

Productivity Analysis of Micro-Trenching Using Symphony Simulation Modeling

Hediyeh Vaseli ^a, Leila Hashemian ^{b*}, Alireza Bayat ^c

^a MSc Student, Department of Civil & Environmental Engineering, University of Alberta, T6G 1H9, Canada.

^b Assistant Professor, Department of Civil & Environmental Engineering, University of Alberta, 7-255 Donadeo Innovation Center of Engineering 9211 116th Street, Edmonton, T6G 1H9, Canada.

^c Professor, University of Alberta, Department of Civil & Environmental Engineering, 7-243 Donadeo Innovation Center of Engineering 9211 116th Street, Edmonton, T6G 1H9, Canada.

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Abstract

Micro-trenching is an innovative method for installing fiber optic cable in residential areas and business districts which minimizes surface scarring and potential negative social and environmental impacts. This method has three major steps including cutting a narrow trench in the pavement, cable installation and trench backfilling. This paper discusses a Symphony simulation model of the micro-trenching procedure and analyzes its productivity. Brief descriptions of the micro-trenching method and two field installations used to validate the model are included. A simulation model was developed for two different installation depths of 7.6 and 23 cm using two different methods. To provide an estimation of project duration, the impact of weather conditions on micro-trenching productivity was 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 the influence of installation depth is more significant than the impact of weather conditions. Reducing installation depth from 23 cm to 7.6 could improve productivity up to 50% while cold weather condition can reduce productivity by 18.8%. The simulation model demonstrates that the productivity can be improved up to 16% by overlapping two steps during the installation process: starting the cleaning procedure when a portion of cutting is completed.

Keywords: Micro-Trenching; Vertical Inlaid Fiber (VIF); Surface Micro Cable Inlay (SMCI); Productivity Analysis; Symphony; Simulation; Fibre to the Home (FTTH); Productivity Improvement; Installation Depth; Cold Weather Condition.

1. Introduction

The number of Internet users has grown considerably over the last twenty years. The Internet has become the dominant source of both entertainment and information and the use of heavy bandwidth applications on mobile devices and personal computers increases every year [1]. Cisco, one of the most prominent networking equipment vendors, estimates consumption trends in North America to reach approximately 35,000 PB/month in 2020 [2, 3].

As overall bandwidth requirements increase significantly, much of the existing copper telecommunication infrastructure becomes inadequate for meeting data transmission demands. High capacity broadband networks are supported by fiber optic cables. When compared to existing copper cabling systems, fiber optic networks offer dramatic improvements in data transmission capacity. Fiber optic cable is smaller, lighter, less prone to interference

* Corresponding author: hashemia@ualberta.ca

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and of high bandwidth and capacity [4]. Fiber Optic (FO) backbone networks improve communication systems, allowing information to transfer faster [1]. In many large North American cities, fiber optic services are installed in downtown areas and business districts [4, 5]. 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 [6]. As Internet Service Providers build extensive Fibre-to-the-Home networks outside of urban cores, they encounter many of the same challenges. The traditional way of completing last-mile fiber optic installation or Fiber to the Home (FTTH) is cutting trenches into or under streets and installing conduits, splicing, and building entrance facilities. The consequences of this uncontrolled trenching are streets with patches and crumbling asphalt [4]. 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 reduces pavement longevity and produces other environmental impacts such as dust and noise [6].

An alternative fibre optic installation method that may be used to build a FO network cost-effectively with much less disruption and negative environmental and social impacts is 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 [7].

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 using spray paint, followed by cutting 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 [8]. 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 [8, 9].

After cutting the trench, 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. 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 some protection from these hazards as well as frost and operational loads (Personal communication, TeraSpan, November 2012). Additionally, according to Telus, the main purpose of a conduit is to allow future installation without trenching (Personal communication, Telus, September 2015). There are various types of conduits used for this purpose which provide stability on edge. Alternatively, cables may be placed inside metallic tubing which is covered by a Polyethylene (PE) jacket providing required crush and temperature resistance [10-12].

