, long-term performance of cables installed using this technique is not well-known.

In this research, various FO installation methods are introduced and discussed. To investigate the long-term functionality and durability of micro-trenching in cold regions, two different technologies were employed and monitored over the course of two winters in a parking lot in Edmonton, Alberta, Canada. Physical integrity and optical performance of cables, were compared and investigated for both methods. In order to analyze the productivity, a Simphony simulation model was developed and validated for field data and finally a modification for productivity improvement was suggested.

To my parents and my dear brother, Hooman

for their support and love

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1.1 Introduction

Broadband is one of the features that a perfect telecommunication network should be characterized with (Fang Lu 2005; Saito 1993). The UK Broadband Impact study conducted by the Department for Culture, Media and Sport (DCMS) in November 2012, investigated economic, environmental and social influences of broadband by reviewing more than 100 publications in this regard. Broadband's positive economic impact includes increase in productivity ,expansion in international business and teleworking which results in workers' time efficiency and productivity benefit (SQW 2013).

According to a study backed up by Cisco, in which data of over 2,000 business in France, Germany, UK and US was investigated to determine influence of "internet business solutions" on cost savings and productivity benefits, it was estimated that for US, in 1996 to 2000, the use of "internet business solutions" had 0.17 percentage points benefit to yearly labour productivity and it was projected that the contribution would increase to 0.43 percentage points in 2001 to 2010. It must be noted that these percentages are in comparison with overall estimated rate of increase in productivity annually, which is 2.1 percentage points. Penetration rate of these solutions is lower in Europe in comparison with the US; therefore, contributions were solely 0.017 percentage point in 1996 to 2000 and it reached to 0.11 percentage points in 2001 to 2010 (SQW 2013).

From an environmental point of view, Information and Communication Technology (ICT) is projected to be the major CO_2 emission source; corresponding emissions are indirectly generated from the coal used for providing electricity required to power our devices and appliances. Currently, ICT uses 10% of all electrical power and it is increasing 6-10% annually. Based on the OECD (Organization for Economic Co-Operation and Development), at this time, energy consumption of ICT equipment is more than conventional devices in our home (Arnaud 2013); Based on SMARTer 2020 report by Global e-Sustainability Initiative (GeSI and Boston Consulting Group 2012) ICT emissions increases from 0.53 Gigatonnes of CO_2 equivalent in 2002 to 0.91 GtCo2e in 2011; it is also estimated that this number reaches to 1.27 GtCo2e in 2020. However, broadband provides the opportunity to decrease these emissions with several mechanisms. Faster broadband network results in more emissions but the network energy efficiency is enhancing persistently. There are positive environmental influences resulting from decreased business travels and cloud computing. Use of shared computing resource results in significant reduction in carbon emission of ICT (SQW 2013).

In social aspect, broadband has significantly positive "impacts in communication, learning, entertainment, health, access to employment, shopping, and interactions with government". These days, internet becomes a major health information source; based on NHS's (National Health Service) report, number of the website visitors increases from 1.5 million in 2000 and 2001 to 18 million in 2009. Internet happens to become a useful tool for employers and job-seekers (SQW 2013).

In addition, superfast broadband raises use of video entertainment and video communications including skype video, google talk and so forth. According to a report by (TokBox 2012) and NPD In-stat estimation, minute number of video calls projected to reach from 141 million in 2010 to 550 million in 2015. Quality and accessibility of broadband is becoming an important criteria in the attractiveness of all living areas, specifically rural locations (SQW 2013).

Considering various impact of broadband and its increasing demand and influence on our life, having fiber optic networks, which support broadband internet become essential. Signal distribution between central office and subscribers are supported by fiber Optic networks which are counted as major building block for high capacity broadband networks (Network Infrastructure Committee 2007; Saito 1993).

1.2 Background

Communication technology plays a critical role in contemporary society and influences daily social interactions including business activities, relationships and entertainment affairs. Currently, internet is the main tool for communication technology. The fact that websites such as Facebook, Twitter, YouTube and other online sites are increasing in popularity and internet become a supplier of information and entertainment indicate that the overall required bandwidth should be increased significantly to satisfy the user demand. In addition, the quantity of internet users has grown considerably over the last twenty years. In 2011, approximately 90% of Canada population have access to internet; and the market is anticipated to be saturated by the year 2025. Current telecommunications infrastructure is unable to support projected growth. Further, copper cabling system's capacity for data transmission is limited (Saeed 2011). Therefore, providing fiber optic (FO) network, which has high data transmission capacity in comparison with copper networks, has become essential (Network Infrastructure Committee 2007; Saeed 2011).

Providing fiber optic networks to homes and businesses and last mile installation, however, can be challenging (Stojicic 2002). Protection of underground utilities, high cost of surface restoration, street blockage, service interruption, and environmental disturbance are examples of challenges in fiber optic installation (Atalah et al. 2002; Stojicic 2002). FO installations in cold regions such as the province of Alberta, Canada, present additional specific challenges such as exposure to frost penetration (potential frost heave), and installation in frozen soils.

Fiber optic installation methods can be divided into two categories: The first category is referred to as "direct buried", and consists of placing the FO cable directly underground or inside a conduit or duct in which the cable is pulled or blown through. This category includes open cut trenching, which can sometimes be costly as underground utilities must be located and protected, in addition to requiring significant surface reinstatement, traffic control, and environmental impact mitigation (Atalah et al. 2002; Jeyapalan 2003). In order to limit potential damage to existing infrastructure and to minimize social and environmental impacts, other trenchless or near-trenchless "direct buried" methods such as micro-trenching, plowing, piercing, and mini-horizontal directional drilling (mini-HDD) have been employed for FO installation (Savage 2005).

The second FO installation category is "utility sharing", which uses existing utilities to accommodate FO cables. Several cities in Japan, Germany, and Austria have broadband networks housed within underground utilities. Due to its extensive underground utility network, there is also significant opportunity for the use of this method in North America (Jeyapalan 2007). Currently there are several methods for FO installation within existing utilities, such as robotic installations including Sewer Access Module (SAM) and Sewer Telecommunication Access by Robot (STAR), Micro Cabling Systems-Drain (MCS-Drain), and Micro Cabling Systems-Liner (MCS-Liner) by Corning cable system, as well as services provided by CableRunner

This study has focused on Micro-trenching, which has minimal social and environmental disturbance and requires low surface restoration, and its application in cold regions. Micro-trenching, an alternative for FO deployment has been seldom used in cold regions such as Alberta, Canada and long-term performance of FO cables installed through micro-trenching is unknown; since in this type of installation cables are installed in shallower depths than traditional deployment methods, they are more susceptible to freeze/thaw cycle, frost heave and future construction actives such as pavement replacement. Therefore, this research focuses on its long-term functionality and viability in addition to of influence of cold weather condition and installation specification of its productivity.

1.3 Objective

The objective of the research is to evaluate various fiber optic deployment methods and micro-trenching in particular in terms of efficiency, cost, productivity and viability. Micro-trenching long-term functionality, viability and its application for Fiber to the Home (FTTH) in cold regions such as Alberta has been investigated through performing two pilot installations. It must be noted that the installations need to be kept under systematic monitoring to be able to evaluate long-term performance of fiber optic cables installed using this method. In addition, a micro-trenching productivity analysis is performed to investigate the influence of cold weather condition and installation depth, using a simulation model. Furthermore, an adjustment in the procedure was made to improve the productivity based on project observation. The change was applied in the simulation model as well to verify the productivity improvement.

1.4 Methodology

This research, sponsored by TELUS, was conducted in two phases, field installation and conducting a productivity analysis. Two pilot micro-trenching technologies, Vertical inlaid Fiber (VIF) and Surface Micro Cable Inlay (SMCI), were installed in a parking lot in Edmonton, provided by TELUS, with collaboration of TeraSpan and JETT Networks. Construction phase data including productivity rate and generated waste material were obtained and compared for both technologies. The installations are also intended to be monitored in several years to investigate the effect of thaw/freeze cycle on the cable and evaluate its long-term physical integrity and optical performance. Physical integrity was determined by locating the conduit depth and monitoring it over the winter using Ground

Penetrating Radar. Optical performance was measured using Optical Time Domain Reflectometer to evaluate its optical performance.

In order to perform a productivity analysis, a simulation model of micro-trenching process was developed. Time distributions, as an input for the simulation model, was obtained from experts based on their past experience and projects for both summer time and winter time. Simulation model was validated using TELUS field installations. Using the simulation model, influence of weather condition and installation depth can be studied. Additionally, a modification in the micro-trenching process was suggested and the increase in the productivity was verified using the simulation model.

1.5 Thesis Structure

The thesis has the following organization:

Chapter 1- Introduction: In this chapter, background, research objective, methodology of the research approach, and thesis organization are provided.

Chapter 2- Literature Review: In this chapter a literature review on various fiber optic installation methods, categorized into direct buried method and utility sharing methods, are provided. In addition, major advantages, disadvantages and their applications are provided which gives an insight of different methods and make the reader familiar with current deployment methods.

Chapter3- Evaluation of Micro-trenching performance in cold regions as an alternative installation method for fiber optic cable: In this chapter, Micro-trenching as an alternative for fiber optic installation is introduced in more details and two pilot installations conducted in Edmonton are discussed. Pilot installations are intended to be monitored over several years to investigate micro-trenching performance over long-term in cold regions such as Alberta. Construction phase data including productivity and generated waste material as well as operational phase data, physical integrity and optical performance of cables, are compared and investigated.

Chapter 4- Productivity analysis of micro-trenching: In this chapter, a simulation model is developed for micro-trenching process using Simphony. The model is validated using

TELUS field installations. Influences of cold weather condition and installation depth were investigated. In addition, a modification for productivity improvement is suggested; the enhancement in productivity is verified using the modified simulation mode.

Chapter 5- Conclusion and future works: In this chapter research findings and results are summarized. Furthermore, suggestions for future work are provided.

Chapter 2. Review of Installation Methods for Fiber Optic Cable Deployment[1]

2.1 Abstract

Demand for high-speed data transmission and bandwidth has increased significantly over the last two decades, making it necessary for internet carriers to provide broadband access through fiber optic cables and overcome capacity limitations associated with traditional copper wiring networks. Fiber optic installation methods can be grouped into two main categories: “direct buried” and “utility sharing” methods. Based on factors such as geotechnical and environmental conditions, available equipment, and project location, either category can be a viable option for fiber optic installation. In this paper, key methods of the two installation categories are discussed. The features and limitations of each method are included to assist in the identification of more cost-effective construction options that have fewer negative impacts on the environment and existing infrastructure.

2.2 Introduction

The number of internet users has grown considerably over the last 20 years. It was estimated that in 2011 approximately 90 percent of Canada’s population had access to the internet, and by the year 2025, it is anticipated that the market will be saturated (Saeed 2011). The internet has become a ubiquitous source of both information and entertainment. As a result, bandwidth requirements have increased significantly (Saeed 2011). Since the data transmission capacity of fiber optic (FO) cables is higher than that of the existing copper telecommunication infrastructure (Network Infrastructure Committee 2007), providing FO networks has become essential to appease the growing demand of users (Saeed 2011).

However, providing FO access to homes, also known as fiber to the home (FTTH) and business (FTTB) can be challenging (Stojicic 2002). Last-mile deployment challenges include the possible disruption of existing utilities, increased surface restoration costs, temporary interruption of services (traffic, waste collection, and so forth), and possible environmental disturbances such as contaminating spills, pollutant emissions, and noise (Atalah et al. 2002; Stojicic 2002). FO installations in cold regions such as the province of

[1] A version of this chapter was submitted to Journal of Construction Engineering and Management, ASCE.

Alberta, Canada, present additional specific challenges such as exposure to frost penetration (potential frost heave), and installation in frozen soils

There are various installation methods that can be used for FO deployment, and each are associated with several advantages and limitations. It is necessary to consider local conditions including climate, ground type and condition, project location, and availability of equipment when choosing a viable installation method. It is imperative to select a cost-effective installation method that causes minimal disruption to the environment and the community, particularly in business districts. Additionally, a different combination of methods might be suitable for creating a cost-effective and environmentally-friendly FO network (Atalah et al. 2002). Therefore, the selection of a proper installation method cannot be made based solely on cost (Ariaratnam et al. 2013). As a result, the use of a decision support system is suggested for the selection of an appropriate FO installation method.

2.3 Objective and Methodology

This paper presents key technologies used for the installation of FO cable. Information used in this paper was collected from academic publications as well as industrial guidelines and specifications from various practitioners specializing in FO cable installation. A portion of the information has also been obtained by conducting interviews with the same companies for detailed and practical information based on their experiences. The use of a combination of academic and industry literature provides a more complete overview of the topic, since academic literature on FO installation methods and their advantages and limitations is relatively scarce.

2.4 Fiber Optic Deployment Methods

Major installation methods for FO deployment are presented in this paper. In general, FO deployment can be achieved using “direct buried” and/or “utility sharing” methods. “Direct buried” methods include any method for burying the cable underground using either open trench or trenchless technologies. “Utility sharing” avoids underground construction by using existing infrastructure (e.g. sewers, utility poles) for FO deployment. Figure 2-1 is a diagram of key FO installation methods, discussed in this paper. The diagram provides a visual classification of FO installation methods.

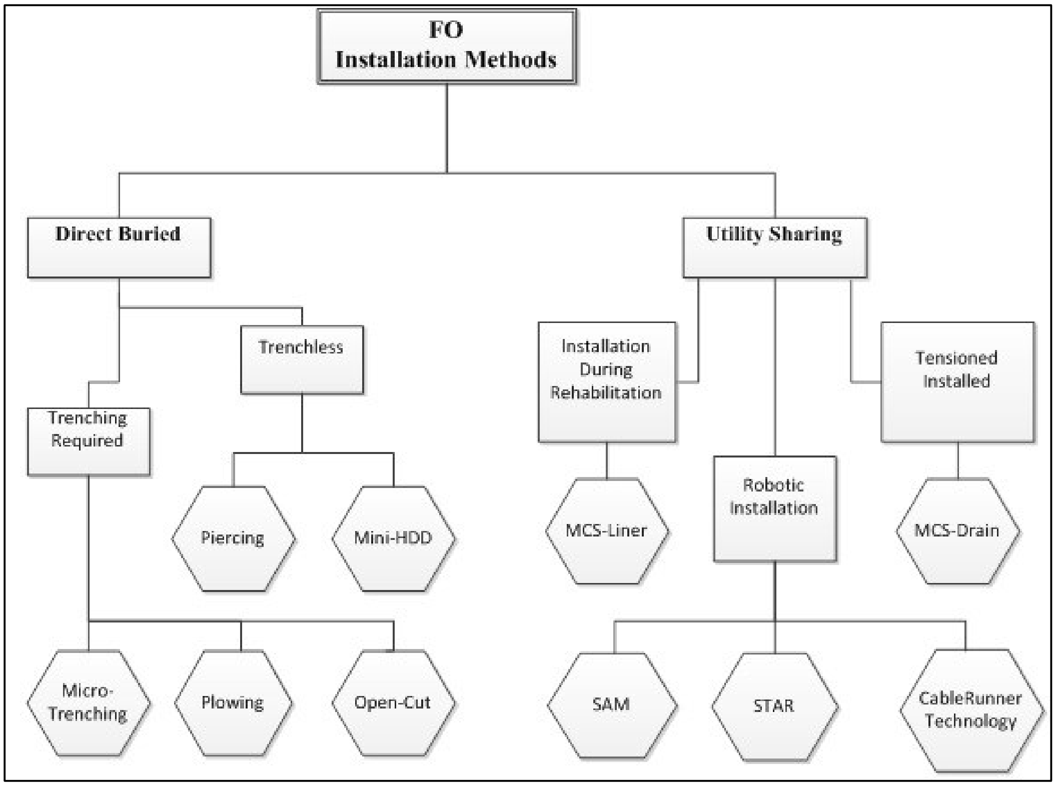


Figure 2-1: Fiber Optic Deployment Methods' Classification Diagram

2.4.1 Direct buried method

In this paper "direct buried" refers to installation methods that involve burying the cable with or without a conduit. For installations including a conduit, the FO cable can be placed in the conduit prior to deployment, or pulled or blown through the conduit after deployment. Although open cut was the traditional approach for installing buried infrastructure, trenchless or near-trenchless methods provide advantages in cases where surface disruption is expensive (Gokhale 2006). Key methods in this category include open cut, micro-trenching, plowing, piercing, and mini-HDD. In addition to the challenges mentioned in the introduction section, there are other challenges associated with "direct buried" methods. For instance, in some buried installation methods, such as micro-trenching, cables are deployed at shallow depths thus increasing exposure to frost and possibly hindering the fiber's performance. The advantages, disadvantages and application of each "direct buried" method are summarized in Table 2-1.

Table 2-1: Advantages and Disadvantages of "Direct Buried" Methods

"Direct Buried" Methods				
Installation Method	**Application**	**Advantages**	**Limitations/ Disadvantages**	**References**
Open cut	Areas where surface disruption has no significant impacts and surface reinstatement is not required or is easily completed.	• Traditional installation method; risks, cost, and procedure are well known.	• Can be costly in areas with hard soils, in areas requiring deep excavation, or excavation under the water table. • Significant surface disruption, which may be costly in busy business districts.	(Atalah et al. 2002)
Micro-trenching	Business districts, downtown areas, and private lots.	• Low surface restoration cost • Environmentally-friendly • Minimal surface scaring • Minimal community disruption • Possible year-round • Applicable to all ground types	• Due to its shallow depth, installations may damage easily and suffer impacts from thermal expansion/contraction, ground freeze/thaw cycles and frost heave.	(ITU 2003) (i3 group n.d.) (TeraSpan 2013a) (Griffin 2010) Personal communication with Metro Fibrewerx Inc. and TeraSpan
Plowing	Rural areas with few obstructions.	• No backfilling required • Compaction is automated	• Not applicable in frozen ground or rocky soil.	Personal communication with Metro Fibrewerx and SpiderPlow (Savage 2005) (Prysmian Cables & Systems 2005)
Piercing	Boring under streets, driveways and other surface obstacles.	• Minimal operating space • Low restoration cost • Reduced surface disruption • High productivity rate (250-450 ft/ eight-hour day with a crew of five people) Relatively economical	• Not steerable Only useful for short distances (25-40 ft)	(Ehm 2008) (Orton 2007) (McGuire 2013) (Savage 2005)
Mini-HDD	Boring under streets, rivers, landscapes, driveways, and other surface obstacles	• Low restoration cost • Reduced surface disruption • Steerable drilling head • Maneuverability around obstacles	• Risk of hydraulic fracturing Risk of bore collapse • Loss of circulation Not steerable in cohesive soils	(Staheli et al. 2012) (Osbak et al. 2012) (Ariaratnam and Allouche 2000)

The following sections describe the main “direct buried” methods used for FO installation.

2.4.1.1 Trenching required methods

2.4.1.1.1 Open cut

The open cut method consists of excavating a trench to a predetermined depth, inserting the conduit inside, and then backfilling the trench and reinstating the surface. For FO deployment, mini excavators are used to create a trench at a depth between 300-600 mm (12-24 in) (CSMG 2010). Manual digging might be essential in areas with sensitive underground infrastructure (CSMG 2010). Locating and protecting the existing utilities increases construction costs, particularly in business districts and congested areas. Additionally, open cut methods have relatively high environmental impacts in urban and business areas, which may also raise construction costs due to restoration efforts. Open cut projects that entail excavation in rock or beneath the water table, or involve shoring may also have significant additional costs (Atalah et al. 2002).

