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Analysis of pipe-bursting construction risks using probability-impact model

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Abstract

Purpose – Civil utility projects, both open-trench and trenchless, are subject to risk. These risks have both direct and indirect effect on project cost, schedule, quality and safety. It is therefore critical for the project management team to include risk management as an integral part of their project planning and execution. The purpose of this study is to identify the pipe-bursting construction risks and determine their probability of occurrence and cost impact and provide the appropriate responses to mitigate the identified risks.

Design/methodology/approach – This is an exploratory design using an industry-wide questionnaire survey to collect data on the probability of occurrence and impact of risks on cost of pipe-bursting projects. A probability-impact model was used to categorize the risks to determine their criticality and the appropriate risk responses.

Findings – The model revealed that majority of the analyzed risks have low impact-low probability of occurrence and high impact-low probability of occurrence. Undocumented repairs to host pipe was the only risk identified as having high probability of occurrence and high impact on cost. The risk responses suggest a combination of risk transfer, reduction and acceptance to be appropriately applied to mitigate the risks. A discussion on the good practices indicates that most pipe-bursting operations can be done safely and successfully if site and project conditions are known before bursting and the appropriate measures are taken to address those conditions.

Research limitations/implications – Although the identified risks may apply to other utility construction methods, the focus of this research is limited to risks that occur during the construction phase of a pipe-bursting construction project.

Practical implications – Risk management is very critical to the success of any construction project. Identification and assessment of risks alone will not serve the purpose of risk management unless meaningful ways to mitigate those risks in a structured way are planned. The probability-impact model for the pipe-bursting construction risks with the mitigation strategies will help owners, engineers and contractors plan for and adequately respond to these risks. Additionally, a logical assessment of the risks will aid in effective decision-making regarding the management of the project.

Originality/value – Extensive literature review indicates that there is no existing literature on the probability of occurrence and impact on cost of risks in pipe-bursting projects. This paper presents the results of a wide-ranging analysis on construction risks in pipe-bursting projects. This is the first analysis incorporating the use of the probability-impact model to determine the criticality of various pipe-bursting construction risks.

Keywords Risk response, Risk, Pipelines, Pipe bursting, Probability-impact model, Trenchless technology

Paper type Research paper

1. Introduction

Risks are commonplace in construction projects. They generally fall into three categories: risks that occur frequently and are an inevitable feature of all construction projects (known risks), risk events whose occurrence is predictable or foreseeable (known unknowns) and

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risks whose probability of occurrence and effect are not foreseeable by even the most experienced professionals (unknown unknowns) (Smith *et al.*, 2014). Irrespective of the category, risks on construction projects can have both a direct and indirect effect on project cost, schedule and quality. It is therefore critical for the project management team to include risk management as an integral part of their project planning and execution (Onsarigo *et al.*, 2014). With proper planning, project managers can avoid many risks. Construction managers can also adopt mitigation strategies for risks that are unavoidable, essentially minimizing their potential negative impact on project success. A proactive approach calls for project participants to:

- identify the potential risk factors;
- quantify their effect on project cost, schedule and quality; and
- develop mitigation strategies to manage the risk should it occur.

Like other construction projects, utility construction projects are not immune to risks. Traditionally, utilities were installed using the open-cut (open-trench) method. The basic approach involves digging a trench, placing a pipe in the trench and filling the excavation. Depending on the project conditions, the process can get more complicated and could involve additional activities like utility exploration (toning), diverting traffic, shoring, dewatering, saw cutting of the pavement, installation of temporary pavement and repair/replacement. Trenchless technologies offer an alternative for the replacement and rehabilitation of deteriorated pipelines. Pipe bursting is a trenchless technology that can be an economic pipe replacement alternative when compared to the open-cut technique. It is especially cost-effective if the existing pipe is out of capacity, deep and/or below the ground water table (Atalah, 2008). Beyond the direct cost advantage of pipe bursting over open cut, trenchless techniques have several indirect cost advantages and considerably lower impact on the environment.

Civil utility projects, both open-trench (open-cut) and trenchless, are subject to risk. While the risks involved in trenchless operations can often be similar to those in the traditional open-trench construction operations, the risk magnitude varies (Ariaratnam *et al.*, 1998). The risks in pipe-bursting operations are wide ranging and include legal, financial, social, political, geotechnical, geographical, design related, commissioning, communications, technological, supply, commissioning, force majeure/act of God, safety related, environmental, social, construction related, etc. This paper focuses on those risks that occur in the construction phase of pipe-bursting projects. Studying these risks and understanding their probability of occurrence, as well as impact on cost, will help owners, engineers and contractors plan for and adequately respond to these risks. Additionally, a logical assessment of the risks will aid in effective decision-making regarding the management of the project.