The third and last step in micro-trenching 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 [13]. Hot liquid bitumen can be implemented for trench sealing using a proper nozzle [10]. The cable may not be secured in its location if the reinstatement is not done appropriately [13].

Micro-trenching application depends on road composition. It is a preferred installation technique for asphalt surfaces with a compact material base [7, 10]. 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 [7]. Quality of backfilling material and also backfilling method have an important role in long-term sustainability of the micro-trench, particularly in cold regions [14, 15].

Micro-trenching provides minimal surface scarring and limits environmental and social disruptions. It is also a cost-effective installation method due to reduced surface restoration and installation time [14, 15]. However, since this method provides shallow installation, cables are more susceptible to frost heave, freeze and thaw cycle and pavement rehabilitation process.

Productivity is considered a key indicator in economic performance assessment [16]. To assess the success of a construction project, labour productivity as a key factor is often included [17]. Productivity 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 [18]. Therefore, it is necessary to analyze micro-trenching productivity and offer suggestions for its improvement.

The objective of this paper is to analyze the productivity of micro-trenching installation. Utilizing time distributions of micro-trenching installation procedures gained from 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 field installation data.

2. Methodology

In order to investigate the productivity of micro-trenching, the installation process was divided into 5 steps and simulated using Symphony 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 (personal communication with 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 estimate 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.

A simulation model allows one to efficiently investigate 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. Figure 1 shows the flowchart:

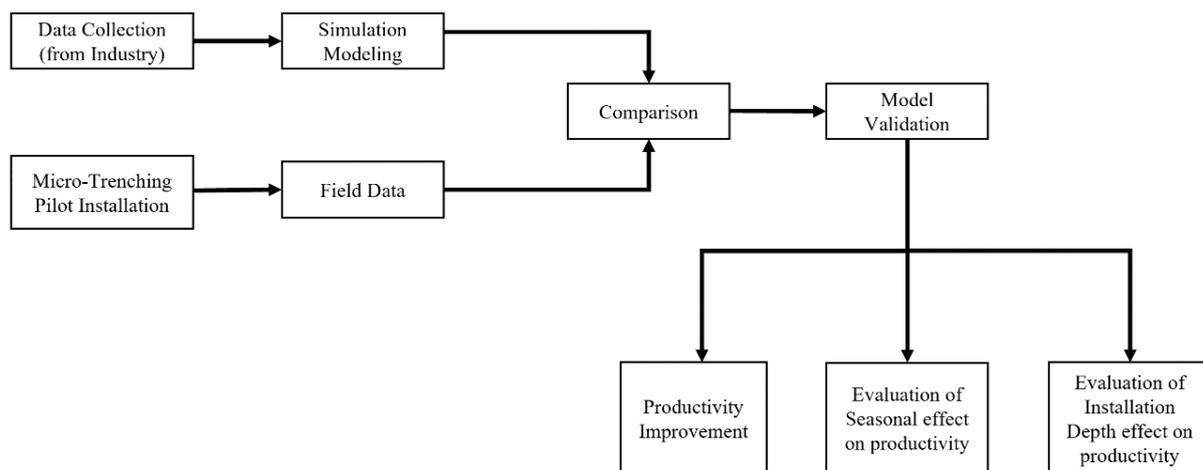


Figure 1. Research Methodology Flowchart

3. Micro-Trenching Field Installation

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 field installations performed on October 2013 and June 2014 in a parking lot in Edmonton, AB.

3.1. Vertical Inlaid Fiber (VIF) Technology

Vertical Deflecting Conduit (VDC) (Figure 2) includes two robust and slim pieces zipped together to enclose 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 [19].



Figure 2. Vertical Deflecting Conduit (VDC) [19]

The installation procedure begins with marking the trench layout using spray paint followed by using 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 VDC channels 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 with a fine finish.