This method is no longer advantageous when project requires provisions such as traffic control (detour), increased excavation depth, or significant surface restoration expenses, and alternative installation methods may be preferable. However, open cut methods may be an economical alternative in unpaved, rural, or low-traffic areas and in shallow installations, where surface restoration is not necessary (Atalah et al. 2002).

2.4.1.1.2 Micro-Trenching

Micro-trenching is a fast installation method with low restoration costs and low environmental impact. Reduced installation time and surface restoration, causes minimal surface scaring and community disruption (Personal communication, Metro Fibrewerx Inc.; November 2012). It is an effective installation method in asphalt pavements with a compacted base layer. Employing this method in granular material and evolved roads is challenging (DCMS 2011; ITU 2003). In this method, a dry or wet blade is used to create a small trench. The use of a dry blade preserves water and inhibits slurry run-off (A2B fiber Inc. 2011); however, dry cutting tends to increase blade wear and consequently, construction costs (Personal communication, TeraSpan; October 2013).

The micro-trenching process starts by cutting a narrow trench. Depending on the size of the conduit used, trench is narrower than 20 mm wide, and up to 120-300mm deep (DCMS 2011). Various types of equipment can be used for cutting. some especially designed vehicles are equipped with a suction system, in which two vacuum pipes evacuate the waste material from the trench as it is being cut. Waste material collected during this process can be stored and used later during the backfilling process (Spadavecchia 2007). The micro-trench is laid alongside the edge of the road curb, not directly in the wheel paths, in a more stable area of the pavement to limit the potential for damage of the cables and ducts due to pavement deflection under traffic loading (Liteaccess Technologies Inc 2010; Network Strategies 2008).

The second step of the micro-trenching process is the placement of cable or conduit inside the trench. The potential for construction damage is a major threat to FO cables that are installed using micro-trenching method. Through the use of ducts and conduits, FO cables can be better protected from construction damages and other hazards such as frost and operational loads. (Personal Communication, TeraSpan; November, 2012). Enclosing the cable in conduits adds a protection layer and provides flexibility in installation and protection against frost and construction damages (TeraSpan 2013b).

(Figure 2-2) shows two different types of conduit; namely Vertical Deflecting Conduit (VCD) and Flatliner that are TeraSpan and GM Plast production respectively. Flatliner has advantages such as flexibility in deployment, adequate rigidity, and durability on edge, for making it an adequate option for FO casing (GM Plast 2014).

(a)

(b)

Figure 2-2: (a) Vertical Deflecting Conduit (VDC), (b) Flatliner (Reprinted from GM Plast 2014, with permission)

The final step in the micro-trenching process is surface reinstatement. The reinstatement has to impede water infiltration and properly support the trench while providing adequate bond to trench walls. However, compaction of back filling material inside the micro-trenches is challenging due to their small size and traditional asphalt mixtures may not be used for trench reinstatement. (Stirling Lloyd Group Plc 2009)

Depending on the used micro-trenching method, possible reinstatement materials could be sand accompanied with sealant on top, cold asphalt, hot liquid bitumen and especial grouts with bitumen sealant (Griffin 2010; ITU 2003).

2.4.1.1.3 Plowing

Plowing is an underground installation method that uses a cable-laying plow to dig a trench, place the FO cable inside, and ultimately backfill the ditch (Cables Plus 2012). Plowing is a suitable solution for areas where few obstructions exist and rural area (Prysmian Cables & Systems 2005). Soil type and burial depth are determinant factors in selecting the cable plow equipment (ofs A Furukawa Company 2012). As the soil type is key factor in the success of plowing, it is essential that the ground is not frozen during the construction time (Personal communication with Metro Fibrewerx Inc and SpiderPlow). Optical Cable Corporation 2008 suggests that FO cables must be located under the frost line. The cable's route must have the fewest obstructions possible and avoid areas where surface drainage is probable, which may lead to soil erosion and ultimately exposure of the FO cable (Prysmian Cables & Systems 2005).

The first step of the plowing process is to place the vibrating plow. The cable or duct is then inserted at a pre-specified depth and path via the cable delivery system, which directs the cable or conduit from the reel to the plow chute and into the ditch as the plow progresses (FDOT 2003). The cable delivery system consists of a reel carrier, rollers or guide tube, and a capstan driver unit mounted on the plow. The capstan is located over the feed chute, and it pulls the cable from the reel to the feed chute center at low tension; it is imperative not to violate the cable's minimum critical bend diameter (ofs A Furukawa Company 2012; Prysmian Cables & Systems 2005).

Following the installation of the cable or duct, ground that has been disturbed during the plowing process is reshaped through grading and compaction and no additional material is required for backfilling. Eventually, cable is installed via pulling or blowing if empty duct is used (FDOT 2003).

2.4.1.2 Trenchless methods

2.4.1.2.1 Piercing

The use of piercing tools is another trenchless alternative for FO deployment. Fundamentally, a piercing tool is a piston inside of a casing; the power of the piston moved by compressed air pushes the tool frontward (Orton 2007). The impact energy of the piston is used to compress the ground and overcome the skin friction along the body of the instrument to move it forward (Personal communication, Ditch Witch; November 2012).

The piercing process begins with the excavation of the entry and exit pits (25 cm (10 in) wide and 76 cm (30 in) deep on average) (Ehm 2008). It is imperative that the piercing tool or "mole" is placed at a depth at least 10 times greater than its diameter. The tool compact the surrounding soil as it moves forward, which is likely to displace the surface if sufficient depth of cover is not considered (No Dig Mole 2013).

In the entry pit, the piercing tool is placed along the desired trajectory and the air compressor is connected to the instrument (No Dig Mole 2013). The crew missiles the tool to the exit pit in 9-12 m (30-40 ft) intervals, referred to as stitch boring (Figure 2-3).

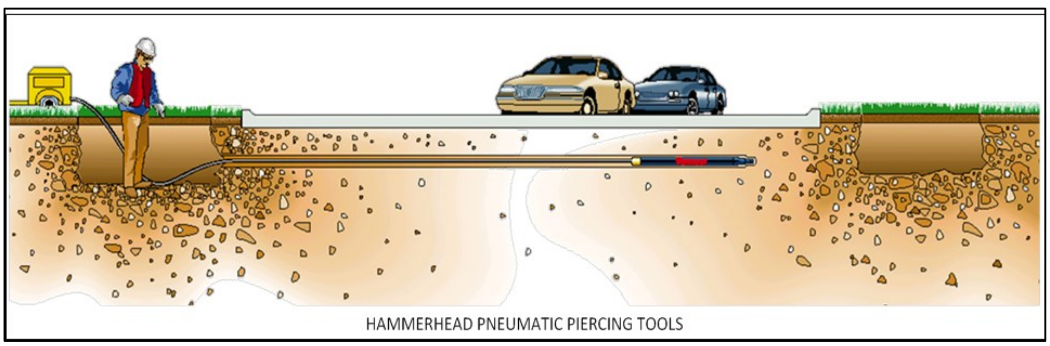


Figure 2-3: Piercing process (Reprinted from Hammerhead Trenchless Equipment 2015, with permission)

The piercing tool pulls in a "high-strength cloth tape" called mule tape, which pulls the conduit along the pierced route (Orton 2007). For FO application and distribution, conduits with 3.2 cm (1.25 in) diameter are utilized. After placing the conduit, the cable is blown or pulled through, the required connections are made, and the network is tested (Ehm 2008). The final step involves backfilling the entry and exit pits, during which an air tamper is used for soil compaction to reduce the risk of possible sink holes (Ehm 2008).

Piercing requires a small crew and therefore its operating cost is relatively low (McGuire 2013; Orton 2007). Advantages of the piercing method include relatively low restoration costs, reduced disruption, minimum operating area (Orton 2007), and high productivity rates (250-450 ft [76-137 m]/ eight-hour day with a five-person crew) (McGuire 2013). Piercing equipment can also be an economical alternative in comparison to HDD equipment (Orton 2007); however, as opposed to HDD tools, piercing instruments cannot be navigated (Orton 2007; Savage 2005). Also, the earliest piercing tools had issues restarting after stoppage and lacked accuracy. Currently, accuracy has been significantly improved through the development of a “reciprocating stepped-cone, chisel-head assembly” (Orton 2007).

2.4.1.2.2 Mini Horizontal Directional Drilling (mini-HDD)

Mini-HDD is a class of HDD used for installing small-diameter cables (5-25 cm [2-10 in]) and is therefore suitable for FTTH applications (Bennett et al. 1995; Savage 2005). It is possible to bore lengths up to 182 m (600 ft) long with an installation depth of up to 4.5 m (15 ft) (Bennett et al. 1995). Through this method, social and environmental disruption as well as restoration costs are minimized (Ariaratnam and Allouche 2000).

In the mini-HDD method, the drilling tool can be steered and navigated, except through hard soils such as sediment soil and clay (Staheli et al. 2012); this provides adequate performance and maneuverability in the presence of underground obstacles (Savage 2005). Electronic sensors, which are located close the head of the drilling tool, provide signals to assist operators in tracking the bore path and retrieve information about location, depth, and instrument orientation (Ariaratnam and Allouche 2000).

Mini-HDD installation begins by investigating the project site and defining a bore-path, exploring existing utilities and underground obstacles, digging a small entry hole, and drilling a pilot bore hole until the required depth is achieved (Contour Directional Drilling Ltd. 2011). Once this is complete, drilling is performed horizontally and the tool is gradually navigated toward the targeted exit point. After the exit point is reached, a reamer, if enlargement is required, and the conduit are attached to the drilling tool. The reamer, conduit, and drilling tool are then pulled back through the bore hole to the entry point, and the pilot hole is enlarged to the required diameter (Ariaratnam and Allouche 2000; Contour Directional Drilling Ltd. 2011). Pressurized drilling fluid is inserted into the bore hole during the process to stabilize the borehole walls and decrease the friction (Ariaratnam and

Allouche 2000). Finally, the FO cable is inserted inside the conduit via blowing, or pulling, if necessary (American Polywater corporation 2008).

There are several risks associated with the mini-HDD method, including: hydraulic fracturing, the flow of drilling fluid to the surface through soil fractures; soil collapse, when the soil surrounding the borehole falls inside; and loss of circulation, the failure of the drilling fluid to flow continuously inside the borehole annulus (Osbak et al. 2012).

2.4.2 "Utility Sharing" Methods

Using existing utilities for FO deployment reduces the required cost and time for installation. FO Cable deployment using "utility sharing" should not affect the utilities' primary function (Network Infrastructure Committee 2007). Initially, this type of installation became commonplace in Japan and Europe by late 1990's (Gokhale 2006).

Robotic installation is employed in pipelines that are not man-accessible (pipe diameter less than 70cm [27 in]). Robots used for this type of installation include the Sewer Access Module (SAM) and the Sewer Telecommunications Access by Robot (STAR) also known as Cable Laying Robot (CLR), and CableRunner robot (W & H Pacific 2001). Micro Cabling Systems-Drain (MCS-Drain), and Micro Cabling Systems-Liner (MCS-Liner) by Corning cable system are also used for FO deployment in sewer systems. Table 2-2 summarizes key advantages and disadvantages of "utility sharing" methods.

Table 2-2: Advantages and Disadvantages of "Utility Sharing" Methods

"Utility Sharing" Methods				
Installation Method	**Application**	**Advantages**	**Limitation/ Disadvantages**	**References**
SAM	Sanitary or storm sewers	• Protection against rodents, corrosive substances, and high pressure cleaning provided by stainless steel conduits.	• Applicable Pipe diameter range 20-50 cm • Future expansion not possible	(W & H Pacific 2001)
STAR	Storm sewers only	• Independent of weather condition • Faster than "direct buried" methods	• Applicable pipe diameter range 20-122 cm • Cable is unprotected	(W & H Pacific 2001) Personal Communication with Ca-Botics
MCS-Drain	Sanitary, storm, and combined sewer systems	• No drilling or mounting required Applicable to all pipe materials	• Applicable pipe diameter up to 18 cm	(Corning Cable Systems 2001)
MCS-Liner	Defective pipe requiring rehabilitation	• Pipe is relined simultaneously while installing FO cable	• Applicable mainly for pipes in need of rehabilitation • Expensive for pipes in good condition	(Corning Cable Systems 2001)
CableRunner system	Sewer systems	• System can be removed easily • Good performance in harsh environments • Future expandability	• Water level inside pipe should be less than 30 percent of pipe diameter	(CableRunner International 2012) Personal Communication with CableRunner International

The main advantage of all "utility sharing" methods is that there is no need for excavation; however, these methods tend to require additional coordination between the utility and the FO network owner. The following sections describe the main "Utility sharing" methods used for FO installation.

2.4.2.1 Robotic installation methods

2.4.2.1.1 Fiber Optic installation using Sewer Access Module (SAM)

SAM is used to install FO in pipes with diameters ranging from 20.3-50.8 cm (8-20 in). This device can be controlled remotely and used in storm and sanitary sewers. The stainless steel conduits used in this method provide the cables with protection against rodents, corrosive substances, and high-pressure water flow and cleaning (W & H Pacific 2001).

The installation process begins by determining the installation route and selecting the most appropriate sewer line for deployment. All aspects of the selected sewer, such as the position of manholes and lateral connections, are mapped as the robot runs the length of the selected route. Mounting clips as conduit holders are then installed in circumferential stainless steel bands mounted inside the pipe. Cameras mounted on the robot enable technicians to control the quality of the band installation. Mounting clips are located at the top of the pipe, adjacent to the spring box, to hold the conduit as high as possible (Figure 2-4). In order to install the conduit, it is pulled from one manhole to the other in a cluster and laid along the bottom of the pipe. The robot then lifts and fixes each conduit with the mounting clips. Finally, the crew pulls the FO cables in the conduit. The cables are then spliced and terminated, and building entries are built (W & H Pacific 2001).

A disadvantage of this system is that future expansion of the installation is not possible as mounting clips cannot be upgraded unless the steel bands are removed. To accommodate any foreseen future expansion, empty conduit must be installed at the time of the original installation (W & H Pacific 2001).

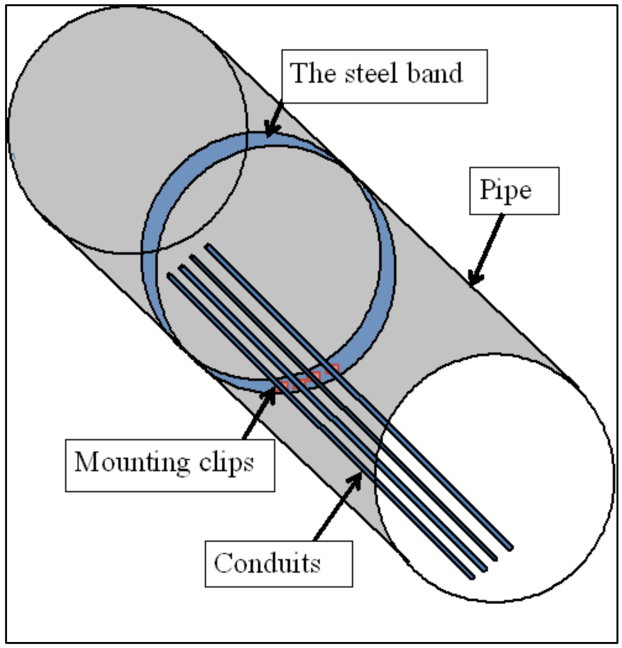


Figure 2-4: SAM Installation Components. Diagram is upside down for clarity

2.4.2.1.2 Fiber Optic Installation Using Sewer Telecommunication Access by Robot (STAR)

STAR or Cable Laying Robot (CLR) is another robot used for the deployment of FO cables inside of sewer systems. Unlike SAM, STAR installation does not employ stainless steel conduits. As a result, the cables are exposed to the sewer's environment, and this device is designed to be used solely in storm sewers (W & H Pacific 2001).

STAR installations can be completed effectively year-round as the procedure is not affected by weather condition, and the crew only requires two labourers and one robot operator. In addition, the speed of installation can reach 762 meters per day (2500 ft/day) (Personal communication, Ca-Botics; February 2013).

To begin the STAR installation process, the sewer line is first cleaned, videoed, inspected, and repaired. The cable is then pulled from one manhole to another, and the remote controlled robot is placed in the sewer line. The robot is used to create holes 1.5 cm (0.6 in) deep and 0.6 cm (0.23 in) diameter along the crown of the pipe at one-meter intervals (Gokhale 2006).The robot then elevates the cable into position and fixes it in place by installing a plastic J-hooks into the holes. J-hooks are able to resist up to 69 Mpa (10,000 psi) water-jetting pressures (W & H Pacific 2001). In the final step of the process, a specific welding instrument employs a polyethylene layer to secure the cable and J-hook anchor in place (Gokhale 2006).

Ca-Botics also suggests a solution for FO last-mile installation: the fiber cable can be pulled through the service laterals, and a thin-walled Cured-in-place Pipe (CIPP) liner can be inverted into the pipe, securing the cable to the inside wall of the pipe. There is no pipe material or size restriction for this method (Personal communication, Ca-Botics; February 2013). The sole limitation of this method is that it only applies to sewers 20-122 cm (8-48 in) in diameter. (Personal communication, Ca-Botics; February 2013).

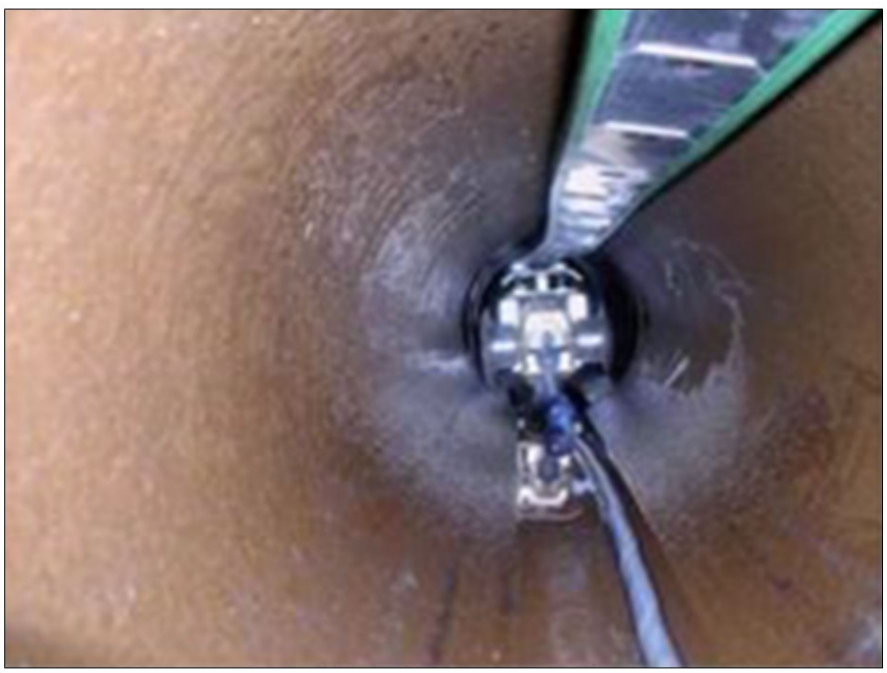
2.4.2.1.3 CableRunner Technology

CableRunner was developed in 1996 by the Sewer Department of the City of Vienna, Austria. Initially, this technology was employed to the City's sewer systems, and the technology has progressed continuously since then (CableRunner International 2012).

The CableRunner system works with flexible microduct cables. It consists of a group of five-millimeter (0.2 in) micro air tubes. Glass fibers are blown into the micro air tubes less than 1.6km (one mile) at a time (CableRunner International 2012)

The CableRunner robot (Figure 2-5a) is capable of working in water if the level is equal to or less than 30 percent of the pipe diameter. A "sealing threaded bolt" secures the cable conduits, and the entire installation can be removed easily (Figure 2-5b).An advantage of this deployment method is that all fibers can be inserted at once, or additional fibers can be inserted in the future without extra installation work (CableRunner International 2012).