2. Pipe-bursting overview

The International Society for Trenchless Technology (2013) defines pipe bursting as a trenchless replacement method in which an existing pipe is broken by brittle fracture, using mechanically applied force from within. The pipe fragments are forced into the surrounding ground. At the same time, a new pipe, of the same or larger diameter, is pulled or pushed in the same alignment as the existing pipe. Pipe bursting was developed in the late 1970’s in the UK by D.J. Ryan & Sons and British Gas mainly for the replacement of small diameter gas lines. The process involved a pneumatically driven, cone-shaped bursting head operated by a reciprocating impact process. This method was patented in the UK in 1981 and in the USA in 1986. However, these patents expired in April 2005 (Atalah, 2008). This method, initially used to replace cast iron gas distribution lines, has continuously improved and is presently used to replace water lines, sewer mains and sewer service lines, gas lines, culverts and communication ducts worldwide (Ariaratnam and Hahn, 2007).

2.1 Pipe-bursting systems

There are two main classes of pipe-bursting systems: pneumatic and static. The pneumatic bursting system uses pulsating air pressure to drive the head forward and burst the old pipe. A small pulling device guides the head via a constant tension winch and cable. In the pneumatic system, the bursting tool is a soil displacement hammer driven by compressed air and operated at a rate of 180 to 580 blows per minute. With each stroke, the bursting tool cracks and breaks the old pipe, the expander, combined with the percussive action of the bursting tool, push the fragments and the surrounding soil providing space to pull in the new pipe. The expander can be front-end (attached to the front end of the hammer) for pipes smaller than 12 inches or back-end (attached to the backend of the hammer) for pipes larger than 12 inches (Atalah, 2008).

The static bursting system uses a static head with no moving internal parts to burst the old pipe. The head is simply pulled through the pipe by a heavy-duty pulling device via a segmented drill rod assembly or heavy anchor chain (Atalah *et al.*, 1998). Tremendous tensile force is applied to the cone-shaped expansion head through a pulling rod assembly or cable inserted through the existing pipe. The cone transfers the horizontal pulling force into a radial force, breaking the old pipe and expanding the cavity providing space for the new pipe (Atalah, 2008). The new pipe is pushed or pulled into place behind the bursting head.

Over the years, modifications have been made to the basic pipe-bursting technique leading to other bursting systems including Pipe Splitting, Pipe Reaming (Inneream), Impactor (Earthtool) Process and Tenbusch Method.

2.2 Applications and limitations of pipe bursting

Pipe bursting is typically used to replace water lines, sewer mains and lateral connections and gas lines ranging from 2 to 36 inches in diameter. The typical length of a replacement run is between 300 and 500 feet; however, successful bursts are possible for longer drives in favorable conditions. Commonly performed replacements are size-for-size and one-size upsize above the diameter of the existing pipe. Larger upsize (up to three pipe sizes) have been successful, but a large upsizing will require more energy and will lead to more ground movement (ASCE, 2007).

Almost all types of pipes can be burst including cast iron, steel, ductile iron, high-density polyethylene (HDPE), polyvinyl chloride (PVC), cast in place concrete, clay, reinforced concrete and asbestos cement. However, pipe bursting cannot be used to replace reinforced concrete cylinder pipes. Almost all types of pipes can be installed using pipe bursting including HDPE, PVC, clay, steel, fiberglass, polymer, ductile iron and concrete (Atalah, 2008; International Pipe Bursting Association (IPBA), 2012; Timberlake, 2011). Sectional pipes are pushed in place while the continuous pipes that can take tension are pulled behind the bursting head.

One of the limitations of pipe bursting is that it requires bypassing the flow to allow work on the pipeline being replaced. Bypass pumping must be part of the design protocol when dealing with live lines. There are other limitations to the pipe-bursting method including the following identified by Atalah (2007):

- Excavation for the lateral connections is needed.
- Expansive soils could cause difficulties for bursting.
- A collapsed pipe at a certain point along the old pipe may require excavation at that point to allow the insertion of pulling cable or rod.
- Point repairs with ductile material can also interfere with the replacement process.
- If the old sewer line is significantly out of line and grade, the new line will also tend to be out of line and grade although minor corrections of localized sags are possible.
- Insertion and pulling shafts are needed, especially for larger bursts.

2.3 General sequence of pipe-bursting operations

A pipe-bursting operation begins at pre-design and design phases where the designer/engineer collects all the relevant information about the existing pipe and the new pipe. The engineer then designs the project and prepares the bid documents. Either through competitive bidding or negotiated contracts, a qualified contractor is selected who prepares all submittals according to bid documents and completes the job according to the specifications.

The steps involved in pipe bursting vary depending on the pipe-bursting technique used and the specific project conditions. It is common for some activities to be done concurrently reducing the duration of the project. For example, machine set up in the reception shaft can be done as insertion shaft is being excavated. The breakdown of the typical steps involved in a pipe-bursting operation are listed below and the sequence of operation shown in Figure 1:

1. Preconstruction survey:
   - site visits; and
   - closed-circuit television (CCTV) inspection and cleaning of old pipe, if needed.
2. Mobilization:
   - transportation of equipment, material and labor to site.
3. Pit preparation:
   - clearing of pits;
   - excavation, shaping and levelling of pits; and
   - excavation at services and setting up temporary bypass.