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

3.2. Surface Micro Cable Inlay (SMCI) Technology

Similar 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 dried with a blower. Water used in the cutting process has to be dried to ensure the adherence of reinstatement material. The FO cable used in this project (Figure 3) consists of a rugged central copper tube enclosing bundles of optical fibers and covered by a polyethylene (PE) jacket to provide corrosion, temperature and crush resistance [20]. 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 [20].

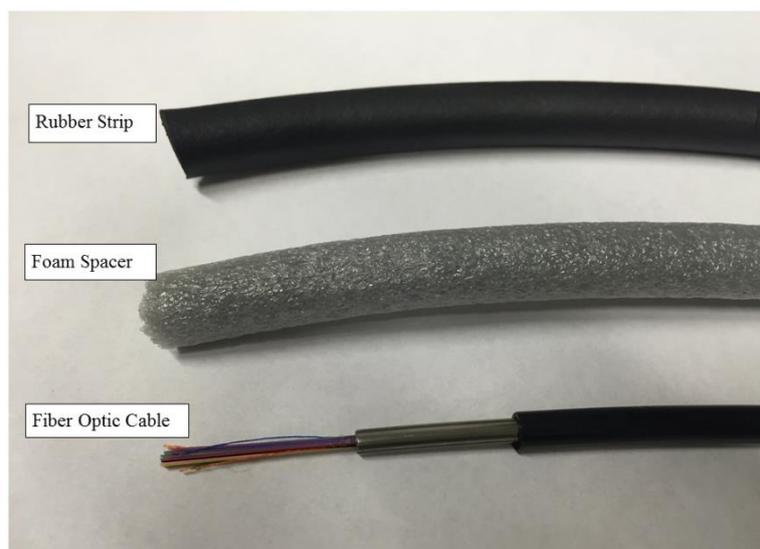


Figure 3. Fiber optic cable used in SMCI [19]

In applying the 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 penetration. Then, a rubber strip made out of 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, followed by using hot asphalt to seal the trench to avoid water ingress.

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

Table 1. Installations specifications- VIF and SMCI technology (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

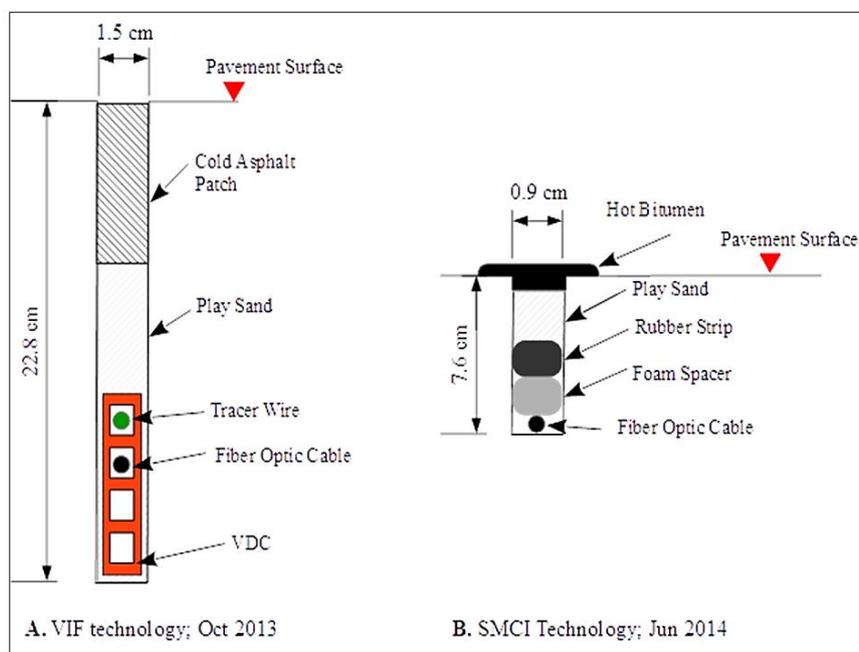


Figure 4. Cross section of VIF and SMCI installations [19]

4. Symphony Background

As cited in Hajjar and AbouRizk [21], Symphony 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. Symphony provides a consistent and standard environment for development and usage of special purpose simulation tools [22].