(a)



(b)

Figure 2-5: (a) Robot, (b) Cable Tray Inside Sewer (Reprinted from CableRunner International 2012, with permission)

Key feature of CableRunner includes the following advantages (CableRunner International 2012):

- It is applicable to all pipe sizes and materials including brick, concrete, and High Density Polyethylene (HDPE);
- It is environmentally-friendly and requires little to no excavation;
- It is a secure process with no extra maintenance; performs well in severe conditions;

It is not affected by high-pressure water flow; and it has the ability to withstand corrosive material present in sewage.

2.4.2.2 Tension installed method (MCS-Drain)

Corning Cable Systems has developed other installation methods of FO cables inside of sewers. Products provided by Corning Cable Systems include Micro Cabling Systems (MCS) known as MCS-Drain and MCS-Liner, which is introduced briefly in these two sections (Corning Cable Systems 2001).

MCS-Drain is proper for FO installation in sanitary, storm, and combined sewers. This system does not require pipe drilling or mounting, since cables are secured solely inside of the manholes (Figure 2-6), and neither excavation nor special equipment is required. Cable can be installed in sewers up to 18 cm (7 in) in diameter regardless of pipe type (Corning Cable Systems 2001).

When installing FO using MCS-Drain, “curved cable guide” and pulling eye attachments are placed in the manholes. The drainage pipe is cleaned, and the MCS-Drain cable is pulled through the drainage system simultaneously. Tension helixes are then connected to the cable through the pulling eye. To finish, the cable is tensioned and set in the crown of the drainage pipe as shown in Figure 2-6 (Corning Cable Systems 2001).

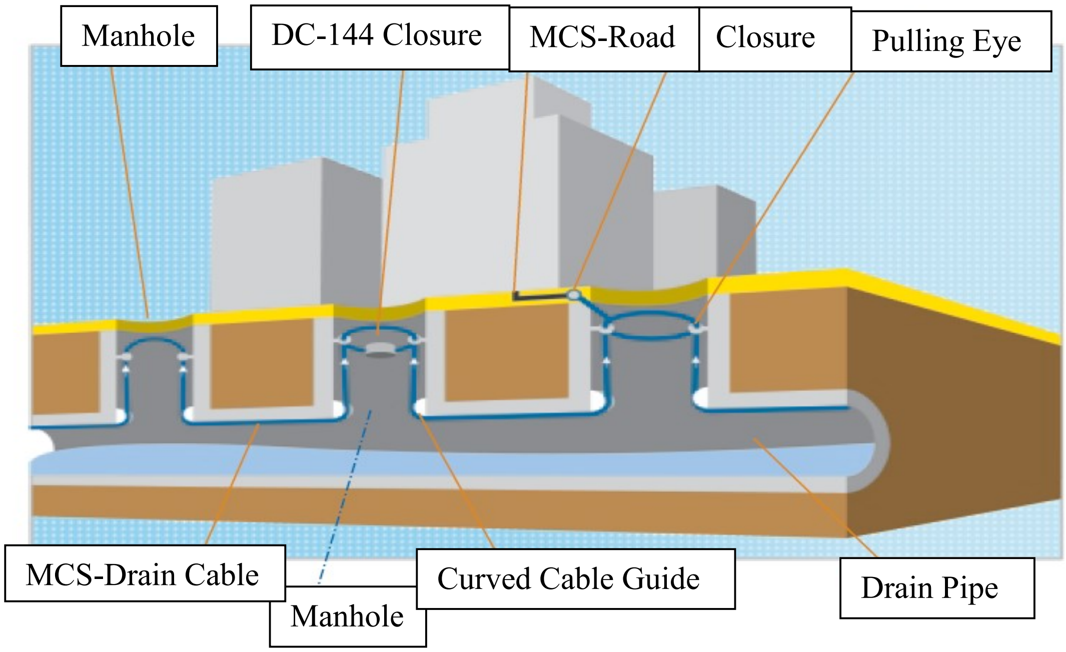
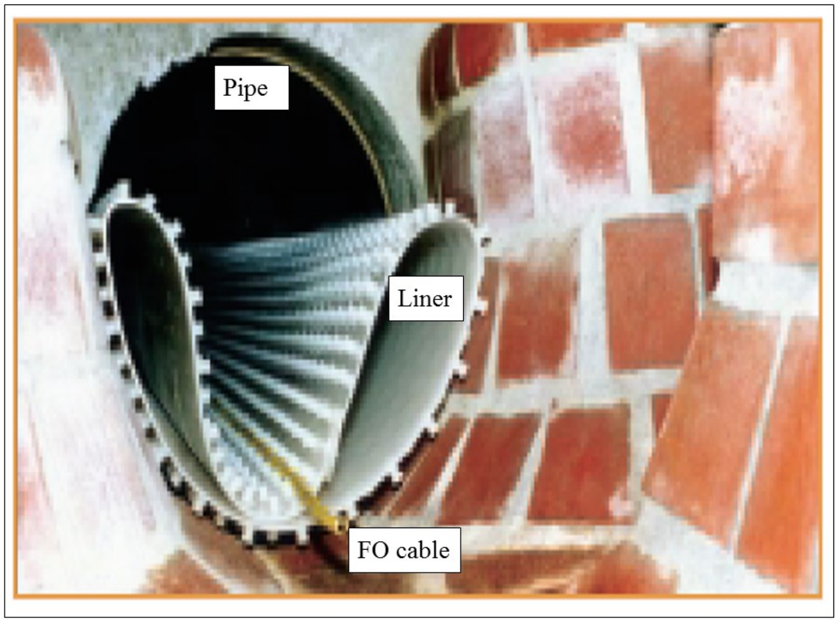


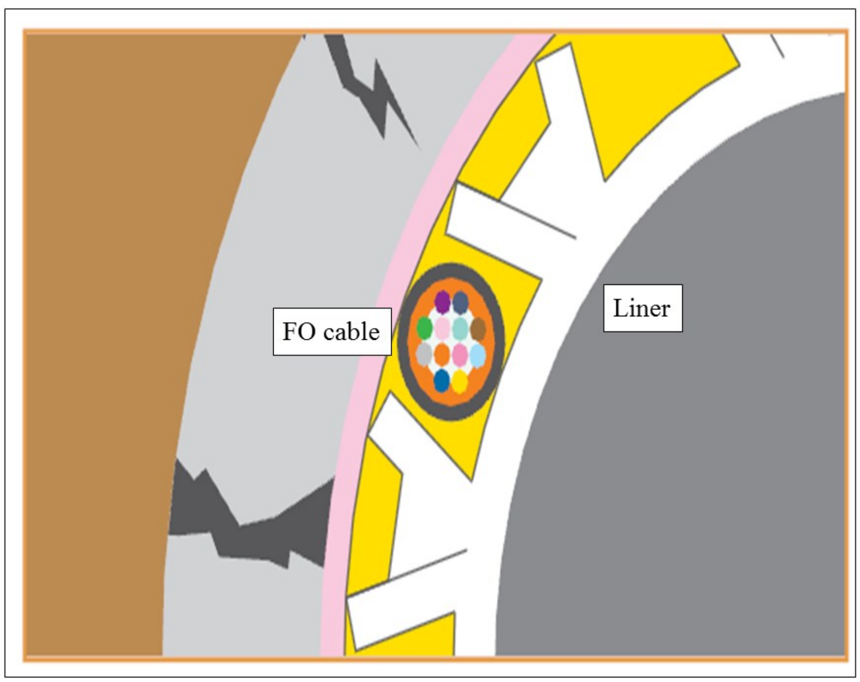
Figure 2-6: MCS-Drain Installation Diagram (Reprinted from Corning Cable System 2001, with permission)

2.4.2.3 Installation during rehabilitation (MCS-Liner)

In the MCS-Liner method, the FO cable is installed in drains and sewers during rehabilitation and repair work. MCS-Liner consists of a two-millimeter (0.07 in) polyethylene high-density (PE-HD) internal liner. FO cables are housed in mortar between plastic nubs on the external surface of the liner, as shown in Figure 2-7 (Corning Cable Systems 2001). Figure 2-7a depicts the MCS-Liner before installation, while Figure 2-7b is a schematic representation of the cable placed between plastic nubs following installation of the liner. The process for installation of MCS-Liner begins by pulling the cable and liner into the damaged pipe simultaneously. The liner gaps are filled with a specific grout that provides a “static load-bearing composite system” which is able to withstand temperature changes and corrosive material (Corning Cable Systems 2001).



(a)



(b)

Figure 2-7: (a) MCS-Liner before installation, (b) Detail of FO cable placement, (Reprinted from Corning Cable System 2001, with permission)

2.5 Summary and Conclusions

The use of open cut methods for deployment of underground FO networks may represent significant environmental and social disadvantages in addition to increased construction costs. Trenchless and near-trenchless installation methods provide a viable alternative to open cut as they minimize surface impacts in busy or environmentally-sensitive areas. Moreover, "direct buried" methods can be avoided altogether by using "utility sharing". Each technology and deployment approach has particular advantages and disadvantages and the selection of the most appropriate deployment method will depend on unique project characteristics including location, expected weather, ground type and condition, existing infrastructure, and available equipment, time and budget. Environmental factors may have significant impact in cold regions such as Alberta, where winter weather, potential frost heave, and seasonal freeze/thaw cycles must be considered for achieving cost-effective and reliable installations. The investigation of varied FO deployment methods as presented in this paper suggests that immediate and long-term impacts associated with different installation methods in cold climates are not fully understood. FO last-mile installation methods in cold regions require further research for ensuring deployment reliability and cost-effectiveness over the deployed infrastructure lifecycle.

2.6 Acknowledgements

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Chapter 3. Evaluation of Micro-Trenching as Fiber Optic Installation Method[2]

3.1 Abstract

Micro-trenching is an innovative and discreet utility installation method that includes the creation of a narrow trench to lay cable or conduit in the ground. This installation method provides minimal disturbance to the community and surrounding environment. It is a convenient solution in business districts and congested areas where there is little room for additional underground utilities and time restrictions for street closure in order to complete construction activities. To investigate the long-term functionality and durability of micro-trenching in cold regions, two micro-trenching technologies –Vertical Inlaid Fiber (VIF) and Surface Micro Cable Inlay (SMCI) – were employed and monitored over the course of two winters in a parking lot in Edmonton, Alberta, Canada. During the construction, productivity rate and generated waste material were studied. The installation's physical integrity and optical performance were also evaluated during the monitoring period. Physical integrity was assessed by monitoring the conduit location using Ground Penetrating Radar (GPR), and the fiber's optical performance was monitored to determine long-term attenuation in performance. Results indicated that the installation experienced undesirable upward and downward movements in sections with high traffic load, which may be prevented with a more effective reinstatement method. However, the fiber's optical performance has not been affected and optical losses are in an acceptable range.

3.2 Introduction

Currently, there are several direct buried and utility sharing installation methods available for providing underground Fiber Optic (FO) networks. The long-term performance of FO cable networks is important due to the significant cost of FO deployment and the impact of broadband failure on community and business (Crandall et al. 2009; Czernich et al. 2011; Holt and Jamison 2009). Typically, open-cut methods result in significant community and environmental disturbance and cost (Atalah et al. 2002; CSMG 2010). Furthermore, high construction costs are also associated with mini horizontal directional drilling (Mini-HDD) in addition to the risks of hydraulic fracturing, bore collapse, and loss of circulation as well as issues arising from steering limitations in cohesive soils (Osbak et

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[2] A version of this chapter was submitted to CSCE's Canadian Journal of Civil Engineering.

al. 2012). Utility sharing methods also present challenges as they require increased effort in coordination between organizations and authorities (FO network and utility owner) (Jeyapalan 2007). As a result, the new and convenient installation method of micro-trenching is increasing in popularity as an option for FO cable installation.

This paper introduces the micro-trenching methods and discusses two different experiments conducted to evaluate installation functionality and its long-term performance in cold regions.

3.3 Background

Micro-trenching is a new installation method used for the distribution of communication infrastructure (commonly FO cables) in roadways. In this method, cables or conduits are placed into a trench not greater than 20mm wide and 120-300 mm deep (DCMS 2011).

The first step in micro-trenching is the creation of the trench in pavement using an appropriate cutter. Trench position is one of the most important concerns in this method, with high risk arising if the trench is located along the vehicles wheel path (DCMS 2011). Therefore, micro-trenches preferably should be located close to the cement curb, along the road edge, instead of in the direct path of traffic to provide added stability (Liteaccess Technologies Inc 2010; Network Strategies 2008). After the trench has been cut, it must be cleaned with high pressure water and dried with compressed air and a blowpipe (ITU 2003).

The second step of the micro-trenching process is installation of cable or conduit inside the trench. The cable must be strong enough to withstand crush and temperature changes. It is sheltered in metallic tubing covered by a polyethylene (PE) jacket. According to ITU 2003, a retaining strip, such as a PE strip, is laid over the cable to stabilize it inside the trench. Then, a water-repulsive material, such as a rubber strip, is placed over the retaining strip for mechanical and thermal protection (ITU 2003). Different types of conduit also can be used for cable protection against frost, operational loads, and construction activity (GM Plast 2013; TeraSpan 2013).

The third and final step of the micro-trenching process is surface reinstatement. As sufficient compaction cannot be provided for micro-trenches due to their small size, traditional asphalt mixes cannot be used for trench reinstatement. Moreover, the reinstatement material must flow freely to the bottom of the trench, impede water penetration, provide bonding to trench sides, and provide stability under traffic load (StirlingLloyd Polychem Ltd 2012). According to (ITU 2003), hot liquid bitumen is a feasible reinstatement material for this method and can be applied to the micro-trench utilizing a nozzle with a proper size.

In some road types, it might not be feasible to carry out surface reinstatement and maintain its long-term reliability at the same time. Micro-trenching disturbs the structural matrix of roads which have been aged over centuries, resulting in its speedy deterioration. Applying this method in granular material can be challenging and may result in aggregate congestion in the trench which impedes the overall cleanliness of the excavation. It is more appropriate to employ micro-trenching for installation in roads or sidewalks with a compact base (DCMS 2011; ITU 2003).

Micro-trenching provides considerable cost savings as it reduces surface restoration and installation time (i3 2012). Despite its multiple advantages, there are several issues associated with micro-trenching due to its shallow installation, which include potential damage of pavement due to trenching, differential thermal expansions of trench backfill and existing pavement matrials and the frost heave effect in cold regions. Also, future pavement maitenace activities such as milling and recycling can damage buried FO cables. In addition to physical risks, the FO cable installed via micro-trenching may be subject to decreased performance due to environmental factors, temperature change, water seepage, and bending radius incurred during construction.

According to TeraSpan (D. Dofher (personal communication, October 2013)), key hazards and risks associated with micro-trenching could be reconstruction or future pavement maintenance activities, which can be reduced greatly through use of the “call before you dig” program, where a designated damage prevention centre will identify existing buried utilities and their locations prior to planned construction or excavation; and old asphalt milling and overlaying which are typical asphalt pavements maintenance procedures. The micro-trench must be located well below the milling level so there is no possibility that this process causes any damage to embedded cables.

As micro-trenching installation is seldom used in cold regions such as Alberta, Canada, the long-term performance of cables installed using this technique is unknown. Therefore, field installations have been performed to be kept under systematic review for performance evaluation to determine micro-trenching's viability in cold weather related to thaw/freeze cycle, traffic loads.

3.4 Field installation

3.4.1 Project location and installation layouts

Two micro-trenching technologies, Vertical Inlaid Fiber (VIF) and Surface Micro Cable Inlay (SMCI), were used for installation in this experiment. The test installation was located at 2920 66 St NW Edmonton, Alberta, in a parking lot belonging to a TELUS operational building. The first installation (VIF) was conducted on October 17, 2013 by TeraSpan. The second installation (SMCI) was conducted on June 6, 2014 by JETT Networks. Details of installation layouts (Figure 3-1) are as follows:

- VIF Technology
  1- 30 m straight layout without traffic load
  2- 30 m straight layout located in the direct path of traffic
  3- 55 m loop layout located in the direct path of traffic
- SMCI Technology
  1- 30 m straight layout without traffic load
  2- 72 m loop layout in the direct path of traffic

All layouts have been monitored to investigate the influence of cold weather conditions, traffic load, and bends (if applicable) on the conduit and cable's physical integrity. The loop layouts also provide information regarding the cable's optical performance in traffic areas.

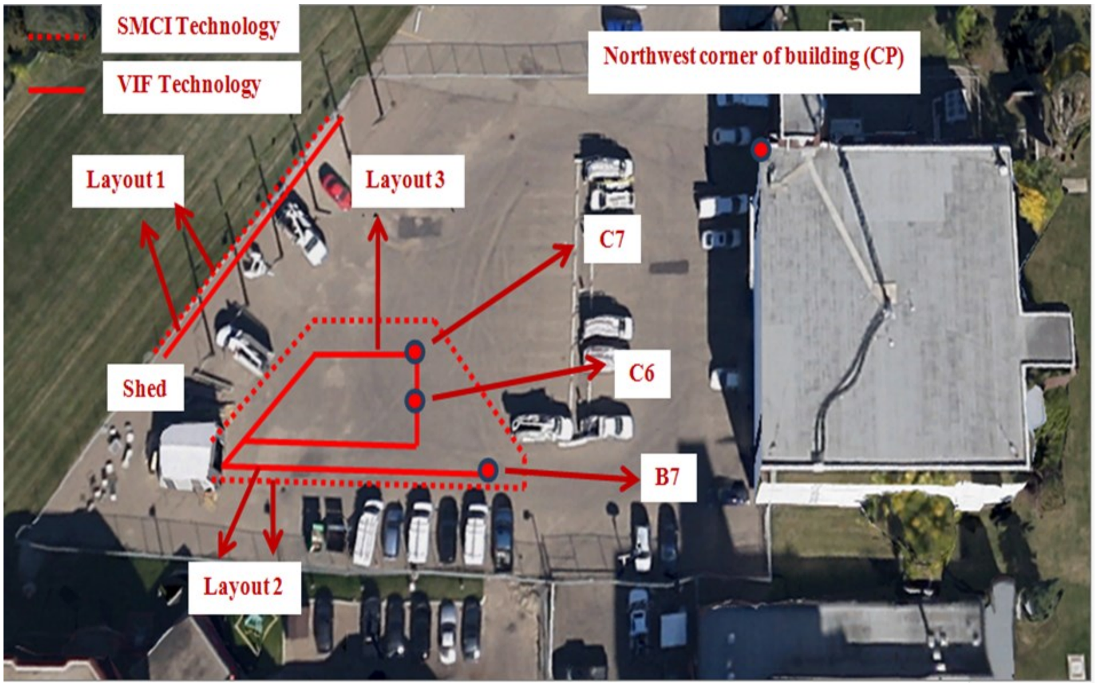


Figure 3-1: Installation layouts, Control Point (CP), shallowest points (C7, C6 & B7)

3.4.2 Vertical Inlaid Fiber (VIF) technology

This technology uses Vertical Deflecting Conduit (VDC) (Figure 3-2a), which consists of two robust, slim conduit halves fastened together by a zipper tool to form a channel that encloses the FO cable. FO cables can be zipped, pulled, or blown into the conduits (TeraSpan 2013).

VIF installation beings by measuring and marking the desired layout with spray paint along the path of a thread strung between predetermined points. Next, the trench is cut using a Husqvarna 6600 concrete cutter. After cutting is completed, the trench is cleaned using a shovel and metal hook, and the trench corners are smoothed using a small saw and metal hook.