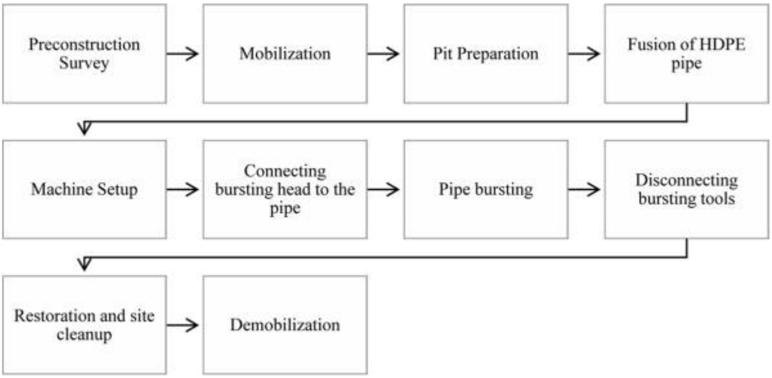

Figure 1.
Pipe-bursting activities

(4) Fusion of new pipe:
  - setting up fusion machine; and
  - fusing the pipe.

(5) Machine setup:
  - setting up winch (for pneumatic system) or hydraulic pulling system (for static system); and
  - inserting winch cable or pulling rods through existing pipe.

(6) Connecting bursting head:
  - installation of air supply hoses through new pipe to bursting head (for pneumatic system);
  - connecting and bolting bursting head to new pipe; and
  - connecting bursting head to pulling cable or rod.

(7) Pipe bursting and replacement with new pipe.

(8) Disconnecting bursting tools:
  - separating bursting head from pipe;
  - disconnecting air supply hoses (for pneumatic); and
  - removal of winch or hydraulic unit from pit.

(9) Restoration and site cleanup:
  - reconnection of services;
  - backfilling; and
  - seeding.

(10) Demobilization.

3. Research methodology

Three main steps were used to collect data for this study as shown in Figure 2. The first step involved extensive literature review, the second step involved informal interviews with industry professionals, and the third step involved a structured questionnaire survey to collect data on the probability of occurrence and impact of the identified risks on cost of pipe-bursting projects.

3.1 Literature review and informal interviews

Several researchers have identified the risks that occur during pipe-bursting operations (Ariaratnam *et al.*, 2014; Atalah, 2006; Atalah *et al.*, 1998; Brachman *et al.*, 2010; Nkemitag

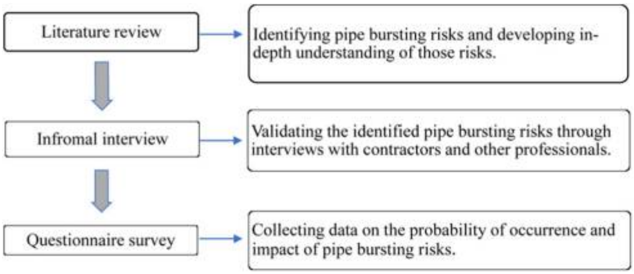

Figure 2.
Data collection methods

and Moore, 2006; Simicevic and Sterling, 2001). However, there is no existing literature on the probability of occurrence and impact on cost of risks in pipe-bursting projects. Extensive literature review was conducted to identify the risks that occur on pipe-bursting projects. In addition to identifying the risks, the literature review provided in-depth understanding of the risks including their causes and effects.

To validate the risks identified through literature review and ensure all risks are included in the survey, the authors conducted two informal interviews with industry professionals. The interviewees are experienced experts from the two major pipe-bursting manufacturers in the country (TT Technologies and HammerHead Trenchless Equipment). These manufacturers, in addition to being the industry leaders of innovation and pipe-bursting technology, provide expert services to utility owners and contractors, which include on-field training and problem-solving. Through the literature review and interviews, 18 risks that occur during pipe-bursting operations were identified and used for the survey. Although some of these risks are interrelated, they are distinctly recognized and defined separately. The pipe-bursting constructions risks are explained below:

- *R1_ Stuck bursting head*: This is the situation in which the forward advancement of the bursting head is halted. This can be a result of several factors including insufficient power of the bursting system, undocumented repairs and presence of obstructions.
- *R2_ Heave on surface*: This is the process in which the ground in front of or above the pipe is displaced forward and upward causing a lifting of the ground surface. This may result in damage of surface structures like pavements.
- *R3_ Subsidence on surface*: This is the measurable downward movement of the ground surface as a result of settlement, movement or consolidation of the underlying soil.
- *R4_Collapsed host pipe ahead of the busting head*: This is where the deteriorated existing pipe buckles or crumples before bursting.
- *R5_Damage to nearby utilities and structures*: This is where the ground movements and vibrations caused by the pipe-bursting operation could potentially damage the existing utilities and other structures in propinquity to the operation.
- *R6_Bypass related risks*: These are risks that occur because of rerouting the flow around the section of pipe being replaced.
- *R7_Unfavorable ground conditions*: This encompasses all ground conditions that are unsuitable to pipe bursting. These include rocks, incompressible soils, highly expansive soils and collapsible soils.
- *R8_Presence of groundwater*: This refers to subsurface water that could affect productivity or success of the bursting operation.
- *R9_Undocumented repairs to host pipe*: These are repairs to the existing pipe that were not recorded or included in the existing as-built documents.
- *R10_Changes in host pipe material*: This is where the existing pipe is made up of different materials. This could occur as a result of a section of the pipe being relined or replaced with a different material.
- *R11_Damage to product pipe during installation*: This refers to damages that could occur to the new pipe before or during installation. This can be a result of poor handling of the pipe, manufacturing defects, existing the safe bend radius or safe pulling loads, or damage from fragments from the broken old pipe.