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” [23]. Symphony is deemed to be a suitable approach for integration of simulation into a construction management procedure [24, 25].

5. Special Purpose Simulation (SPS) for Micro-Trenching Process

A 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 Symphony, 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, the 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. Each step in the model requires a resource. Step 2) requires a micro-trencher, and all other steps require a two-person work crew.

Duration estimates of each step for the two-person crew, found in Table 2, were fed into the simulation model. These duration estimates were obtained from industry experts based on their experience from past projects. The duration of each step and its labour productivity varies depending on different factors: ground conditions, weather, temperature, employee 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, with different distribution estimates for winter and summer work.

Table 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

To validate the model, we compared the expert estimates to field installations done using the VIF and SMCI technologies, as described in Section 5. The simulation results were compared to the actual data gathered by direct observation of these two field installations.

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. Simulation results indicate that the winter weather conditions can reduce the microtrenching 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%.

Table 3. Micro-trenching productivity: (a) Seasonal comparison, (b) Installation depth comparison.

(a)			
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)			
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%

5.1. 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.

Table 4. 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%

The 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, the cleaning procedure and lack of available project's data.

5.2. Productivity Analysis of Micro-Trenching

Construction productivity plays a major role in 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 [18].

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 [25]. Labour productivity is influenced by such factors as temperature, wind speed, relative humidity, precipitation, type of work and crew composition [17]. 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 [18].

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

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

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 [18].

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 Equations 3 to 5 [26]. In this study, micro-trenching productivity is defined as installation meter per hour.

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

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

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

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 [27]; 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 [27].

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 Figure 5.