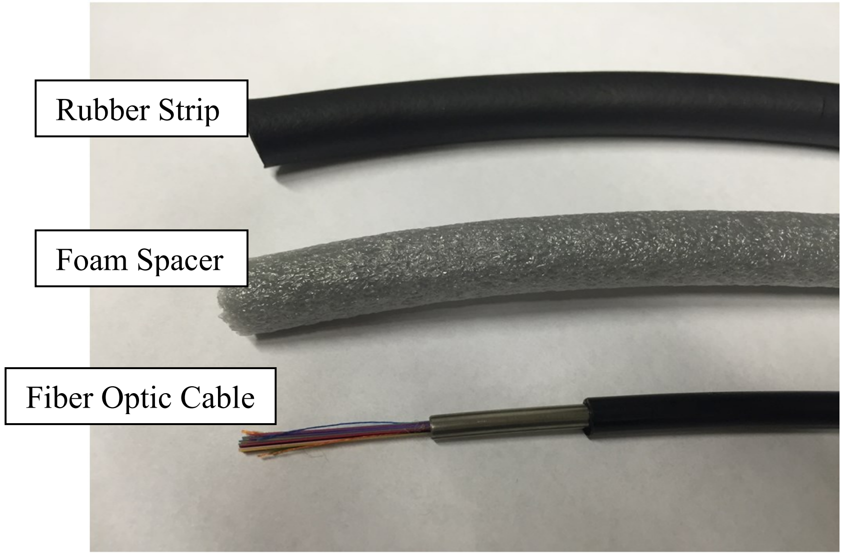
The cable and wire tracer are inserted into the channels of the VDC and zipped up. After the conduit is zipped, it is laid in a vertical position inside the trench. The last step in the installation procedure is surface reinstatement. The trench is first filled with a layer of sand, followed by a layer of cold asphalt. A 100 lb packing wheel is then used for compaction to provide a fine finish on the pavement's surface.

3.4.3 Surface Micro Cable Inlay (SMCI) technology

This technology uses Micro Cabling Systems (MCS) road cable, consisting of a rugged central copper tube including packages of 12 optical fibers. In order to impede water penetration, thixotropic gel is used to fill the cable and a polyethylene sheath covers the cable for identification purposes and corrosion resistance (Figure 3-2b). A copper and polyethylene coating provides sufficient protection and crush resistance for the cable (JETT Networks 2014).

The installation procedure for SMCI technology begins similarly to VIF; once measured, the layout is marked using a thread and spray paint. The trench is wet-cut using a Husqvarna FS 4800 D. A vacuum and blower are then used to clean and dry the trench. With this technology, cable installation consists of three phases: laying fiber optic cable in the trench, placing a layer of foam spacer over the cable, and placing a rubber strip over the spacer to secure the cable and foam spacer in the trench. The spacer is round, and made from flexible closed cell foam to deter movement caused by freeze/thaw cycles and protect the cable from moisture and water ingress. The rubber strip is a heat and chemical resistant neoprene which holds and fixes the cable and foam spacer in place (Figure 3-2b).

(a)



(b)

Figure 3-2: (a) Vertical Deflecting Conduit (VDC), (b) SMCI cable, foam spacer and rubber strip

Surface reinstatement starts by filling the trench with a layer of play sand, which is uniformly graded with small particle size, followed by sealing the trench with hot bitumen to prevent water ingress. To reduce the hot bitumen's stickiness before cooling down, the reinstated surface is coated with sand.

3.4.4 Installation specification

Installation specifications and a cross section of the VIF and SMCI technology are provided in Table 3-1 and Figure 3-3, respectively.

Table 3-1: Installations specifications- VIF and SMCI technology

Installation specification (all units in cm)		
Description	VIF technology	SMCI technology
Trench depth	22	7.6
Trench width	1.5	0.9
VDC thickness	5.2	NA
FO cable thickness	0.6	0.6
Foam spacer thickness	NA	1
Rubber strip thickness	NA	1.2
Sand layer thickness	7.2	3.8
Hot bitumen sealer thickness	NA	1.27
Cold asphalt layer thickness	9	NA
Existing Asphalt thickness	Almost 9	Almost 9

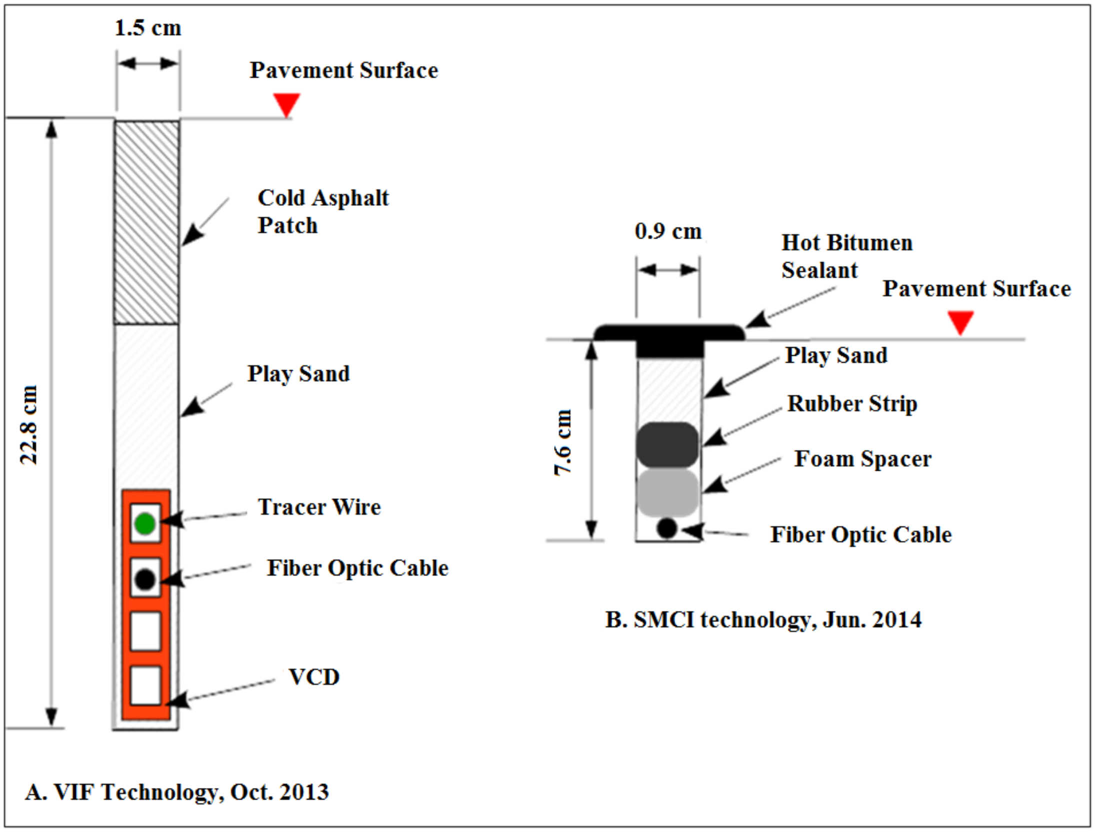


Figure 3-3: Cross section of VIF and SMCI installations

3.5 Installation monitoring result

The above mentioned installations allowed the evaluation of construction phase parameters, including productivity rate and generated waste material, as well as operational phase parameters, including installation physical integrity and the fiber's optical performance.

3.5.1 Construction phase

3.5.1.1 Activity duration and productivity rate

Some activities in the micro-trenching process were completed with different crew sizes; therefore, the durations were normalized assuming a two-person crew. An exception was made for cutting the trench, as this step is completed with one cutter that requires only a single person for operation. Table 3-2 contains the normalized durations and time distribution of activities for both installation technologies.

Table 3-2: Normalized activity durations

Normalized activity durations and time distribution with a two-person crew						
Activity	VIF technology			SMCI technology		
	Project length (m)	Activity duration (hr)	Time distribution	Project length (m)	Activity duration (hr)	Time distribution
Marking the layouts	115	0.9	4.91%	102	0.57	8.02%
Cutting the trench	115	2.5	13.13%	102	0.58	8.25%
Cleaning the trench and smoothing the corners	115	7.2	38.57%	102	3.38	47.88%
Cable installation	115	2.1	11.43%	102	0.97	13.68%
Reinstatement	115	6.0	31.96%	102	1.57	22.17%
Total	115	18.67	100%	102	7.07	100%

Figure 3-4 represents the measured productivity of each micro-trenching activity in both installation technologies using a two–person crew. For both technologies, marking the layout has the highest productivity rate among all activities, while cleaning the trench has the lowest productivity rate because it is the most time consuming activity. Furthermore, the productivity rates of SMCI technology are significantly higher than VIF technology, which is due to the shallower depth of SMCI installations. Shallower depth results in less waste material, less required reinstatement material, and easier creation and reinstatement of the trench. The total micro-trenching productivity associated with VIF and SMCI technologies with a two–person crew is 6.2 m/hr and 14.4 m/hr, and considering an eight-hour workday, productivity rate is approximately 50 m/day and 115 m/day, respectively. In total, the productivity of SMCI technology is approximately two times that of VIF technology. It should be noted that as the estimated productivities are based only on installations of a pilot project, they are not representative of micro-trenching in general; however, they can provide insight into the productivities of these installation technologies.

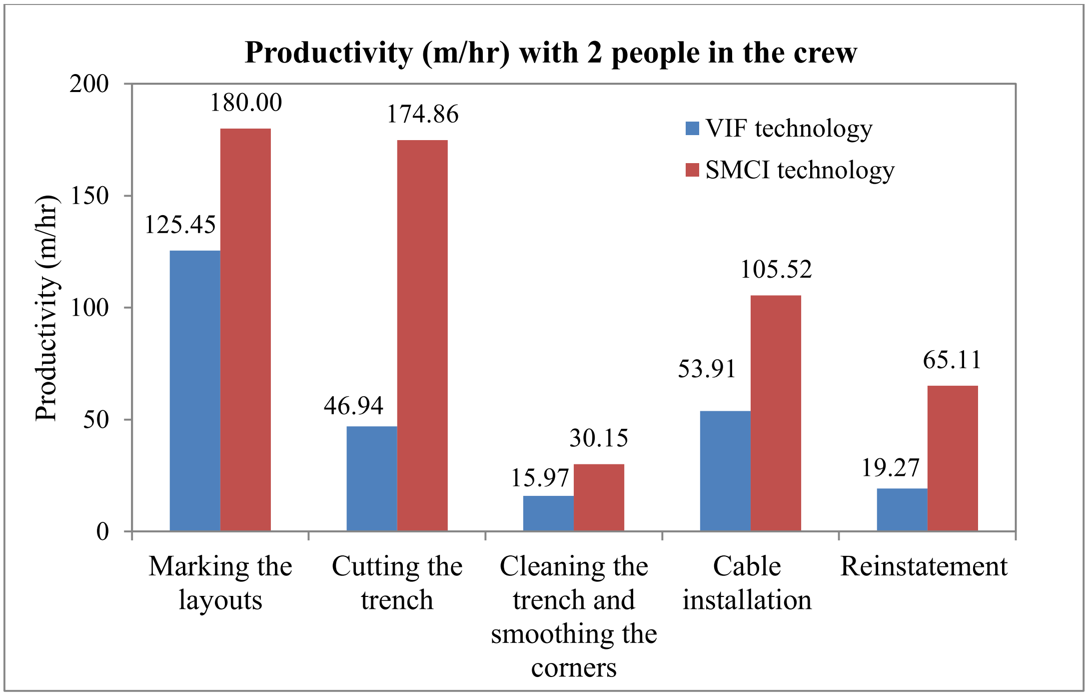


Figure 3-4: Productivity rates in both FO installation technologies

3.5.1.2 Generated waste

The excavation waste generated during this project was ground rock, asphalt, and dirt. The volume of generated waste of both technologies was estimated using trench dimensions, with the total approximate generated waste estimated as 0.42 m3 and 0.07 m3; 3586 cm3/meter and 710 cm3/meter for VIF and SMCI installations respectively. Typically, waste generated by micro-trenching is lower compared to the traditional open cut trenching method, which is a significant advantage of micro-trenching.

3.5.2 Operational phase

To investigate long-term performance and functionality of the installation technologies used in this study, GPR inspection and an Optical Time-Domain Reflectometer (OTDR) test were performed.

3.5.2.1 Ground Penetrating Radar (GPR) results

GPR is an electromagnetic time-dependent technique which provides high-resolution images of shallow ground subsurface and can estimate the location and depth of buried objects. This equipment operates by scattering electromagnetic waves through material, allowing it to locate shallow underground objects via radio waves (Daniels 2000; Sensors & Software 2013).

In VIF technology, the tracer wire, inserted in the channels of VDC, is a copper-coated wire used to make the conduit more detectable by GPR when determining conduit location and movement. GPR inspections were conducted on November 8, 2013, May 12, 2014, July 30, 2014, and May 4, 2015. Figure 3-5 Shows the GPR inspected points in both VIF and SMCI installations.

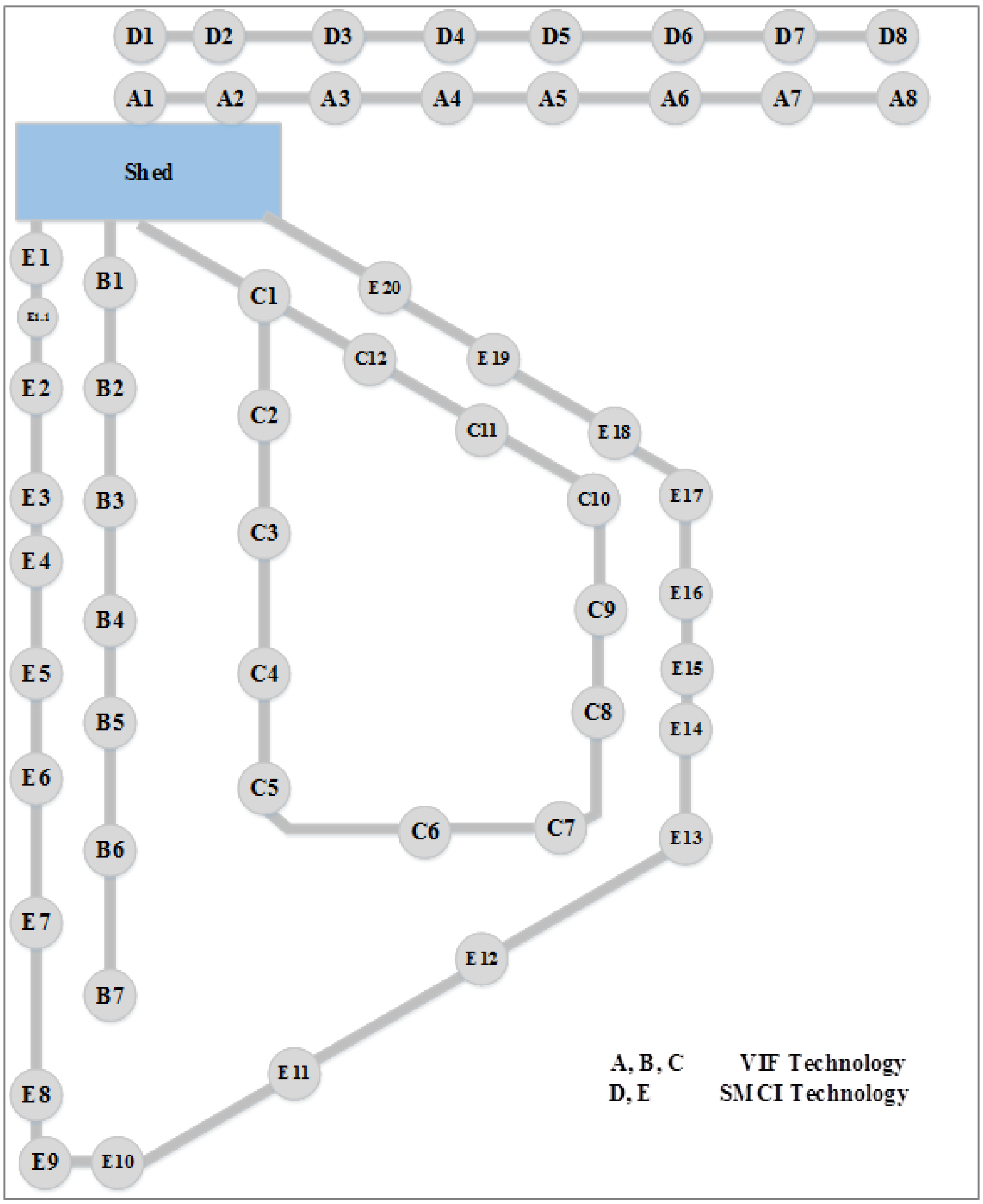
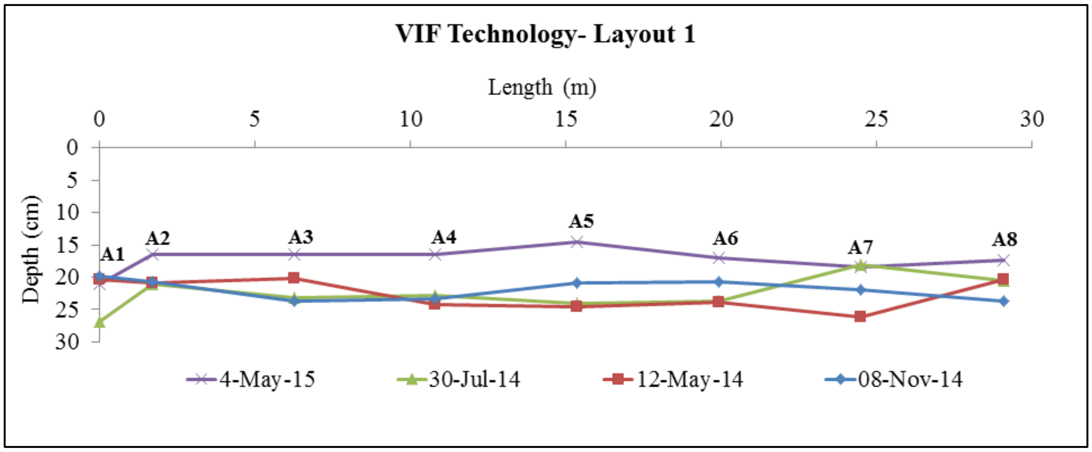
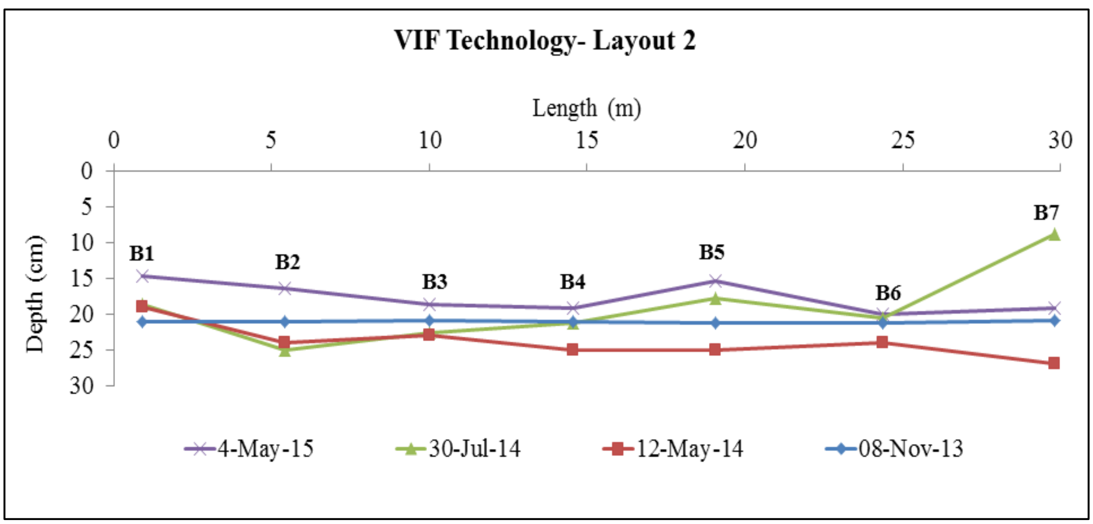


Figure 3-5: GPR inspected points in VIF and SMCI installations

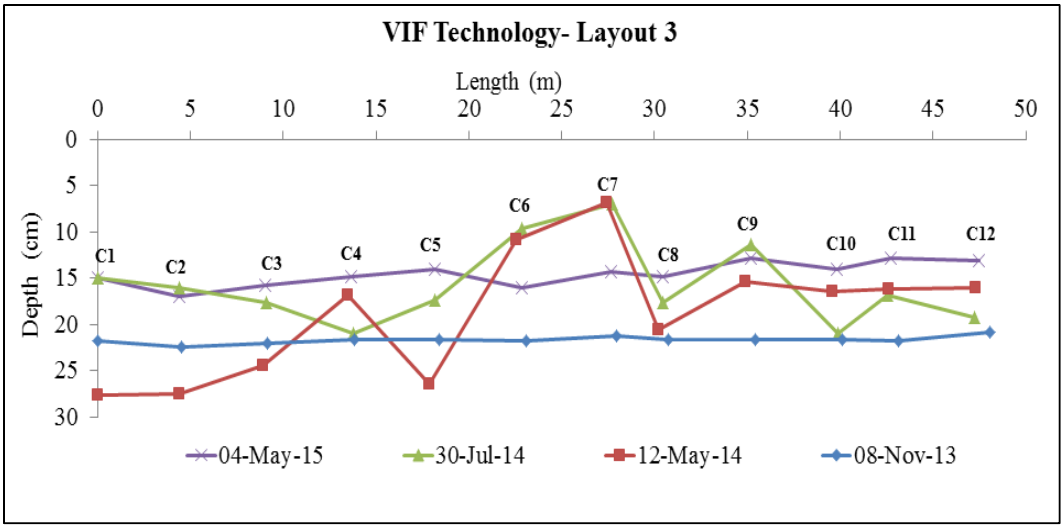
To investigate physical integrity of the installation, conduit location was detected using GPR. Figure 3-6a to 6c display the conduit profile of Layout 1(A), 2(B), and 3(C) for VIF technology. It must be noted that the conduit profile is obtained using its depth relative to surface. In Layout 3(C), the loop is unfolded and the conduit profile is provided. Points C5, C7, and C10 are located in the bends of the layout (intersection of straight lines).