- *R12_Damage to lateral connections*: This is damage to other pipes connected to the pipe being burst.
- *R13_Maintaining proper grade*: This is where the installed pipe is out of grade and may not effectively serve its intended purpose.
- *R14_Sags in the installed pipe*: This refers to dips in sections of the installed pipe.
- *R15_Safety of workers and public*: This refers to job site hazards that can harm the workers and the public. Examples include open excavations that present fall risk, trench collapses, proximity to moving equipment, etc.
- *R16_Weather related risks*: These are unanticipated unfavorable weather conditions that affect the success of the project. These include heavy snow and rainfalls, extreme heat, etc.
- *R17_Concrete encasement*: This is where a section of the existing pipe is enshrouded in concrete. This presents a challenge when bursting the existing pipe.
- *R18_Operational risks*: These are bursting equipment performance risks. Examples include inadequate equipment capacity, poor maintenance, etc.

3.2 Questionnaire survey

A questionnaire survey was adopted as the appropriate method for the data collection in this study. This quantitative data collection method has been widely used by researchers to collect and analyze data on construction risks (Akintoye and MacLeod, 1996; Al-Shibly *et al.*, 2013; Hwang *et al.*, 2014; Kartam and Kartam, 2001; Shen, 1997; Wang and Yuan, 2011).

The survey questionnaire used consisted of two main parts. The first part was intended to collect data on the probability of occurrence of the pipe-bursting risks. Respondents were asked to determine the probability of occurrence of the risks using a five-point Likert scale where “1” represented very low probability of occurrence and “5” represented very high probability of occurrence. The second part was designed to collect data on the impact of the risks on cost of pipe-bursting projects. A five-point Likert scale was used where “1” represented no impact on cost and “5” represented very high impact on cost.

The questionnaires were distributed to pipe-bursting contractors, engineers and pipe-bursting equipment manufacturers. To assure maximum level of research sample engagement, the authors attended the 2017 North American Society for Trenchless Technology (NASTT) No-Dig Show and administered the questionnaires to both contractors and equipment manufacturers. The NASTT No-Dig show is the largest trenchless technology conference in the world and it is the society’s flagship educational and networking event. The questionnaires were also distributed online to other contractors from the NASTT industry directory. In 2017, 18 pipe-bursting contractors and two pipe-bursting equipment manufacturers attended the NASTT conference and the questionnaire was distributed to all of them. A total of 49 questionnaires were sent out (including those sent online) and 32 were returned completed forming a 65 per cent response rate. Considering the relatively small number of pipe-bursting contractors, the researchers deem the response reflects the opinions of the pipe-bursting contractors who are members of NASTT.

4. Data analysis and results

There are many methods that can be used to analyze construction risks. Generally, these methods are classified as quantitative and qualitative. The quantitative methodology implies that the risk probability and risk impact can be calculated using one of the known quantitative risk-analysis methods (Ceric *et al.*, 2011). Many methods of quantitative risk analysis in use today, such as probabilistic analysis, sensitivity analysis and Monte Carlo simulation, require the specification of key project variables and their corresponding probability distributions. This requires the accumulation of relevant database and involves large number of calculations that can only be carried out by the speed and processing power of a computer (Smith *et al.*, 2014).

Qualitative analysis, on the other hand, involves subjective judgement of the risk probability and risk impact. According to Zhi (1995), subjective judgement means directly estimating the risk impact and probability from experience and objective scrutiny. Frequently, no further analysis is done beyond the subjective analysis. More likely, further analysis is rooted in the qualitative process. However, weighting factors can be applied to the qualitative assessment to provide a quasi-quantitative form of analysis (Smith *et al.*, 2014).

Quasi-quantitative analysis was used for the risk assessment and data analysis for this research. The weighting factors of each risk was collated and the relative importance calculated for each risk. Further, a probability-impact (PI) model was created to effectively identify critical risks based on the product of degree of impact and probability of occurrence (Degree of risk = Impact × Probability). The analysis provides the logical basis for effective decision making in risk management.

4.1 Probability of occurrence of pipe-bursting construction risks

The analysis of the probability of occurrence is presented in Figure 3. From the analysis, R9 (undocumented repairs to host pipe), R10 (changes in host pipe material) and R8 (presence of ground water) have the highest probability of occurrence, whereas R15 (safety of workers and public) was reported to have the least probability of occurrence.

4.2 Impact of pipe-bursting construction risks on project cost

Figure 4 indicates the impact of the various risks on the cost of pipe-bursting projects. According to the survey, R9 (undocumented repairs to host pipe) was perceived to have the highest impact on cost, whereas R16 (weather related) was projected to have the lowest impact on cost.