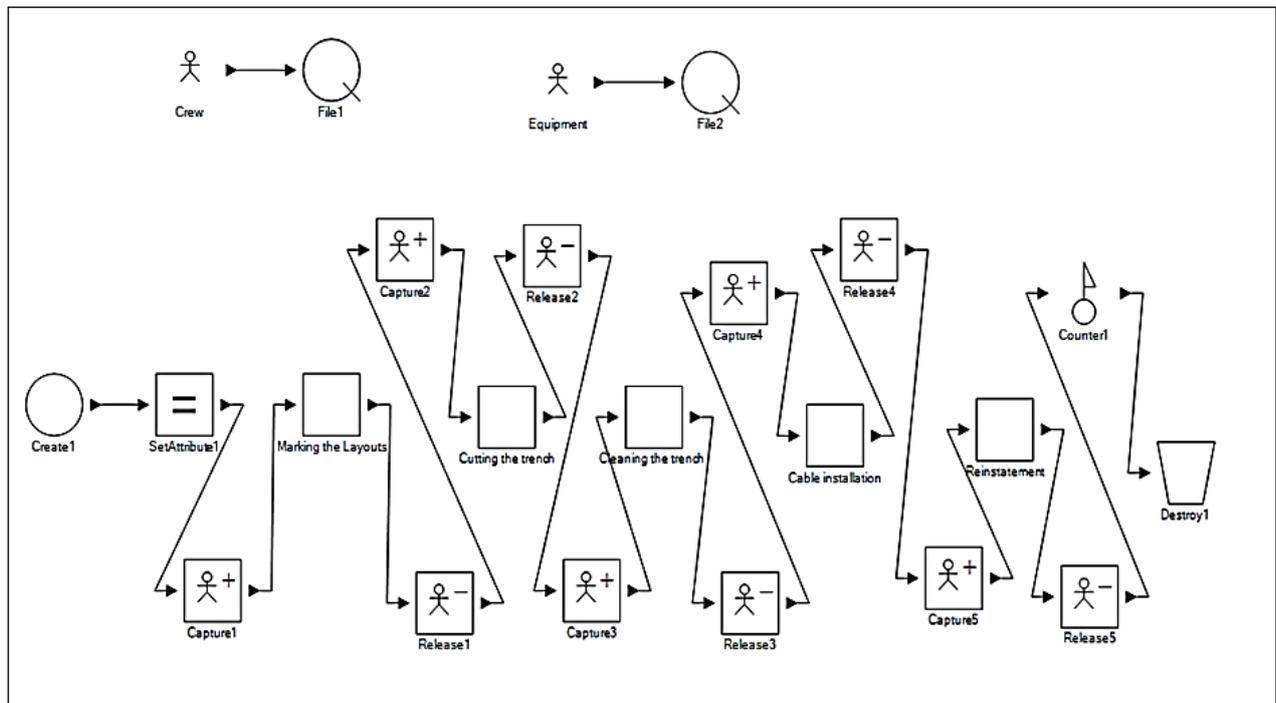


Figure 5. Simulation model for micro-trenching productivity analysis

Simulation results indicate that the winter weather conditions can reduce the micro-trenching productivity by 16.7%, 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 6 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 an 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 summertime and 11.03-15.26 m/hr in the wintertime. 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).