(a)



(b)



(c)

Figure 3-6 - Conduit profile for VIF technology- (a) Layout 1(A), (b) Layout 2(B), and (c) Layout 3 (C)

Figure 3-6a and Figure 3-6b show that both Layouts 1 and 2 are in relatively good condition with little vertical displacement toward the surface, except at point B7, which had a shallow depth of 8.8 cm according to the GPR inspection on July 2014; however, it moved downward and has a depth of 19 cm according to recent GPR inspection. Additionally, in the northeast corner of Layout 3 (loop layout), the conduit depth was significantly shallower than its initial depth in July 2014. In Figure 3-6c, it can be seen that C7 and C6, with respective depths of 7 cm and 9.7 cm according to the GPR inspection on July 2014, were the shallowest points of the conduit profile in layout 3 and had respective approximate displacements of 14 cm and 12 cm toward the surface. However, C6 and C7 moved downward and their current depths are 16 cm and 14 cm respectively according to recent GPR inspection. These three points (C6, C7, and B7) are in a more direct path of traffic compared to other points, as depicted in Figure 3-1.

Recent GPR inspection demonstrates that although there are not significantly shallow points in the three layouts, the installations have moved upward from their installed depth (November 2013). Layout 3(C) has an average depth of 14.55 cm (compared to 21.5 cm at November 2013); this value is 17.4 cm for layout 1 (A) and layout 2 (B) (compared to 21.5 cm at November 2013).

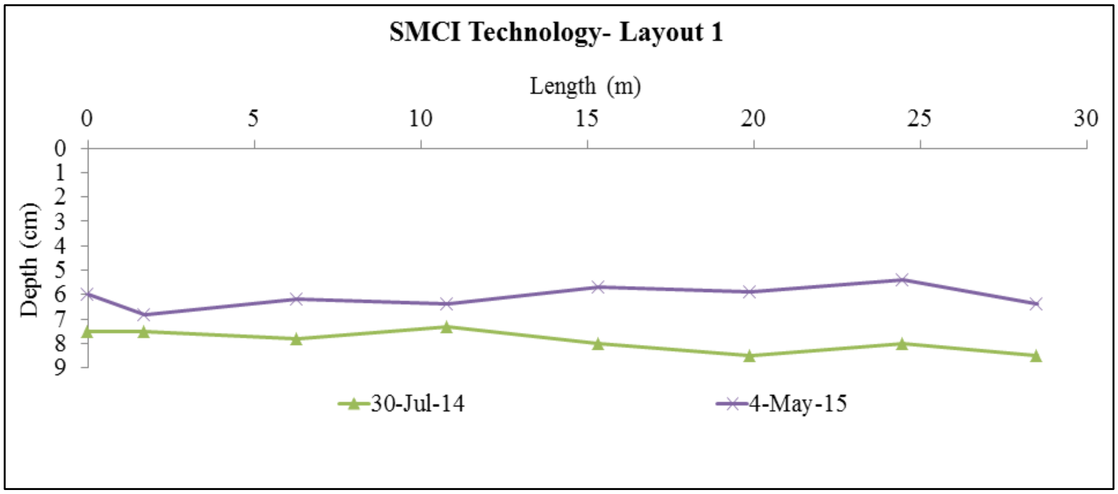
It can also be concluded that traffic load results in increased conduit movement in layouts with bends compared to strictly straight layouts. In loop layouts, the conduit has increased upward and downward movement, which may be the result of stresses induced in the bent portions of the layout.

To validate movements measured with GPR, three specific points (C6, C7, and B7) were excavated, and the locations of the conduit were measured manually. Table 3-3 represents the GPR measurements versus observed depth in the excavated sections in July 2014. The observed depths matched with the GPR results; this verifies that GPR measurements are reliable and correct. The consistent approximate 1.5cm difference between GPR results and the observed depths occur as the GPR measures the depth of the wire tracer within the conduit channel, while the observed depth measures the depth of the top of the conduit.

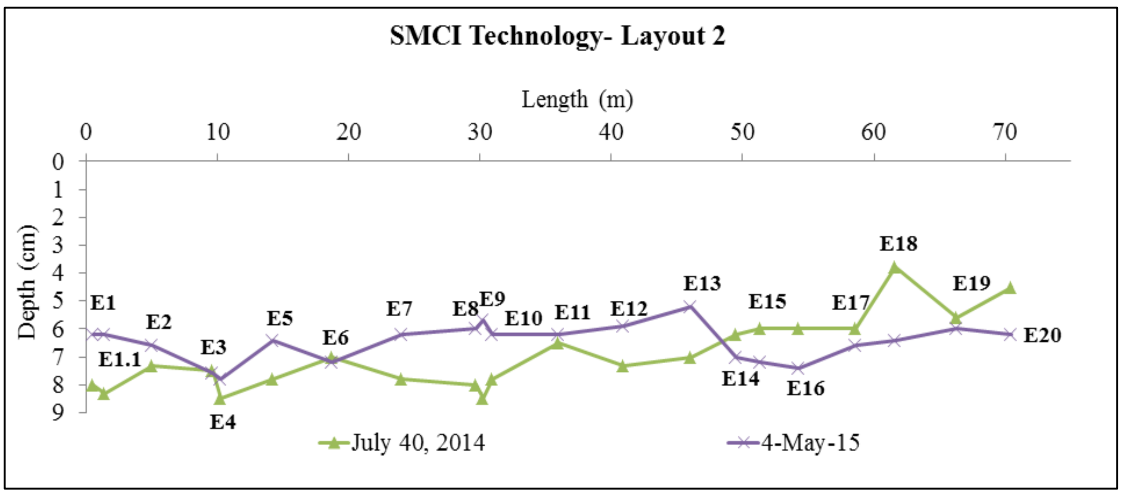
Table 3-3: GPR measurement vs. observed depth in open sections (cm)

Point ID	GPR depth (wire tracer depth)	Observed depth (Top of the conduit)
C6	9.7	8
C7	7	5.5
B7	8.8	6

Figure 3-7a and 3-7b display the conduit profile of Layout 1(D) and 2(E) for SMCI technology. It must be noted that the conduit profile is obtained using its depth relative to the surface. In Layout 2 (E), the loop is unfolded and the conduit profile is provided. Points E9, E10, E13, and E17 are located in the bends of the layout (intersection of straight lines). GPR results indicate that there is not much upward and downward fluctuation in movement in these installations; however, the installations had average upward movement of 1.7cm in straight layout (D) and 0.44 cm in loop layout (E) toward the surface. The low fluctuation suggests that using a rubber strip and foam spacer for the purpose of stabilizing the cable in the trench is a promising technique, but the installation needs to be inspected for several years to be able to draw stronger conclusions on its effectiveness.



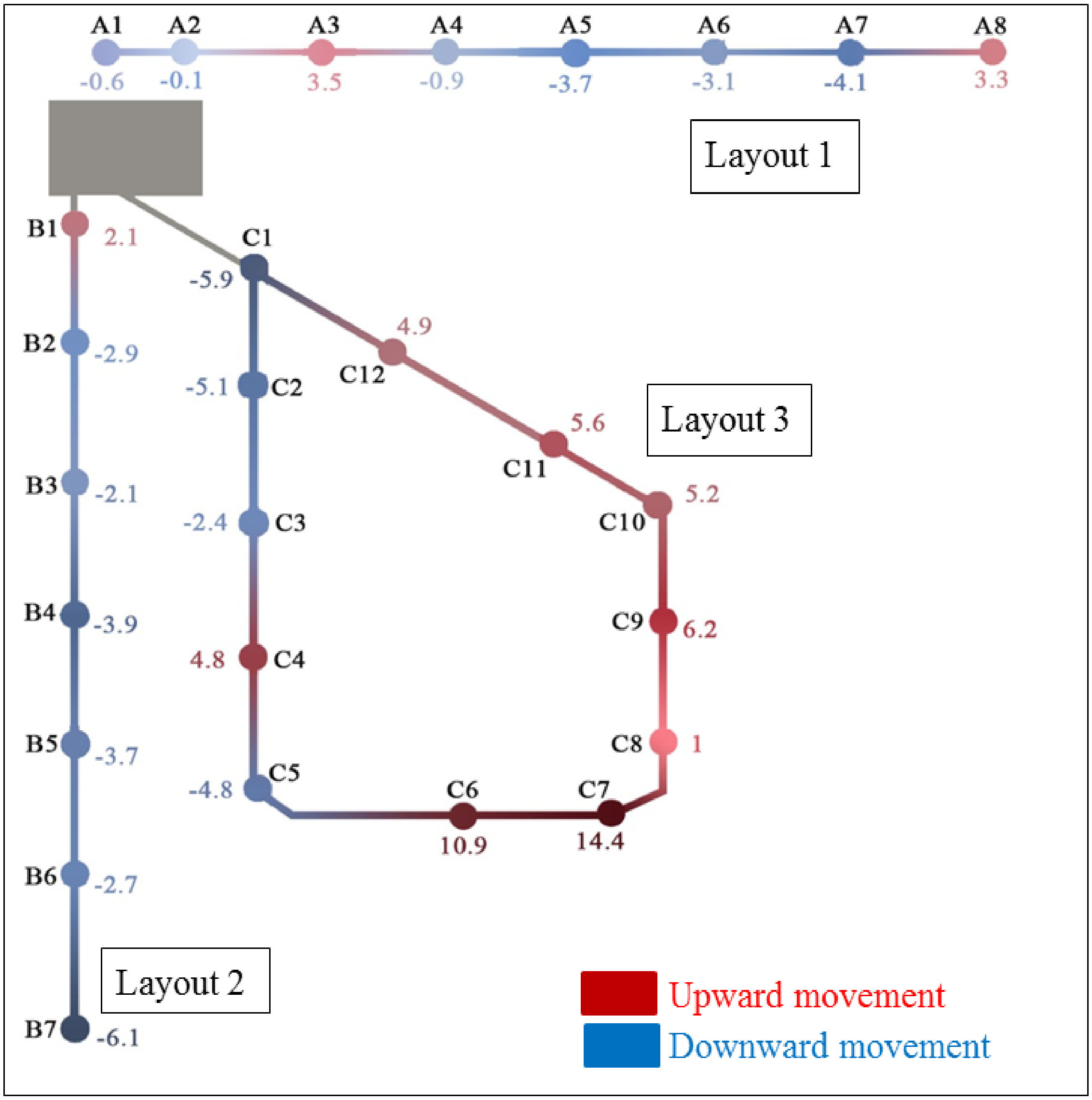
(a)



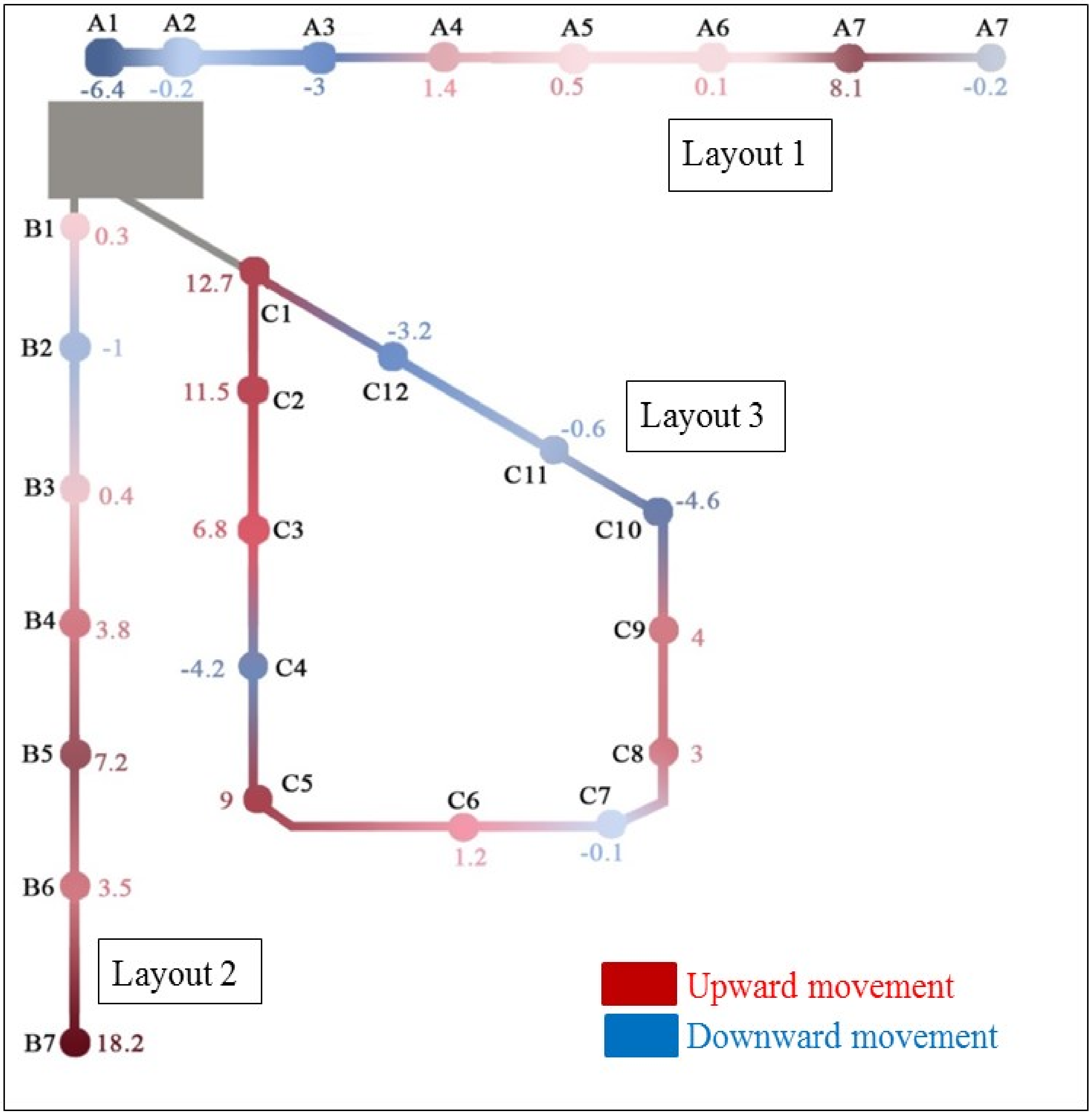
(b)

Figure 3-7 - Conduit profile for SMCI technology-(a) Layout 1(D) and (b) Layout 2 (E)

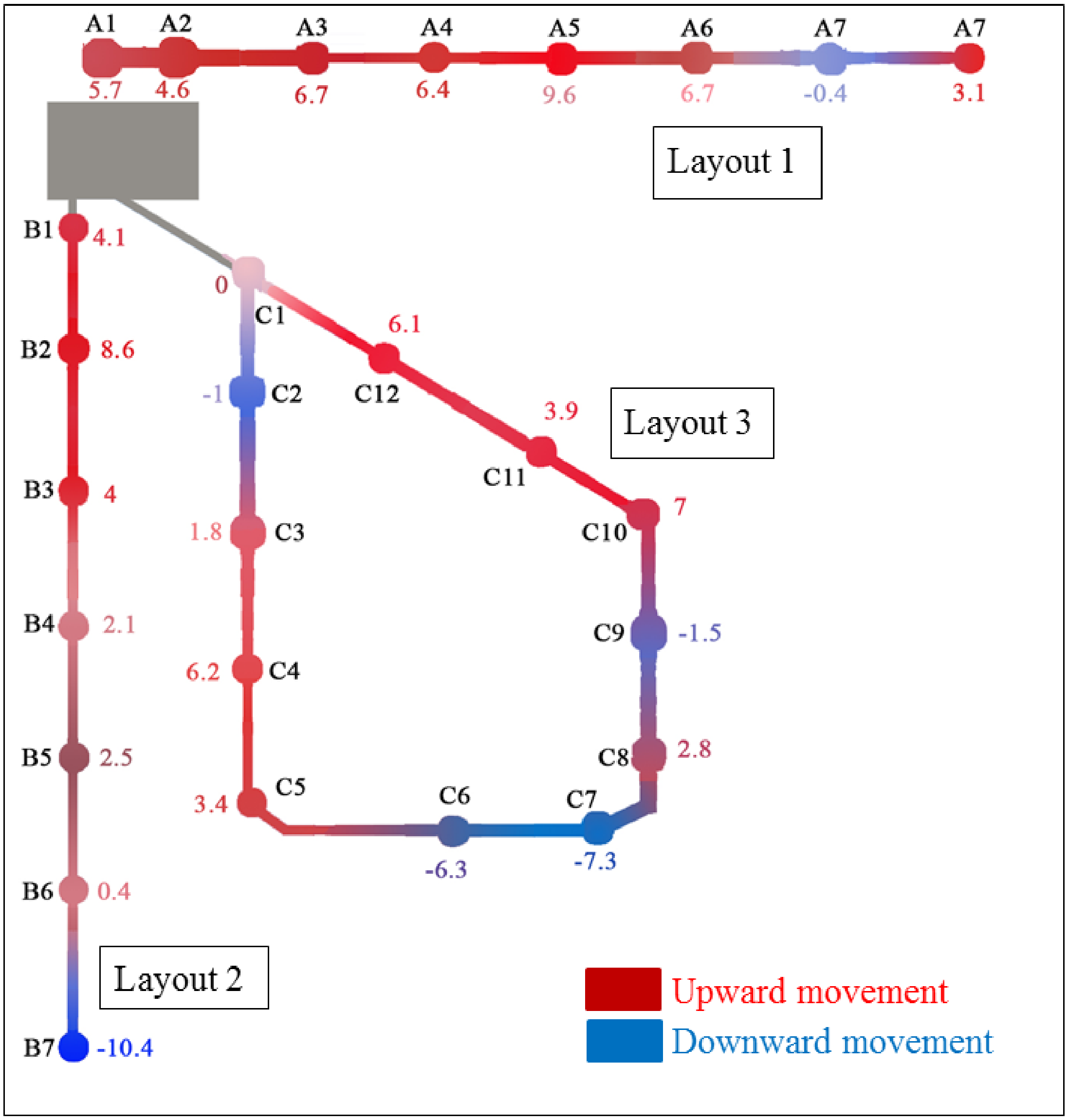
Figure 3-8a to 3-8c and Figure 3-9 show the seasonal movement of conduit for both VIF and SMCI installations from November 2013-May 2014 (winter), May 2014-July 2014 (summer) and July 2014-May 2015 (winter). Negative signs indicate downward movement of conduits while positive signs indicate upward movement with both measured in centimeters.