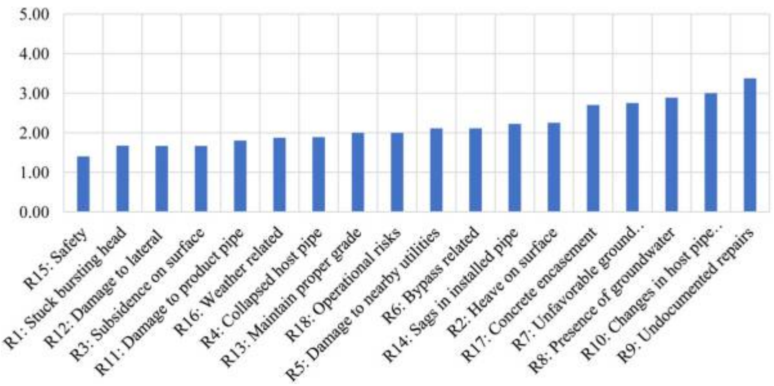

Figure 3.
Probability of occurrence of pipe-bursting construction risks

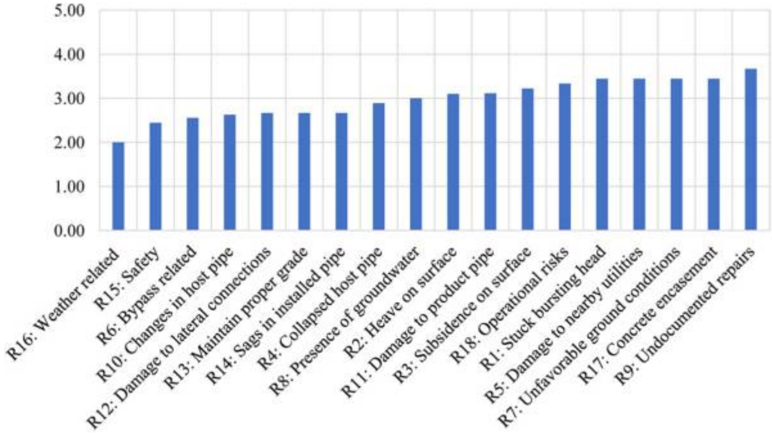

Figure 4.
Impact of pipe-bursting construction risks

4.3 Probability-impact model analysis

Risk management involves risk identification, risk assessment or analysis and risk response. The PI model is an effective tool to analyze the criticality of risks based on their impact and probability of occurrence and to provide the appropriate responses to the risks. Having identified and assessed the risk impact and probability, the PI model was used to prioritize the risks and propose suitable risk response strategies. The model should place the contractor in a good position to make the right decisions on the mitigation strategy to adopt for the related risks.

The PI model was constructed as a chart using the *x*- and *y*-axes. The *x*-axis represents the cost impact of the pipe-bursting construction risks and the *y*-axis represents the probability of occurrence of the risks. The chart was subsequently divided into four groups to indicate the criticality of the risks as:

(1) high probability-low impact;
(2) high probability-high impact;
(3) low probability-low impact; and
(4) low probability-high impact.

Based on the impact of the risks and the probability of occurrence, the risks were plotted on the PI model indicating their criticality and consequently, the appropriate risk response. The PI model of the pipe-bursting construction risks is presented in Figure 5 and the four quadrants are discussed below.

4.3.1 High probability-low impact risks (Quadrant 1). These risks are in the top left quadrant and they have low impact on the cost of project but high probability of occurrence. Although these risks are considered acceptable, which means the contractor can cope with them if they do occur, mitigation strategies may be used to reduce the probability of occurrence. R10: changes in host pipe falls within this quadrant.

4.3.2 High probability-high impact risks (Quadrant 2). The risks in the top right quadrant have high impact on the project cost and high probability of occurrence. These risks are critical to project success and the contractor must take the necessary measures to reduce their probability of occurrence and potential impact. Where possible, the contractor

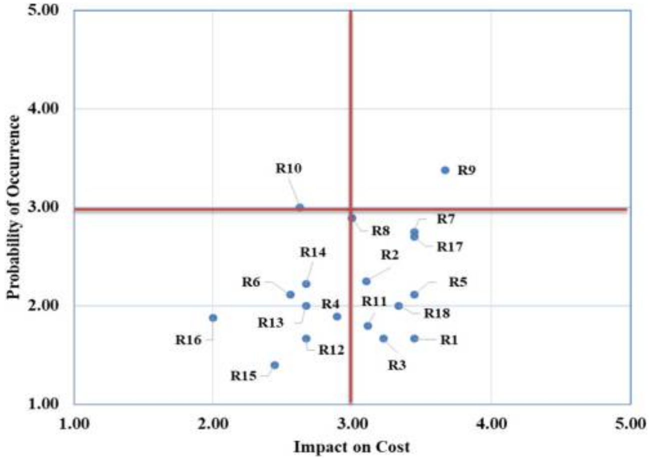

Figure 5.
Probability-impact model of pipe-bursting construction risks

should avoid these risks. R9: undocumented repairs to host pipe is the only risk that falls within this quadrant.