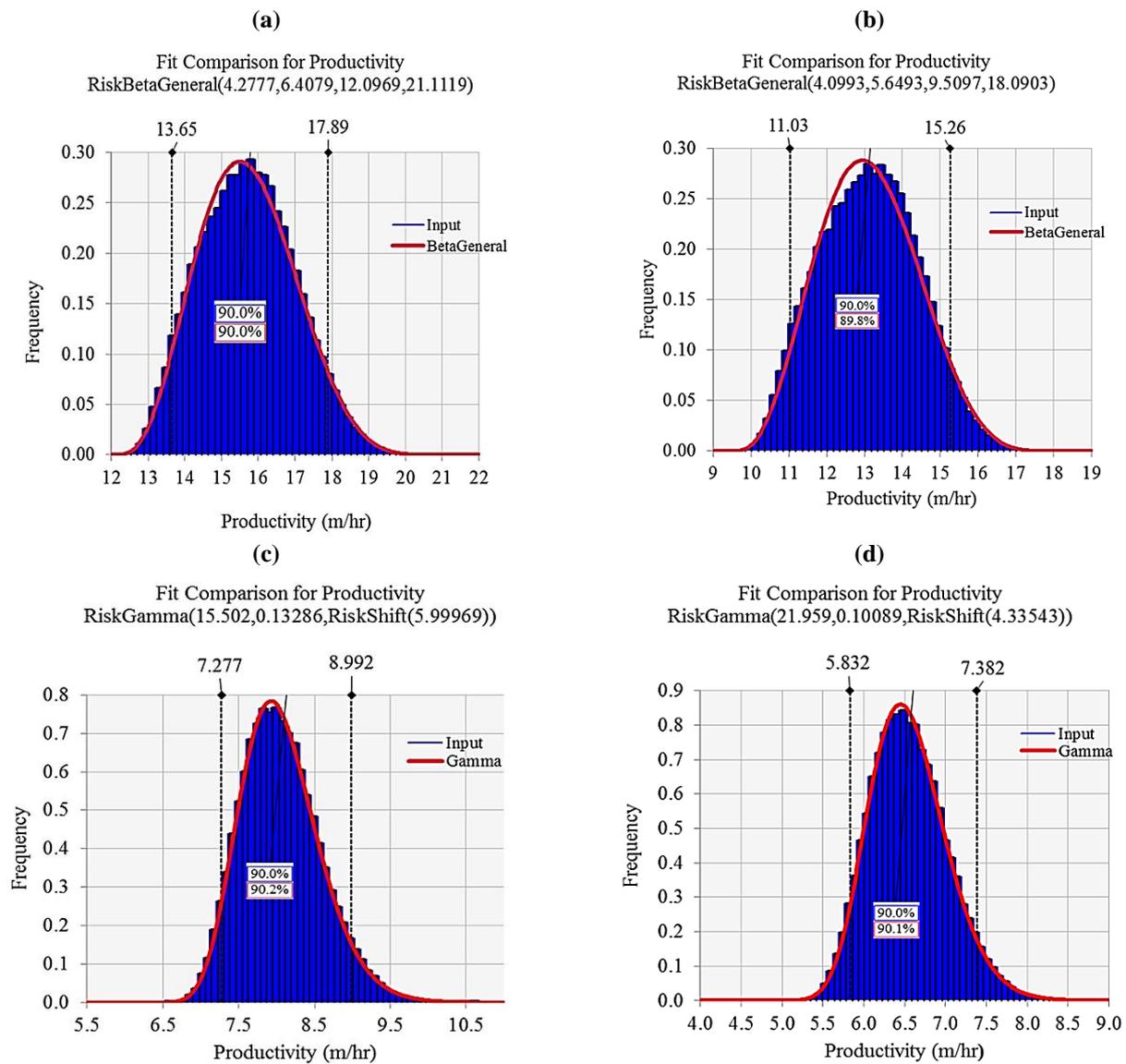


Figure 6. Productivity distribution: (a) Summer time, installation depth of 7.7cm, (b) Winter time, installation depth of 7.7, (c) Summer time, installation depth of 22cm, (d) Winter time, installation depth of 22cm

6. Productivity Improvement of Micro-Trenching

As described in Section 4.5, the second step in the 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 7 demonstrates the modified simulation model used for micro-trenching productivity improvement analysis. Figure 8 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.

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 a two-person crew. There is a 9.5% error between simulation results and actual productivity data when 5% of cutting is completed before starting the cleaning.