A1
A2
A3
A4
A5
A6
A7
A8
-0.6
-0.1
3.5
-0.9
-3.7
-3.1
-4.1
3.3
Layout 1
B1
2.1
C1
-5.9
4.9
B2
-2.9
-5.1
C2
C12
5.6
Layout 3
C11
B3
-2.1
-2.4
C3
C10
5.2
B4
-3.9
C9
6.2
4.8
C4
B5
-3.7
C8
1
-4.8
C5
C6
C7
10.9
14.4
B6
-2.7
Layout 2
B7
-6.1
Upward movement
Downward movement

(a)


A1
A2
A3
A4
A5
A6
A7
A7
-6.4
-0.2
-3
1.4
0.5
0.1
8.1
-0.2
Layout 1
B1
0.3
B2
-1
B3
0.4
B4
3.8
B5
7.2
B6
3.5
B7
18.2
Layout 2
12.7
C1
11.5
C2
6.8
C3
-4.2
C4
9
C5
C6
1.2
C7
-0.1
C8
3
C9
4
C10
-4.6
C11
-0.6
C12
-3.2
Layout 3
Upward movement
Downward movement

(b)



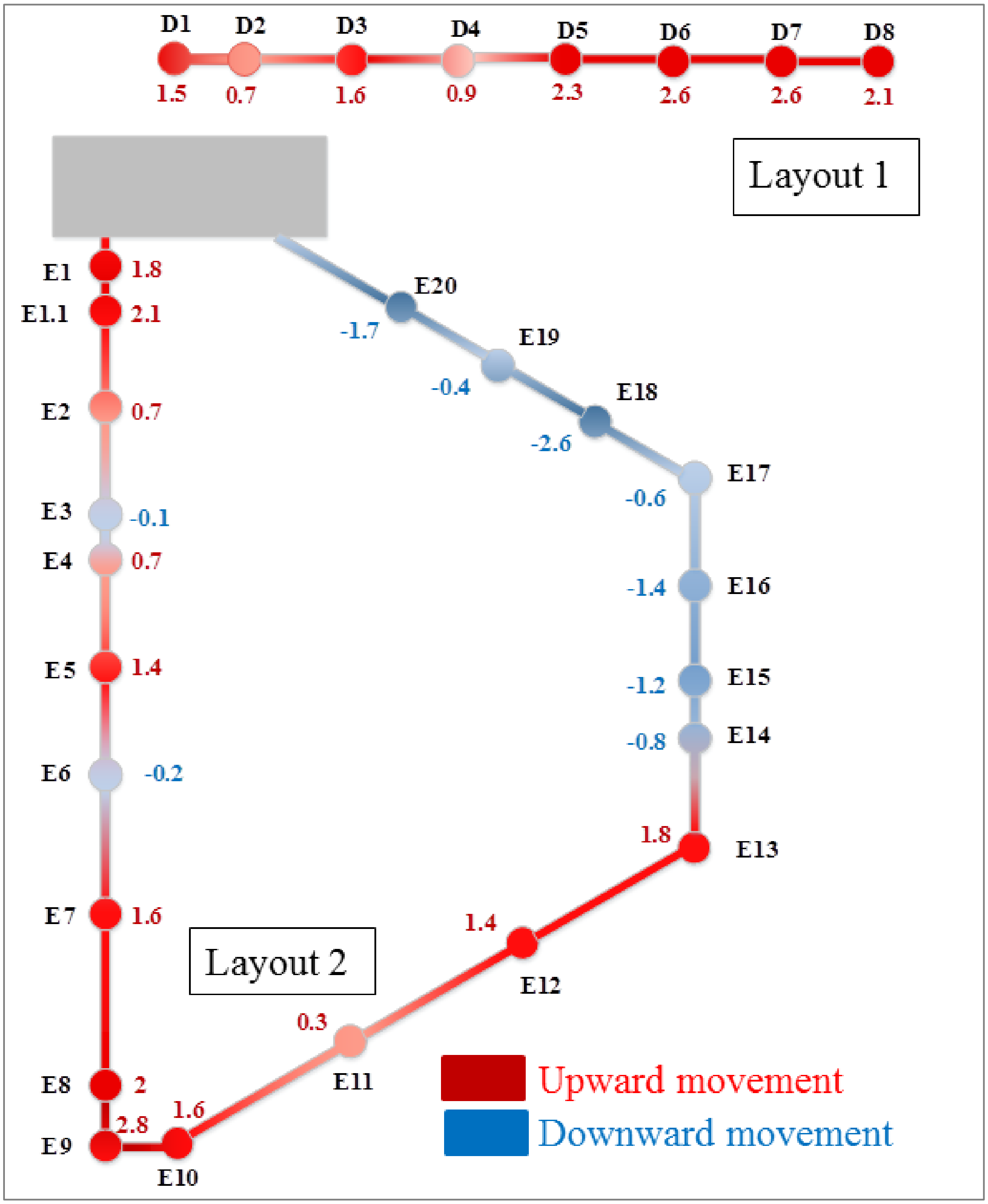
(c)

Figure 3-8: Conduit location variation relative to surface for VIF technology: (a) November 2013 to May 2014 (winter), (b) May 2014 to July 2014 (summer), (c) July 2014 to May 2015 (winter)

In winter 2014 (Figure 3-8a), in the VIF installations, Layout 1 (A) and Layout 2 (B) experienced downward movements of up to 6 cm with the exception of points A3, A8, and B1. The straight section of the loop layout (C) experienced the same behaviour, with the exception of C4. Conversely, C10 to C12 had upward movements of approximately 5 cm. These points in addition to A3, A8, B1 and C4 follow a different trend due to conduit rigidity. When a portion of the conduit rises towards the surface, the other sections sink to maintain conduit stability. In addition, the northeast corner of the loop layout (C6, C7, C8, and C9) have lifted toward the surface significantly.

In the summer of 2014 (Figure 3-8b), conduit in Layout 1 (A) and Layout 2 (B) moved toward the surface, most significantly at B7 with an upward movement of 18 cm; however, A1 and A3 in Layout 1 experienced downward movements of 6cm and 3cm, respectively. The straight section of Layout 3 (C) experienced similar conditions, with an upward movement of 6-12cm towards the surface at all points except C4. The conduit had little movement in C6 and C7 as maximum movement occurred in winter and the asphalt layer impeded further upward movement. C10 through C12 and C4 moved downward in response to upward movement in other sections of the loop due to conduit rigidity and stability maintenance.

In winter 2015 (Figure 3-8c), layout 1 (A) and layout 2 (B) had moved toward the surface up to 9.6 cm, except at point B7 which had 10 cm downward movement. Additionally, in layout 3 (C), at most points the conduit moved upward up to 7 cm, except the points that had the shallowest depth according to July 2014 GPR inspection, C6 and C7, which had downward movement of 6 cm and 7 cm.



(d)

Figure 3-9: Conduit location variation relative to surface for SMCI technology- July 2014 to May 2015 (winter)

In winter 2015 (Figure 3-9), in SMCI installation, Layout 1 (D) and the straight section of layout 2 (E) moved toward the surface up to 2.8cm. However, the other section of the loop layout (E) had a slight downward movement up to 1.7 cm.

According to TeraSpan (2014), the shallow depth observed at selected points is an installation-related issue. Specifically, certain points may not have been excavated as deeply due to obstacles within the ground or hard ground surface conditions. As a result, the conduit cannot be placed deep enough and compression on either side of the spot creates potential for upward movement. The only solution for this issue is to ensure the trench is clean and the depth is consistent along the installation length (Personal communication with TeraSpan, July 2014).

A critical way of preventing vertical movement, such as that experienced in the select sections of this project, is the effectiveness of the micro-trench's reinstatement. Based on research results of VIF installation, using sand and cold asphalt above the installed conduit is not a viable solution for trench reinstatement in cold regions. The material used in this step must flow easily inside the trench and stabilize the conduit in its place preventing future vertical displacement. Future research is suggested to focus on reinstatement modification toward more stabilization of conduit in the trench and, ultimately, preservation of road strength.

3.5.2.2 Optical Time-Domain Reflectometer (OTDR) result

OTDR is an instrument used for investigating the FO integrity and measuring optical power loss associated with FO cables due to different elements such as splices, cable, or connectors (The Fiber Optic Association 2014). This instrument provides a graphical display of optical loss of the system, which is referred to as a signature trace (Corning Cable Systems 2002). The optical trace is useful for visual purposes and troubleshooting (Corning Cable Systems 2009).

To investigate the optical performance of FO cable in the loop layout, an OTDR, EXFO FTB-1, was used several times following the project's installation. Cables were tested by the OTDR with a 1310 nm wavelength and 50 ns pulse width. Fiber span refers to the length of fiber which is investigated by the OTDR (Corning Cable Systems 2009). Several OTDR tests were performed, and the span losses of fibers are provided in Table 3-4.

Table 3-4: OTDR results, Span loss (Wavelength: 1310nm)

OTDR results-Span loss (1310nm)				
Fibers	Nov 20-2013 (-18C)	Jan 06-2014 (-10C)	Jan 22-2014 (-8.7C)	April 29-2014 (18C)
1	0.258	0.246	0.253	0.246
2	0.245	0.289	0.176	0.243
3	0.245	0.251	0.257	0.243
4	0.258	0.233	0.239	0.253
5	0.260	0.241	0.239	0.253
6	0.222	0.235	0.23	0.239
7	0.258	0.238	0.236	0.240
8	0.249	0.265	0.272	0.239
9	0.237	0.241	0.243	0.245
10	0.249	0.215	0.238	0.269
11	0.250	0.259	0.22	0.226
12	0.221	0.228	0.245	0.247

According to TELUS (2014), 0.5 dB/Km is the maximum allowable loss in a fiber span. In this project, the total length of fiber is 0.7048 Km; therefore, the maximum allowable span loss is 0.7048*0.5=0.3524. The totaled span losses equate to less than 0.3524, which means current cable performance is acceptable.

3.6 Summary and Conclusion

Micro-trenching is a new, less-invasive fiber optic deployment method used in business districts and congested urban areas as the environmental impacts and community disruption associated with its operations are significantly lower than that of traditional installation methods. However, due to its shallow depth, installations may be easily impacted and damaged by thermal expansion/contraction, ground freeze/thaw cycles, and frost heave.

To investigate micro-trenching's viability in cold regions, a pilot installation was performed with two micro-trenching technologies (VIF and SMCI) in October 2013 and June 2014, respectively. Installations are intended to be monitored over several years to evaluate the techniques' viability.

In both technologies, cleaning the trench and smoothing its corners were the most time consuming activities, followed by trench reinstatement. Overall, SMCI technology had a higher productivity rate in comparison to VIF technology. However, the risk of FO damage when using SMCI technology is greater due to the shallow installation depth.

Both GPR inspections and OTDR tests were performed for VIF technology beginning in November 2013. Although monitoring the installation is an ongoing process that requires several years for accurate performance evaluation, results gathered from 2013-2015 for VIF technology suggest that optical performance has not changed. However, according to the GPR results of May 2014, the conduit has risen to 14 cm at a point -- C7 -- located in the traffic zone. Comparing this value to the initial installation depth of 22 cm, 65% vertical movement of the conduit had occurred in the trench. There was also upward and downward movement in the loop layout, which may be caused by the induced stress associated with bends in the conduit within the layout. At most points, the conduit moved downward in cold weather conditions and rose in the summer, possibly due to the thermal expansion of the conduit. In VIF technology, comparison of the initial and recently obtained GPR results indicate that the whole installation moved upward for 3-7 cm; for SMCI technology, this value ranges between 0.44-1.7 cm.

Monitoring results of SMCI technology from 2014-2015 demonstrates that the conduit's maximum observed displacement is 2.8 cm, which indicates 36% vertical movement, considering the installation depth of 7.6 cm. Comparing this value with the 65% movement of VIF technology suggests the effectiveness of the SMCI technique's foam spacer and rubber strip for the purpose of fixing the cable in the trench. The decrease in motion confirms that reinstatement procedure is critical to micro-trenching installations, especially in cold regions. Reinstatement material should be fine enough to easily fill the narrow trench; however, it must also hold the conduit and cable in place to prevent upward movement. The results of this study suggest that both of the reinstatement methods investigated are not sufficiently reliable for widespread Fibre-to-the-Home installation, and improved reinstatement methods are required to stabilize the conduit in the trench and preserve road strength. Additional research on micro-trenching installations is needed to identify and test alternative methods.

Chapter 4. Productivity Analysis of Micro-trenching Using Simphony Simulation Modeling [3]

4.1 Abstract

Micro-trenching is an innovative installation method of fiber optic cable in residential areas and business districts which minimizes surface scaring and potential negative social and environmental impacts. Installation process entails the following: creation of a narrow trench, insertion of the conduit or cable and trench reinstatement. This paper discusses a Simphony simulation model of the micro-trenching procedure and analyzes its productivity. Brief descriptions of the micro-trenching method and two field installations implemented for the model validation are included. The details on Simphony simulation are further discussed to present the model development, validation and productivity analysis of micro trenching

Simulation model was developed for two different installation depths, 7.6cm and 23 cm. To provide an estimation of project duration, the impact of weather conditions on micro-trenching productivity is also considered. The developed model can be used for *what if* scenarios and for predicting the outcomes, which may be useful for studying the procedure and verifying if any productivity improvement can be achieved. The results indicate that influence of installation depth is more significant than the impact of weather conditions and the depth of installation can reduce the productivity up to 50%. The simulation model demonstrates that the productivity can be improved up to 16% by overlapping of the two steps during the installation process: starting the cleaning procedure when a portion of cutting is completed.

4.2 Introduction

The number of internet users has grown considerably over the last twenty years. Internet has become a ubiquitous source of both entertainment and information and the use of heavy bandwidth applications on mobile devices and personal computers proliferates considerably (Saeed 2011). CISCO, an American multinational technology corporation that deals with designing, fabricating and selling networking equipment, estimates

[3] A version of this chapter was submitted to International Journal of Construction Management, Taylor and Francis.

consumption trends in North America to reach approximately 35,000 PB/month (CISCO systems Inc. 2012, CISCO 2010).

For the above mentioned reasons, overall bandwidth requirements have increased significantly and existing copper telecommunication infrastructure could no longer be sufficient for data transmission. As population density and distance between them increase, inherent limitations of data transmission capacity of copper become more obvious and apparent (Saeed 2011). High capacity broadband networks are supported by fiber optic cables; comparing with existing copper cabling system, fiber optic networks are characterised by unlimited data transmission capacity. Fiber optic cable is smaller, lighter, less delicate to interference and of high bandwidth capacity (Gokhale 2006). Fiber optic (FO) backbone networks improve communication hardware allowing information to transfer faster (Saeed 2011). In North America and in many large USA cities, fiber optic services are installed in downtown areas and business districts (Gokhale 2006; W & H Pacific 2001). Such areas with highly concentrated population, ascending volume of electronic data transmission, overcrowded underground space and artistically landscaped ground surface render traditional trenching methods nearly impossible to implement (Atalah et al. 2002). Particularly, the traditional way of completing last-mile fiber optic installation or Fiber to the Home (FTTH) is cutting trenches into/under streets and installing conduits, splicing, and building entrance facilities. The consequences of this uncontrolled trenching are streets with patches and crumbling asphalt (Gokhale 2006). Besides, open-cut excavation does not turn out to be a reasonable and viable installation method due to the high costs of utility exploration and protection, surface restoration and landscaping, traffic control, and economic impact on surrounding businesses. It also casts negative impact on pavement longevity and other environmental impacts such as dust and noise (Atalah et al. 2002).

Micro-trenching, as it is fully described further, is one of the alternative fiber optic installation methods that may be used to build a FO network cost-effectively with much less disruption, negative environmental and social impacts.

Productivity is considered a key indicator in economic performance assessment (OECD 2008). To assess the success of construction project, labour productivity as a key factor is often included (Khan 2010). It is measured by the output value divided by the unit of resource input; high productivity results in lower per-unit cost to perform a task or operation (Su 2010). Therefore, it is necessary to analyse micro-trenching productivity and offer suggestions for its improvement.

4.3 Objective

The objective of this paper is to analyse the productivity of micro-trenching installation. Utilizing time distributions of micro-trenching installation procedures gained from the industry experts, a simulation model is developed and the impacts of weather conditions and installation depth on micro-trenching productivity are investigated. An amendment in the installation process is also suggested to improve the productivity which may be demonstrated by using the results of the modified model. Simulation results are considered reliable since the model is validated using the field installation data.

4.4 Methodology

In order to investigate the productivity of micro-trenching, the installation process was divided into 5 steps and simulated using Simphony software: a computer simulation platform for modeling of the construction systems. Time distributions of each activity for winter and summer time and for two different installation depths were obtained from the industry experts based on their experience and fed to the model (TeraSpan and JETT Networks, December 2014 and January 2015). In order to validate the model, field installations at two different depths were performed and the model results were compared to field data. This model also provides a seasonal comparison in addition to comparing results for two different installation depths. It must be noted that the generated output of micro-trenching productivity is considered an estimation due to the lack of available data on micro-trenching installations. Notably, by employing more data, simulation may be expanded to be applicable to other installation depths and various seasonal conditions.

Simulation model allows applying different scenarios and observing the variations in results. Since the simulation is validated, in case of any modification in the procedure, the validity of the results will not be affected and the outcome of the simulation is expected to be reliable. Having observed and investigated the micro-trenching procedure, its productivity may be improved by modifying the timing of the installation steps. The obtained results demonstrate the productivity enhancement.

4.5 Micro-trenching

Micro-trenching is an innovative technique for installation of communication infrastructure specially fiber optic cables in roadways. It includes placing a cable or conduit inside a trench narrower than 20mm wide and up to 120-300mm deep (DCMS 2011).

There are three main steps of the micro-trenching procedure: 1) creation of the trench, 2) installation of conduit or cable, and 3) surface reinstatement.