4.3.3 Low probability-low impact risks (Quadrant 3). These risks are in the bottom left quadrant and have low impact on the total cost of the project and low probability of occurrence. These risks are considered acceptable and they do not pose any major threats to the success of the project. However, the contractor should take measures to reduce the impact if it is worth the effort. These risks include the following: R4: collapsed host pipe ahead of the bursting head, R6: bypass-related risks, R12: damage to lateral connections, R13: maintaining proper grade, R14: sags in the installed pipe, R15: safety of workers and public and R16: weather-related risks.

4.3.4 Low probability-high impact risks (Quadrant 4). The risks in the bottom right quadrant have high impact on the cost of the project and low probability of occurrence. Risks in this quadrant should be transferred to third parties capable of handling them. They include the following: R1: stuck bursting head, R2: heave on surface causing damage to pavement, R3: subsidence on surface causing damage to pavement, R5: damage to nearby utilities and structures, R7: unfavorably ground conditions, R8: presence of ground water, R11: damage to product pipe during installation, R17: concrete encasement and R18 operational risks. It is not typical for pipe-bursting contractors to transfer all these risks. The contractor will usually absorb most of these risks and put in place the necessary measures to reduce both their probability of occurrence and their impact.

5. Discussion of results and risk responses

From the model, only one risk (R9: undocumented repairs to host pipe) has high probability of occurrence and high impact on cost. With most of the risks in Quadrants 3 and 4, we can deduce that the respondents generally perceived the risks to have low probability of occurrence.

Identification and assessment of risks alone will not serve the purpose of risk management unless meaningful ways to mitigate those risks in a structured way is planned (Panthi *et al.*, 2007). The PI model, as discussed above, provides the structured mitigation responses to manage the risks. The risk responses should be appropriate, affordable, actionable, achievable, assessed, agreed and allocated (Hillson, 1999). Four general responses are considered based on the quadrants in which the risk falls. These are risk avoidance, risk transfer, risk reduction and risk acceptance.

When the probability of occurrence of a risk and the impact associated with it are high, then risk avoidance is the response that should be followed. This means not choosing to do the project (Onsarigo *et al.*, 2014). However, if by avoiding the risk the contractor will lose a big financial opportunity, then efforts should be made toward clarifying the requirements by obtaining more information (Hillson, 1999). Undocumented repairs to host pipe may lead to stuck bursting head which can halt progress of the bursting operation. If the contractor decides to undertake the project, then all efforts should be made to gather enough information about the host pipe. Robotic inspection can be employed to collect material information of the host pipe. It is imperative to understand that different material repairs on the host pipe may require different bursting head or different bursting system with sufficient power to burst.

Risk transfer is the appropriate response when the impact is high and the probability of occurrence is low. This can be achieved through insurance, which transfers the risk to insurance companies, or through provisions in the contracts that will transfer the risk to either the owner or other stakeholders. Damage to product pipe and damage to nearby utilities and structures can be covered through insurance. When the owner is a department of transportation or public entity, the contract should be drawn to transfer the risks of heave and subsidence causing damage to pavement to the owners because they are in a better position to handle such risks. Proper ground investigation can help the contractor prepare for unfavorable ground conditions. However, a clause can be included in the contract to give a reprieve to the contractor for delays caused by unfavorable ground conditions and, allow the contractor to recoup extra cost that would be incurred. The same should be applied to presence of ground water and stuck bursting head. Concrete encasement can halt the bursting process and therefore the contractor should ensure that the right bursting system is used. The engineer should be able to collect the necessary information during geotechnical investigation to properly design the project. This will enable the contractor to select the appropriate bursting system and adequately price and submit a proper bid. The contractor's ability to make the right decisions during bidding will greatly increase the probability of project success.

Risk reduction is another response that can be used to either lessen the impact or the probability of occurrence. If the risk occurs very often, it is wiser to tackle the risk sources at their root by inhibiting their trigger (Hillson, 1999). Through proper host pipe investigation, the contractor can identify the changes in host pipe and select the appropriate bursting system for the project. When the risks have a low impact and low probability of occurrence, risk acceptance is the appropriate response. Acceptance can be passive when the impact is minor for which no prior plans may be required. Acceptance can be active if the impact needs to be further reduced and for such risks, contingency plan should be put in place by allocating sufficient time and resources (Panthi *et al.*, 2007).

As seen above, although a quadrant may determine the appropriate risk response, more than one response can be applied to a given risk. The decision on the response to adopt will be greatly dictated by the size of the project and project-specific conditions. The contractor's ability to identify and adequately respond to these risks is paramount to the success of the project. It is important to state that there are well known solutions to all the identified risks and contractors must be able to develop a risk management plan to address the risks for specific projects (Atalah, 2008).

6. Good practices for risk management in pipe-bursting projects

As discussed earlier, risk management is very critical to the success of any construction project. It is important to understand the risks inherent to a project to make better decisions with regard to the management of the project. A deliberate effort to minimize the probability of occurrence and impact of risks in pipe-bursting projects calls for contractors to follow good construction practices.