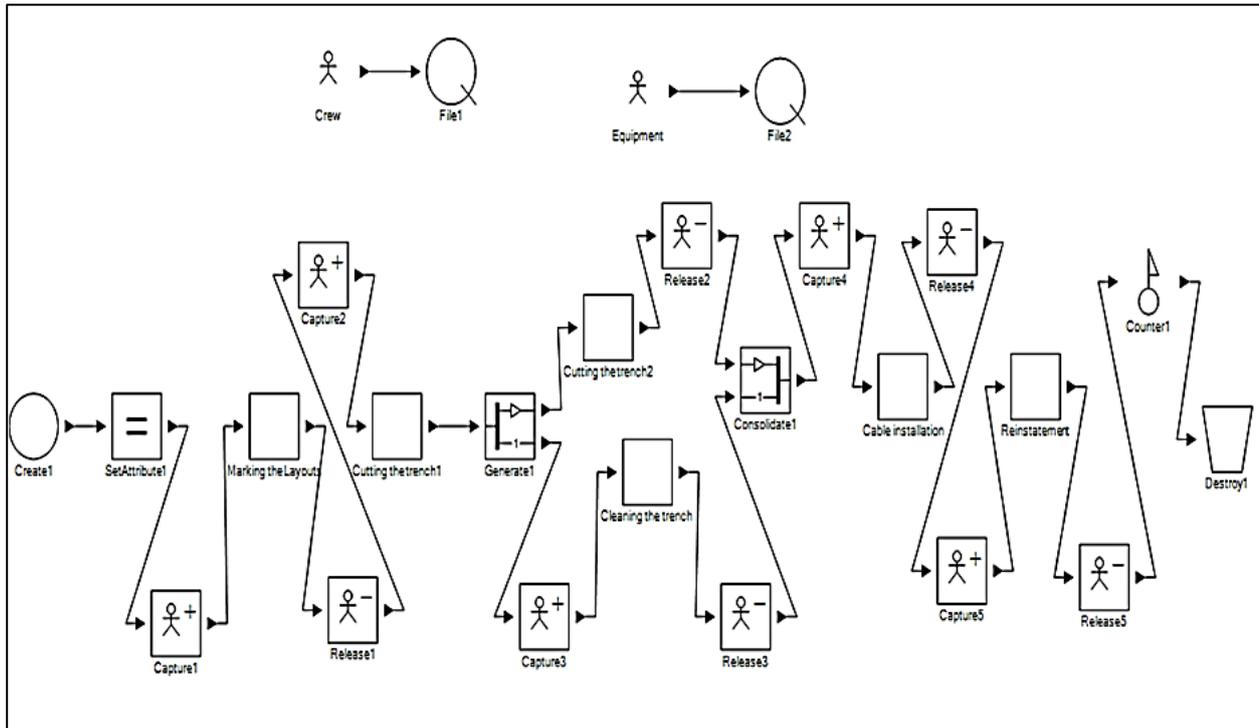


Figure 7. Modified simulation model to improve micro-trenching productivity

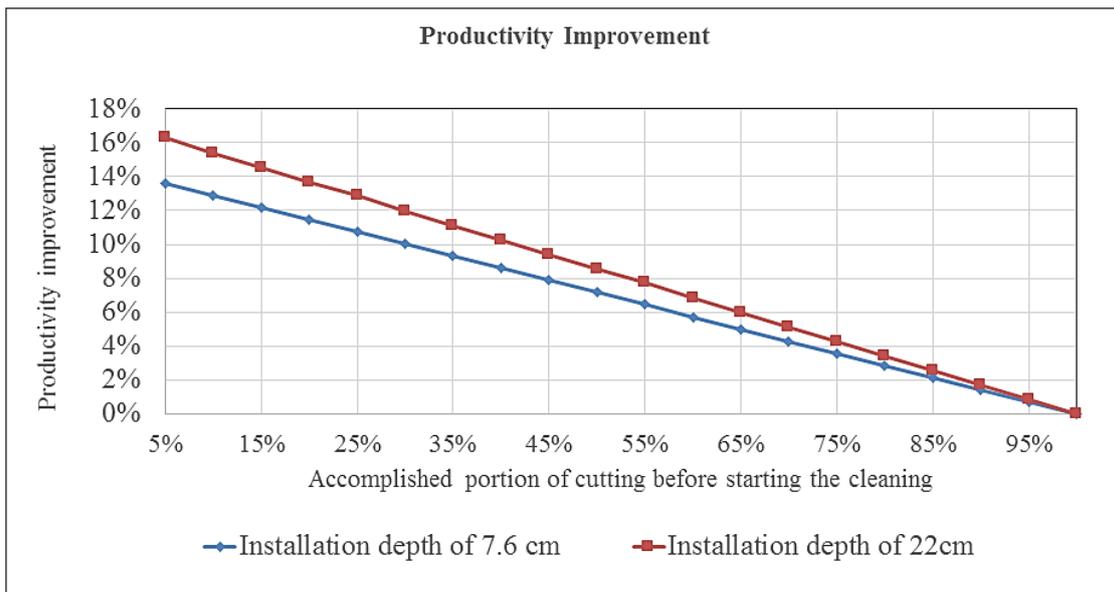


Figure 8. Productivity improvement vs. completed portion of cutting before starting the cleaning

7. Conclusions

In this paper, a special purpose simulation (SPS) for micro-trenching productivity analysis is developed using two micro-trenching field installations with different methods including Vertical Inlaid Fiber (VIF) and Surface Micro Cable Inlay (SMCI) with installation depth of 23 and 7.60 cm, respectively. This model 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. The following conclusions are driven from the study:

- Results from the presented model indicate that cold weather conditions decrease the productivity up to 16.7% and 18.8% for SMCI method with the installation depth of 23 cm and VIF method with the installation depth of 7.6 cm, respectively.
- 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).

- It was revealed that by overlapping some activities and reducing delay times, for example starting the trench cleaning procedure when a portion of cutting is completed, productivity could be increased by 14% and 16% for SMCI and VIF methods, respectively.
- This SPS can be used for estimating the project duration. What-if scenarios can also be applied to the developed simulation model, so the effectiveness of any modification method for the installation.

It is worth mentioning that the results of this study are limited to only two field projects with two different installation methods and backfilling material. It is recommended that more case studies will be considered in future to enhance the prediction models.

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9. Conflicts of Interest

The authors declare no conflict of interest.

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