The first step of the micro-trenching procedure begins with marking the layouts to be trenched by a paint spray, followed by cutting of the micro trench using a saw, which is often referred to as a micro-trencher.

The road surface may shift due to the traffic weight, and even small movements and deflections can cause damage to the cables and ducts (Network Strategies 2008). Therefore, a micro trench is excavated along the road gutter edge near the cement curb. This provides the trench with extra stability, and there is less potential for damage as the trench is not situated along the wheel path (Liteaccess Technologies Inc 2010; Network Strategies 2008).

After completing the first step, it is necessary to clean and dry the trench before cable installation. Pressure washers are usually used for cleaning, and drying can be performed utilizing compressed air and a blowpipe (ITU 2003).

The second step of the procedure is cable or conduit deployment inside the trench. Since this method is commonly used for fiber optic deployment in city centers and business districts, future construction activities, excavation or infrastructure installation pose a major threat to the installed cables. Using conduits provides a required protection from these hazards as well as frost and operational loads (Personal communication, TeraSpan, November 2012). There are various types of conduits used for this purpose which provide stability on edge (GM Plast 2014; TeraSpan 2013). Alternatively, cables may be placed inside a metallic tubing covered by a polyethylene (PE) jacket providing required crush and temperature resistance (ITU 2003).

The third and last step of micro-trenching procedure is surface reinstatement. The small size of a micro-trench prevents sufficient compaction; therefore, traditional asphalt cannot be a solution for surface reinstatement. The reinstatement material needs to flow freely and easily inside the trench, prevent water penetration, provide a strong bond to the trench side walls, and be stable enough to carry traffic load (StirlingLloyd Polychem Ltd 2012). Hot liquid bitumen can be implemented for trench sealing using proper nozzle (ITU 2003).

Micro-trenching application depends on road composition. It is a preferred installation technique for asphalted surfaces with a compact material base (DCMS 2011; ITU 2003). - Applying this method in unpaved roads can be challenging since complete cleanliness of excavation is not feasible due to congestion of aggregates in the trench. Additionally, micro-trenching causes rapid deterioration in the structural matrix of evolved roads that have been aged over centuries (DCMS 2011).

Micro-trenching provides minimal surface scaring and limits environmental and social disruptions. It is also a cost-effective installation method due to reduced surface restoration and installation time (A2B fiber Inc. 2011; i3 2012). However, since this method provides shallow installation, cables are more susceptible to frost heave, freeze and thaw cycle and pavement rehabilitation process.

4.6 Micro-trenching field installations

In this study, two micro-trenching technologies, Vertical Inlaid Fiber (VIF) and Surface Micro Cable Inlay (SMCI) with installation depth of 23 cm and 7.62 cm were investigated. Both of the technologies are introduced briefly in the following section. In order to validate the model, simulation results were compared to data collected during these two field installations performed on October 2013 and June 2014 in a parking lot in Edmonton, AB.

4.6.1 Vertical Inlaid Fiber (VIF) technology

Vertical Deflecting Conduit (VDC) (Figure 4-1) includes two robust and slim pieces zipped together for enclosing of the fiber optic cable. VDC provides cables with protection against frost, operational loads and construction activities. It also allows for flexibility in deployment, which is achieved by the possibility of cables being pulled, blown or zipped in the conduit (TeraSpan 2013).

Figure 4-1: Vertical Deflecting Conduit (VDC)

Installation procedure begins with marking the trench layout using paint spray followed by utilizing a micro-trencher to create a narrow ditch. Then cleaning is performed using a vacuum for liquid mud and a shovel for solid mud. Fiber optic cable is inserted in the channels of VDC and zipped up. Afterwards, the conduit is laid vertically inside the trench. The final step of this procedure is surface reinstatement which includes filling the trench with a layer of sand on top of the conduit and then placing a layer of cold asphalt to provide the pavement surface a fine finish.

Installation specifications and cross section of VIF technology are provided in the Table 4-1 and Figure 4-3, respectively.

4.6.2 Surface Micro Cable Inlay (SMCI) technology

Similarly to VIF technology, this procedure also begins with marking the layout and cutting the trench. Then the trench is cleaned with both vacuum and shovel, and then dried with a blower. Water used in cutting process has to be dried to ensure the adherence of reinstatement material. The FO cable used in this project (Figure 4-2) consists of a rugged central copper tube, enclosing bundles of optical fibers and covered by a polyethylene (PE) jacket to provide required corrosion, temperature and crush resistance (JETT Networks 2014). Two of these protective layers allow direct buried deployment of cable inside the trench. Cables are filled with thixotropic gel to ensure protection from water ingress (JETT Networks 2014).

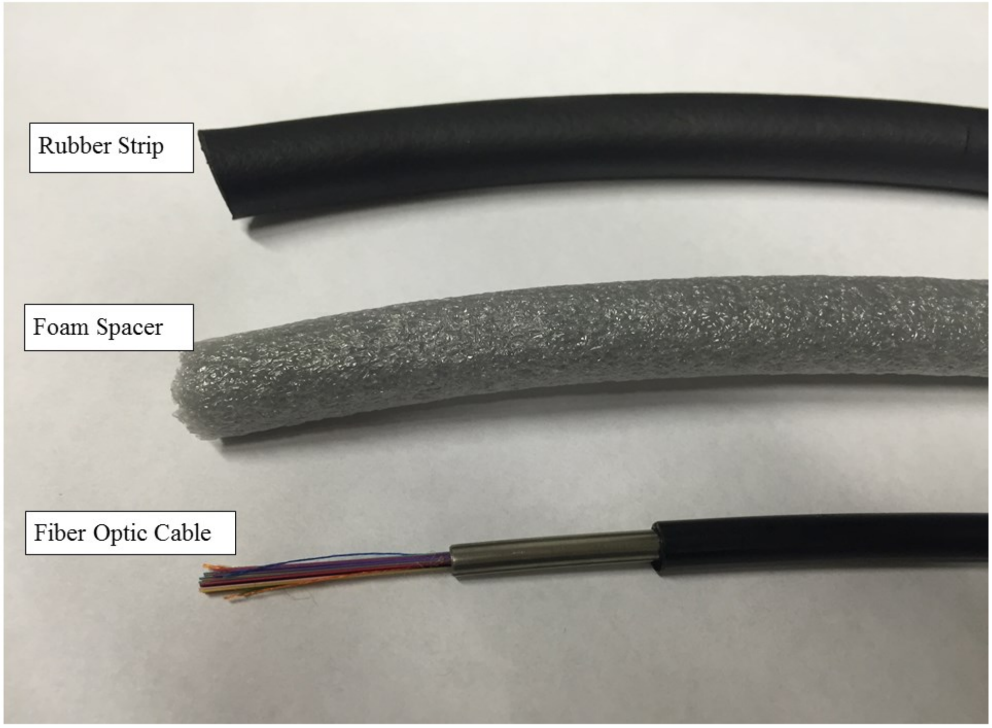


Figure 4-2: Fiber optic cable used in SMCI

In applying of SMCI technology, cable installation includes three steps. First, FO cable is laid in a vertical position inside the trench. After laying the cable, a layer of the foam spacer is placed inside the trench. The foam spacer is round closed cell foam that has enough flexibility to limit undesirable cable movements due to freeze and thaw cycles. Additionally, it protects the cable from moisture and water ingress. Then, a rubber strip made out of heat and chemical resistant neoprene is placed on top of the foam spacer to secure and retain the cable in place. The final step, surface reinstatement, includes filling the micro trench with uniformly graded sand of small size particles, known as “play sand”, followed by using hot asphalt to seal the trench to avoid water ingress.

Installation specifications and cross section of SMCI technology are provided in the Table 4-1 and Figure 4-3, respectively.

Table 4-1: Installations specifications- VIF and SMCI technology

Installation specification (all units in cm)		
Description	VIF technology	SMCI technology
Trench depth	22	7.6
Trench width	1.5	0.9
VDC thickness	5.2	NA
FO cable thickness	0.6	0.6
Foam spacer thickness	NA	1
Rubber strip thickness	NA	1.2
Sand layer thickness	7.2	3.8
Hot bitumen sealer thickness	NA	1.27
Cold asphalt layer thickness	9	NA
Existing Asphalt thickness	Almost 9	Almost 9

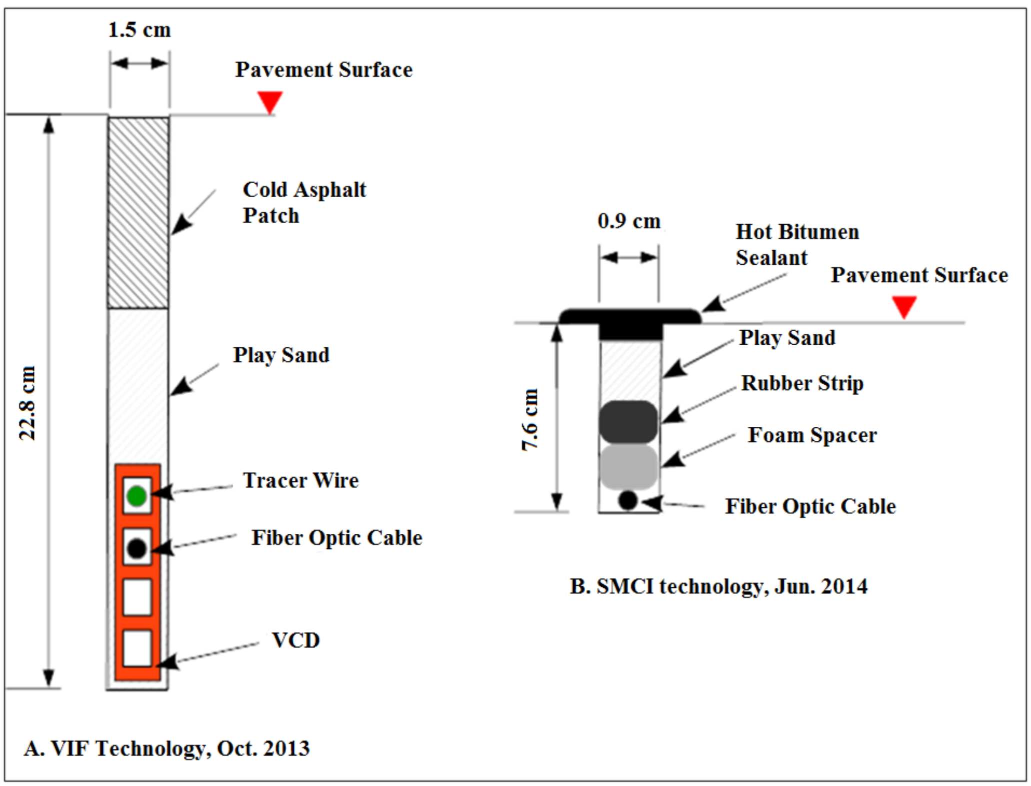


Figure 4-3: Cross section of VIF and SMCI installations

4.7 Simphony background

As cited in Hajjar and AbouRizk (2000), Simphony is a Microsoft Windows-based simulation platform that is developed under the guidance of Natural Sciences and Engineering Research Council (NSERC) and Alberta Construction Industry Research Chair Program in Construction Engineering and Management. Simphony provides consistent and standard environment for development and usage of special purpose simulation tools (Ruwanpura and Ariaratnam 2007).

According to AbouRizk and Hajjar (1998), Special purpose simulation (SPS) is defined as "a computer-based environment built to enable a practitioner who is knowledgeable in a given domain, but not necessarily in simulation, to model a project within that domain in a manner where symbolic representations, navigation schemes within the environment, creation of model specifications and reporting are completed in a format native to the domain itself" (as cited in Lueke et al. 1999). Simphony is deemed to be a suitable approach for integration of simulation into a construction management procedure. (AbouRizk et al. 1999; Lueke et al. 1999).

4.8 Special Purpose Simulation (SPS) for micro-trenching process

Special Purpose Simulation (SPS) was developed to estimate the micro-trenching projects duration and productivity. Specifically, it also investigates the impact of weather conditions and installation depth on micro-trenching productivity.

In Simphony, a key modeling feature is an entity which represents material, resource or finished product. This software also calculates the total time required for the task completion. In this model, an entity is considered as one micro-trenching project; trench depth and project length are assigned as the entity attributes.

In order to develop a model, micro-trenching procedure was divided into 5 steps: 1) marking the layouts, 2) cutting the trench, 3) cleaning the trench and smoothing the corners, 4) cable installation and 5) surface reinstatement. The model was developed with regards to these five stages and corresponding resource, the installation crew, was assigned to each of them. An exception was made to the "cutting the trench" step which is solely accomplished by using a micro-trencher, considered as the equipment.

Then, the duration of each step for the 2 people crew was fed into the simulation model using (Table 4-2); time duration data was obtained from industry experts based on their past projects' experience during summer and winter time. Notably, the duration of each step and labour productivity varies depending on different factors: ground condition, weather temperature, employees' proficiency level and type of equipment. To consider all these aspects, the triangular distribution, which employs three scenario types: worst case, most-likely case and best case, was used.

Table 4-2: Time distribution parameters (min), based on experts' opinion

Time duration for 1 meter of installation- Depth of 23 cm-Summer time			
Activity	Best case scenario	Most-likely scenario	Worst case scenario
Marking the layout	0.4	0.5	0.65
Cutting the trench	0.9	1.45	1.6
Cleaning the trench and smoothing the corner	1.5	2.25	3
Cable installation	0.3	0.58	0.8
Surface reinstatement	2	3	3.5
Time duration for 1 meter of installation- Depth of 23 cm-Winter time			
Activity	Best case scenario	Most-likely scenario	Worst case scenario
Marking the layout	0.5	0.57	0.75
Cutting the trench	1	1.6	2
Cleaning the trench and smoothing the corner	1.8	2.8	4
Cable installation	0.4	0.7	1
Surface reinstatement	2.5	3.5	4.5
Time duration for 1 meter of installation- Depth of 7.6 cm-Summer time			
Activity	Best case scenario	Most-likely scenario	Worst case scenario
Marking the layout	0.25	0.34	0.4
Cutting the trench	0.3	0.6	0.75
Cleaning the trench and smoothing the corner	1	1.5	2.4
Cable installation	0.4	0.5	0.6
Surface reinstatement	0.7	0.8	1
Time duration for 1 meter of installation- Depth of 7.6 cm-Winter time			
Activity	Best case scenario	Most-likely scenario	Worst case scenario
Marking the layout	0.25	0.38	0.5
Cutting the trench	0.33	0.7	0.97
Cleaning the trench and smoothing the corner	1.2	1.7	3.2
Cable installation	0.43	0.55	0.7
Surface reinstatement	0.8	0.9	1.25

In order to validate the model, two field installations using the VIF and SMCI technologies, were performed at different installation depths as explained in Section 5. The simulation results were compared to the actual data gathered from these two field installations; data collection was performed by direct observation of the installations.

Figure 4-4 illustrates the simulation model used for the micro-trenching productivity analysis and indicates the steps and assigned resources. Empty squares represent each task in the micro-trenching process; squares with a human symbol and a plus sign indicate assigning the resource while a minus sign demonstrates the resource release.

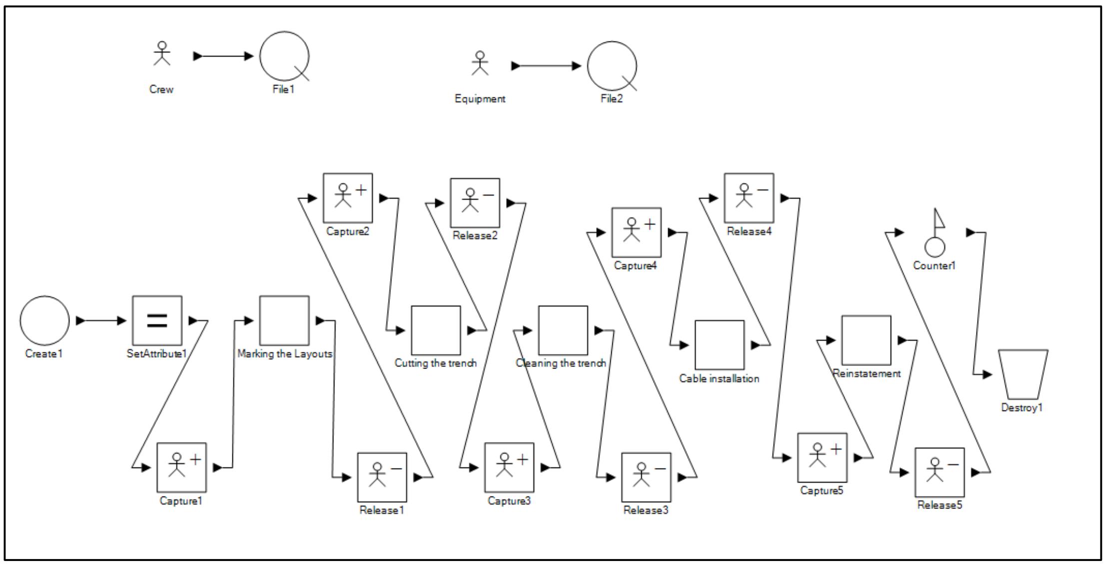


Figure 4-4: Simulation model for micro-trenching productivity analysis

4.8.1 Simulation Validation

As stated previously, our model validation is achieved by comparing the simulation results (100,000 iterations) to the actual field installation data, as presented in Table 4-3.

Table 4-3: Productivity result comparison for model validation

Productivity result comparison for model validation			
Description	Simulation result (m/hr)	Field installation result (m/hr)	Percentage error (%)
Installation depth of 7.6 cm-Summer time	15.6	14.42	8.14%
Installation depth of 23 cm-Winter time	6.51	6.15	5.81%

Slight differences between the simulation results and field installation productivity indicate that the simulation results are reliable. These minor differences may be caused by a variety in the equipment type used for cutting the trench and the cleaning procedure.

4.9 Productivity analysis of micro-trenching

Construction productivity plays a major role in the project success. High productivity results in lower unit cost to perform a task or operation. Conducting productivity analysis may be challenging due to variable field conditions. It is also very time-consuming: it may take weeks to gather the required data to be able to conduct basic analysis. Monitoring productivity regularly allows for making necessary changes to optimize the project in case of unexpected events (Su 2010).

Productivity is calculated through the ratio of produced output to unit of resource input such as labour, energy, raw material etc. (Equation 1). Common productivity ratios, considering the resources used, are the total factor productivity or multi-factor productivity, in which the output is in relation to all used resources; and labour productivity, in which the output is in relation to only labour. In labour productivity calculation (Equation 2), labour is represented by the employed persons, working hours or labour cost (O'Grady 2014). Labour productivity is influenced by such factors as temperature, wind speed, relative humidity, precipitation, type of work and crew composition (Khan 2010). Generally, calculating labour productivity over time provides beneficial information for further investigation and evaluation of the system effectiveness and efficiency and enables managers to move toward saving costs and increasing performance (Su 2010).

$$\boldsymbol{Productivity = \frac{Output}{Resources\ used}} \quad (1)$$

$$\boldsymbol{Labour\ Productivity = \frac{Output}{Labour\ input}} \quad (2)$$

In the construction industry, the amount of time required for completing a unit of an output is considered as the resource input. Output unit is selected with the consideration of the purpose of conducting productivity investigation. In our project, output unit is the 1 meter FO installation (Su 2010).