Pipe-bursting projects are not immune to unanticipated changes including changes in existing pipe material, significant changes in soil conditions and the presence of concrete encasements. These unanticipated changes in conditions may cause the forces required to continue forward movement to exceed the capacity of the equipment. When this occurs, the rate of burst is observed to be slower than anticipated. If the bursting is significantly slower than expected, the contractor should investigate the reason and study the available corrective actions. Atalah (2008) and Najafi (2013) explain some of the reasons for the slowdown in bursting and propose some corrective measures to remedy the situation:

- The bursting system does not have sufficient power to burst the pipe. If this is the case, the system should be replaced with a higher capacity one especially if the slowdown occurs at the beginning or middle of the burst. If it occurs in the middle of the burst, a shaft may be needed at that location to replace the system. If the slowdown occurs close to the pulling shaft, then the process should be continued till the head exits and the burst is completed.
- Some components such as the winch, cutting accessories or air compressor are unmatched or probably undersized. If this is the case, these components must be changed and the appropriate components must be used.
- The soil or ground conditions are causing friction that exceeds the pulling force. In this case, the replacement pipe should be lubricated to reduce the friction.
- There are other obstacles such as concrete encasement, ductile repair fittings, or change in the existing pipe material along the line. If this occurs close to the exit shaft, then the process should be continued till the head exits. If this occurs in the middle, then an excavation should be made from the ground surface to remove the obstacle, change the bursting head, or add/change cutting accessories.

Changes in the soil conditions over the length of the pipe can present challenges during the bursting operation. The soil type and its level of consolidation or compaction will affect the force required to compress it. Encountering a more compact soil will slow down the process and affect both the schedule and cost of the project. Engineers should pay special attention to the soil surrounding the existing pipe and design the project appropriately. This ground information is typically presented in the geotechnical reports [International Pipe Bursting Association (IPBA), 2012].

Sometimes, the existing pipe material or size differs from what is indicated in the plans and specifications. This could be a result of documentation errors or unrecorded repairs on the pipeline. If this is encountered, the method of pipe bursting may need to be changed or tooling used to break the existing pipe modified to suit the actual pipe type and size [International Pipe Bursting Association (IPBA), 2012].

Although sags in the installed line are not a concern in pressure applications, they can be very problematic in gravity applications. If there are unacceptable sags in the existing sewer line, these sags need to be corrected before bursting. The sags can be corrected by localized excavation to improve the soil under the pipe or grouting to stabilize the soil underneath the pipe. Some reduction of sag magnitude may be expected (without corrective measures) from the bursting operation, but the extent to which the problem is corrected depends on the relative stiffness of the soil below the sagging section. The use of more rigid pipes like PVC may also assist in correcting minor sags; however, the final line and grade will follow the existing alignment and may not be corrected by pipe bursting [International Pipe Bursting Association (IPBA), 2012].

Surface heave or subsidence can cause a lot of problems on the nearby infrastructure like roads, pavements, railways, other utilities or other surface structures. Some of the factors that can cause heaving on the surface during a pipe-bursting operation include shallow depth of cover, incompressible soil or soil with low compressibility and large upsizing leading to large volumetric displacement of soil. Voids or loose and unconsolidated soil above the pipeline can lead to subsidence when vibration caused by the bursting head causes the soil to collapse or consolidate (Najafi, 2013). Utilities, including gas lines and water lines, that are close to the pipe should be exposed prior to bursting using methods that will not damage the line such as vacuum or manual excavation (Atalah, 2004). They can then be monitored during the bursting operation to ensure that they do not move excessively and are safe. If excessive ground movement is anticipated very close to an existing structure or utilities, a ground movements and vibrations monitoring plan should be developed. The burst rate should be reduced if excessive movements are observed. If the movement persists after slowing down, the operation should be halted and alternative solutions should be explored (Atalah, 2008).

If the existing pipe is greatly deteriorated, part of it may collapse before the pipe bursting begins or ahead of the busting head. If a section of the pipe has collapsed, an excavation may be required at the collapsed location to allow insertion of the pull rod or cable [International Pipe Bursting Association (IPBA), 2012]. If the pipe collapses ahead of the bursting head, the force required to advance may increase because of the ground that collapses on the path of the bursting head.

The new pipe being installed can be damaged before installation or during installation. Improper handling including dragging over abrasive surfaces like pavements and improper shipping and unloading practices can damage the pipe. If the safe bend radius is exceeded at the entry pit or the safe pulling load is exceeded, the pipe can be damaged. Fragments from the existing pipe can also damage the new pipe as it is being pulled/pushed in place. Caution must be taken by the operators to ensure that the pipe is not damaged before and during installation. The contractor must ensure that the new pipe meets the specification before, during and after bursting. It is recommended that the pipe fusion is performed by certified and well-trained workers under appropriate supervision (Najafi, 2013; Atalah, 2008). The new pipe should also be inspected and tested before bursting and after it is installed.

7. Conclusions and recommendations

While pipe busting can be an economic alternative to the conventional open cut, the method has its own risks that must be appropriately managed to ensure the delivery of a successful project. This paper has identified and analyzed 18 risks that occur during the construction phase of pipe-bursting operations. The PI model was used to categorize and prioritize the risks and to provide the appropriate responses to the risks. The model revealed that majority of the analyzed risks fall within the Quadrants 3 and 4 indicating low impact-low probability of occurrence and high impact-low probability of occurrence, respectively. Undocumented repairs to host pipe was the only risk identified as having high probability of occurrence and high impact on cost. The risk responses from the model suggests a combination of risk transfer, reduction and acceptance to be appropriately applied to mitigate the risks. Good practices for risk mitigation such as matching the right bursting system with the project requirements and the need to monitor ground movements and vibrations were discussed. Importantly, the discussions on the good practices revealed that most pipe-bursting operations can be done safely and successfully if site and project conditions are known before bursting and the appropriate measures are taken to address those conditions. While different projects will encounter different risks, the findings of this study will help contractors to better prepare for these risks should they occur.

The study was limited to risks that occur during the construction phase of pipe-bursting installations. For future research, the study can look at design risks and operation and maintenance risks. Other methodologies for analyzing construction risks could also be investigated to assess the probability and impact of the risks.

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Further reading

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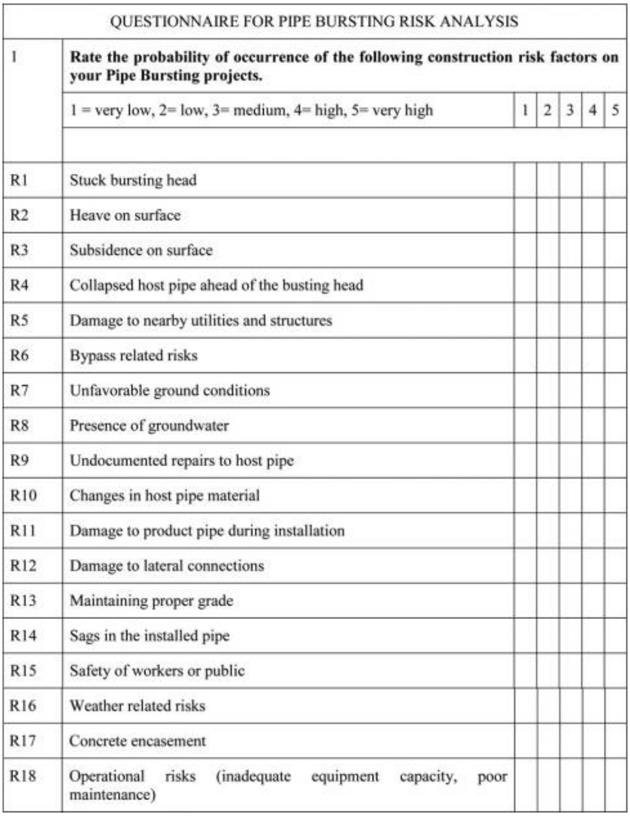
Appendix. The questionnaire

You are invited to participate in a research study titled "Managing Risks in Utility Construction Projects: Analysis of Pipe Bursting Construction Probability-Impact Model". The objective of this study is to determine both the probability of occurrence and impact levels of various construction risks on pipe-bursting projects. A probability-impact model will be used to analyze critical and non critical risks. It is our goal to see the results of this study play a major role in enabling contractors to adequately mitigate pipe-bursting construction risks to provide a safer working environment and avoid project delays and cost overruns. Some of these risks have social and environmental effects, and mitigating them will be beneficial to the project participants and the general public. Participants of this study will be given the results of the study.



QUESTIONNAIRE FOR PIPE BURSTING RISK ANALYSIS						
I	**Rate the probability of occurrence of the following construction risk factors on your Pipe Bursting projects.**					
	1 = very low, 2= low, 3= medium, 4= high, 5= very high	1	2	3	4	5
R1	Stuck bursting head					
R2	Heave on surface					
R3	Subsidence on surface					
R4	Collapsed host pipe ahead of the busting head					
R5	Damage to nearby utilities and structures					
R6	Bypass related risks					
R7	Unfavorable ground conditions					
R8	Presence of groundwater					
R9	Undocumented repairs to host pipe					
R10	Changes in host pipe material					
R11	Damage to product pipe during installation					
R12	Damage to lateral connections					
R13	Maintaining proper grade					
R14	Sags in the installed pipe					
R15	Safety of workers or public					
R16	Weather related risks					
R17	Concrete encasement					
R18	Operational risks (inadequate equipment capacity, poor maintenance)					

2	Rate the impact of the following risks on the total cost of projects in which they were encountered.					
	1=No impact, 2=Low impact, 3=Moderate impact, 4=High impact, 5=Very high impact	1	2	3	4	5
R1	Stuck bursting head					
R2	Heave on surface					
R3	Subsidence on surface					
R4	Collapsed host pipe ahead of the busting head					
R5	Damage to nearby utilities and structures					
R6	Bypass related risks					
R7	Unfavorable ground conditions					
R8	Presence of groundwater					
R9	Undocumented repairs to host pipe					
R10	Changes in host pipe material					
R11	Damage to product pipe during installation					
R12	Damage to lateral connections					
R13	Maintaining proper grade					
R14	Sags in the installed pipe					
R15	Safety of workers or public					
R16	Weather related risks					
R17	Concrete encasement					
R18	Operational risks (inadequate equipment capacity, poor maintenance)					

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