Production rate (daily output), which may be used for prediction of project duration or estimation of required man-hours for completing a job over a specific period of time, is obtained using Euqation 3, Equation 4 and Equation 5 (Navab-Kashani 2014). In this study, micro-trenching productivity is defined as installation meter per hour.

$$\boldsymbol{Daily\ output\ or\ production\ rate\ \left(\frac{meter}{day}\right) = \frac{Crew\ hours\ \left(crew\text{–}\frac{hours}{day}\right)}{Unit\ Crew\ hours\ \left(crew\text{–}\frac{hours}{meter}\right)}} \ldots\ldots\ldots(3)$$

$$\boldsymbol{Duration\ (days) = \frac{Quantity\ (meter)}{Production\ rate\ \left(\frac{meter}{day}\right)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$\boldsymbol{Duration\ (labour\ hours) = Quantity\ (meter) \times}$$
$$\boldsymbol{Unit\ labour\ hours\ \left(labour\frac{hours}{meter}\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Continuous data collection with the consideration of work methods, workers' level of skill and motivation, and visual, nasal and thermal condition of work delivers the accurate production rate (Karger and Bayha 1987); however, it is a time-consuming and expensive approach. Alternatively, average performances under various conditions may also indicate the existing production rate. It must be noted that it is vital to present results validation and the work conditions associated with the data collection (Navab-Kashani 2014)

Productivity analysis was grouped into two categories: 1) seasonal and 2) installation depth. The analysis reflects the influence of weather conditions and installation depth on micro-trenching productivity. Simulation results with 100,000 iteration for seasonal and installation depth comparison are provided in Table 4-4.

Table 4-4: Micro-trenching productivity: (a) Seasonal comparison, (b) Installation depth comparison.

(a)

Micro-trenching productivity- Seasonal comparison			
Description	Productivity during summer time (m/hr)	Productivity during winter time (m/hr)	Percentage difference (%)
Installation depth of 7.6 cm	15.6	12.99	16.72%
Installation depth of 23 cm	8.02	6.51	18.80%

(b)

Micro-trenching productivity-Installation depth comparison			
Description	Installation depth of 7.6 (m/hr)	Installation depth of 23 (m/hr)	Percentage difference (%)
Summer time	15.6	8.02	48.42%
Winter time	12.96	6.51	49.84%

Simulation results indicate that the winter weather conditions can reduce the micro-trenching productivity by 16.72%, and by 18.8% for the installation depth of 7.6 cm and 23 cm respectively. However, installation depth was proven to have more impact on productivity. When compared to deep installations, shallow installations are characterized with faster cutting, less waste material to clean and easier reinstatement. As the results indicate, deep installations reduce productivity by approximately 50%.

Figure 4-5 demonstrates the productivity distribution of micro-trenching with different installation depths and weather conditions. *X-axis* represents the productivity and *y-axis* represents the frequency of productivity. These graphs are obtained using the simulation results with 100,000 iteration and appropriate distribution function is fitted to probability bar charts. It can be seen that with a certainty level of 90%, the productivity of installation with depth of 7.6 cm will be between 13.65-17.89 m/hr in the summer time and 11.03-15.26 m/hr in the winter time. Corresponding distribution function is RiskBetaGeneral (α_1, α_2, min, max). For deep installation (depth of 23 cm), these values are 7.27-8.99 m/hr in the summer and 5.83-7.38 m/hr in the winter; corresponding distribution function is RiskGamma (α,β).

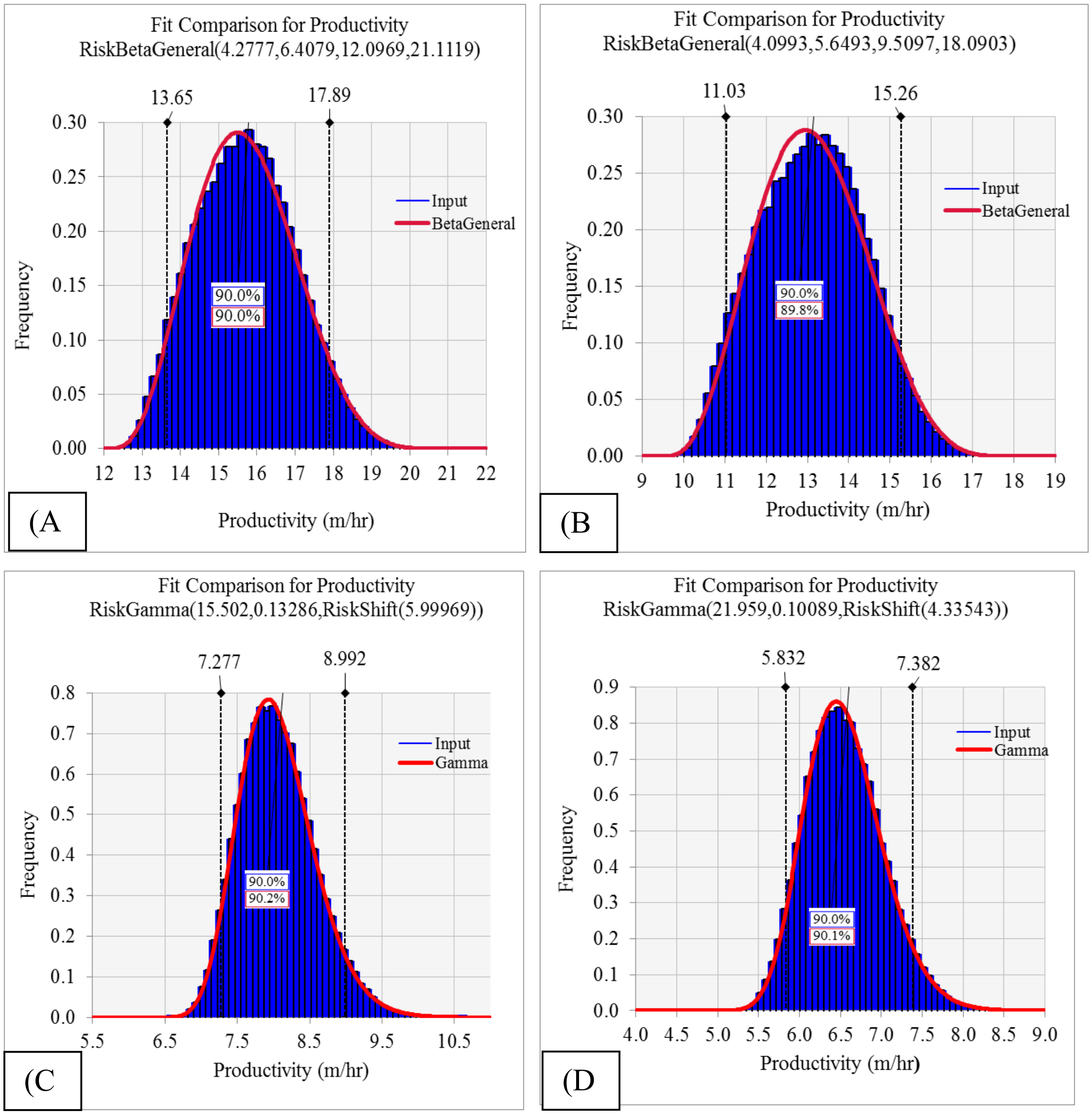


Figure 4-5: Productivity distribution: (a) Summer time, installation depth of 7.7cm, (b) Winter time, installation depth of 7.7, (c) Summer time, installation depth of 22cm, (d) Winter time, installation depth of 22cm

4.10 Productivity improvement of micro-trenching

As described in Section 4.5, the second step in micro-trenching procedure is the micro-trench creation. In the field installations, it was observed that the crew tends to be idle during this step. Its productivity may be increased by conducting the cleaning process at the time of cutting. The overlapping of cutting and cleaning steps can start when a certain portion of cutting is completed leaving sufficient space for cleaning.

In order to verify the productivity improvement, the simulation model can be modified in a way that the cleaning process starts after a portion of cutting is completed. Since the model developed for analyzing micro-trenching works properly and results are matched with the gathered site data and case studies, it can be concluded that the results from the simulation are reliable.

Figure 4-6 demonstrates the modified simulation model used for micro-trenching productivity improvement analysis.

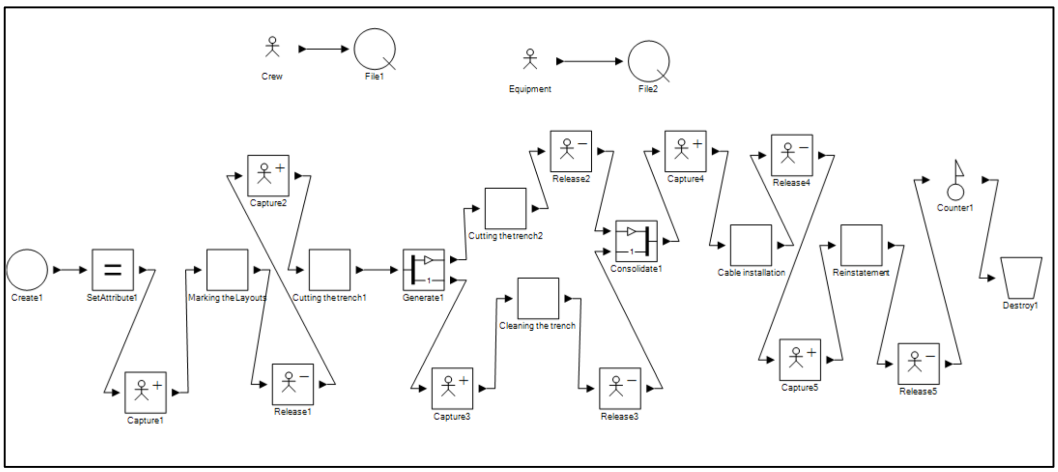


Figure 4-6: Modified simulation model to improve micro-trenching productivity

Figure 4-7 demonstrates the percentage of productivity improvement for different completed portions of cutting before starting the cleaning process. It is clear that by increasing the completed portion of cutting before starting the cleaning process, the productivity improvement decreases. However, it is not feasible that both cutting and cleaning start at the same time since there must be sufficient space for the crew to clean the trench. Depending on project length, 5%-15% may be an appropriate percentage which results in almost 14%-16% increase of productivity.

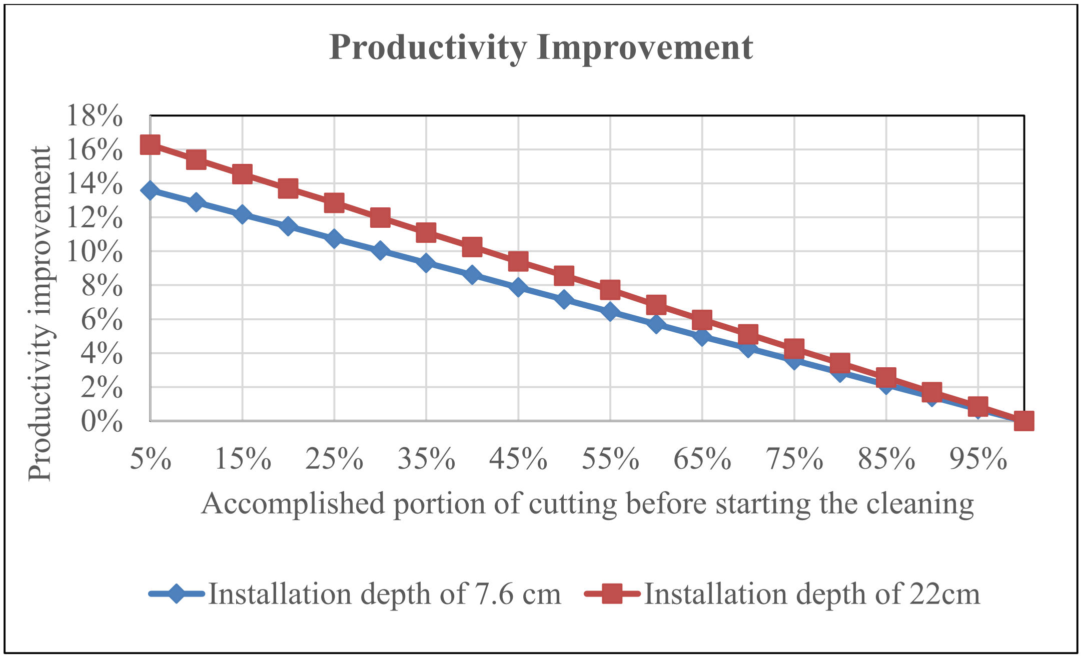


Figure 4-7: Productivity improvement vs. completed portion of cutting before starting the cleaning

Simulation results of the modified model were compared to an actual case study (VIF technology) performed in Langford, BC with productivity of 7.06 m/hr with the two people crew. There is a 9.5% error between simulation results and actual productivity data when 5% of cutting is completed before starting the cleaning.

4.11 Conclusion

In this paper, a special purpose simulation for micro-trenching productivity analysis is developed which can assist in further investigation of the impact of weather conditions and installation depth on micro-trenching productivity. This model also can be extended to fit other conditions and other installation depths if more actual data is available.

Results from the presented model indicate that cold weather condition decrease the productivity up to 18.8%. Installation depth can also have a considerable impact on micro-trenching productivity. Shallow installations (7.6 cm) were shown to be approximately 50% more productive in comparison with deep ones (23 cm).

This SPS can be used for estimating of the project duration. *What if* scenarios can also be applied to the developed simulation model, so the effectiveness of any modification for the installation procedure can first be verified by the model before implementing any changes to the project. Using the modified model, the productivity of this method can be increased by 14% to 16% by overlapping the cutting and cleaning tasks during the micro-trenching process.

Chapter 5. Summary and Conclusions

5.1 Summary

Significant increase in the number of internet users and required bandwidth necessitates having FO network due to its high capacity of data transmission. There are several installation methods categorized in "direct buried", which includes inserting the cable directly underground or inside a conduit in the ground followed by blowing or pulling the cable, and "utility sharing", which consists of accommodating the cable inside the existing utilities such as sewer lines.

Among "direct buried" methods, open-cut trenching results in considerable social and environmental disturbance; therefore, in order to limit its negative impacts, alternative methods such as micro-trenching, plowing, piercing, and mini-hdd needs to be taken into consideration.

This study focused on micro-trenching for deployment of FO cables. Micro-trenching provides installation in shallow depth increasing exposure to frost and possibly hindering the fiber's performance. It is imperative to investigate long-term performance of cables installed using micro-trenching in cold regions such as Alberta, Canada. For this purpose, two micro-trenching technologies were performed in Edmonton and being kept under monitoring to study their performance in cold weather condition. Investigation was performed in two aspects, physical integration and optical performance. Ground Penetrating Radar (GPR) was used to locate the conduits or fiber optic cable in the ground to determine the upward and downward movements of conduits. Additionally, Optical Time Domain Reflectometer was used to evaluate installations' optical performance over the time.

In addition, construction productivity plays an important role in the project success; high productivity results in lower unit cost to perform a task; therefore, it is necessary to analyse micro-trenching productivity which can be influenced by different factors including weather and installation depth. In order to analyze productivity, micro-trenching procedure was simulated using Simphony and time distributions for summer time and winter time and considering two installation depths were obtained from experts based on their experience and fed to the simulation model. Micro-trenching productivity was analysed and influence of installation depth and weather condition on its productivity was investigated.

Furthermore, the procedure was modified in a way to achieve improvement in the productivity. Productivity enhancement was shown using the modified model result.

5.2 Conclusion

Micro-trenching is generally a convenient solution for installation in business districts and downtown areas due to low restoration costs. It is also an environmentally-friendly method which causes minimal surface scaring and disruption to the community. Considering these advantages, micro-trenching seems to be a viable alternative over open-cut trenching; however, further investigation is required to assess the possible impacts of cold weather condition on installations in cold regions such as Alberta. Such an investigation could entail monitoring the cable and conduit of a trial FO installation over several winters to study the effects of severe weather conditions on the installation.

Two micro-trenching installations, Vertical Inlaid Fiber (VIF) and Surface Micro Cable Inlay (SMCI) were performed on October 2013 and June 2014 on a TELUS parking lot in Edmonton. Data collection was conducted in both construction phase and operational phase.

Construction phase results

- Among micro-trenching activities, cleaning the trench and smoothing the corners was the most time consuming activity, 38.57% of total project duration for VIF and 47.88% for SMCI.
- The second time-consuming activity was surface reinstatement, which took 31.96% and 22.17% of total duration for VIF and SMCI respectively.
- The total micro-trenching productivity associated with VIF and SMCI technologies with a two–person crew is 6.2 m/hr and 14.4 m/hr and considering an eight-hour workday, productivity rate is approximately 50 m/day and 115 m/day, respectively. In total, the productivity of SMCI technology is approximately two times that of VIF technology.
- Total approximate generated waste estimated as 0.42 m^3 and 0.07 m^3; 3586 cm^3/meter and 710 cm^3/meter for VIF and SMCI installations respectively. Typically, waste generated by micro-trenching is lower compared to the traditional open cut trenching method, which is a significant advantage of micro-trenching.

Operational phase results

Operational results of VIF technology:

- In straight layout in no traffic area, not much upward and downward movement in the conduit profile was observed.
- In straight layout located in traffic area, little vertical displacement was observed except the end point of the installation, which moved toward the surface and had shallow depth of 8.8cm according to GPR inspection on July 2014 and moved approximately 10 cm downward according to recent GPR inspection result. GPR results reflect that this point is a loose end and have more freedom to move.
- According to GPR inspections, the points that are subjected to direct traffic have moved upward and downward more than the other points; hence, traffic load caused much more conduit movement in layouts with bends than straight layouts, this can be due to induced stresses in the bended sections of the layout and also lack of appropriate compaction of restatement material.
- Annual comparison of depth data demonstrates that the entire installations had moved toward the surface since the installation time (November 2013). Average depth in straight layouts varied from 21.5 in November 2013 cm to 17.4 cm in May 2015. In loop layout in traffic area, average depth decreased from 21.6 in November 2013 to 14.5 in May 2015.
- Optical performance of installed cables has not been compromised and span losses measured by OTDR are in acceptable range.

Operational results of SMCI technology:

GPR inspection results indicate that these installations, both layouts, have not displaced much. In this installation, the greatest vertical displacement is 36% (considering the installation depth). Comparing this value with maximum displacement of VIF technology (65%) shows that using foam spacer and rubber strip on the top of cable with the purpose of stabilization has been effective so far. However, monitoring is an ongoing process and installations need to be kept under review for several years.

Productivity analysis result

Micro-trenching process was simulated and after model validation seasonal comparison and installation depth comparison was performed.

- Simulation result demonstrates that cold weather condition in winter results in 16.72% and 18.8% decrease in the micro-trenching productivity relative to summer time productivity with respect to the installation depth of 7.6cm and 23 cm.
- Moreover, influence of installation depth on productivity is much more than weather condition. Deeper installation can reduce the productivity for 48.42% in summer time and 49.84% in winter time.

By performing cleaning process and cutting the trench simultaneously after a portion of cutting has completed, productivity can be improved. Modification was applied in the simulation model to verify the improvement. Results indicate that depending on project length, when cleaning starts after 5% of cutting is accomplished micro-trenching productivity can be improved for 14% and 16% for depth of 7.6 cm and 23 cm.

5.3 Future research

Monitoring the micro-trenching installation with the purpose of long-term performance evaluation is an ongoing process; however, this study only has the monitoring results for two years. The installation is required to be kept under monitoring for over several winters to be able to certainly predict the conduit's movements underground.

In addition, research results indicate that current reinstatement method (using sand and cold asphalt on top or hot bitumen sealant) is not a viable solution for trench reinstatement and cannot provide sufficient protection and failed to avoid vertical movements; therefore, the reinstatement procedure can be modified in a way to provide stabilization of conduit inside the trench, preventing future vertical movement toward the surface.

The developed simulation model is based on obtained data for winter and summer seasons and two installations depths. This model can be expanded and applicable to more projects with different installation depths, various conditions and different specification by getting more data of micro-trenching projects.

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