

Reducing Damages to Underground Utilities: Importance of Stakeholders' Behaviors

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Abstract: Vital services like clean water, sewer, and electricity utilize underground infrastructure. Unfortunately, many damages to underground utilities are happening during the course of construction activities. Therefore, there is a need for a greater understanding of damage causes to better manage risks to underground utilities during construction work. Understanding the root causes will help stakeholders and policymakers make the best possible decisions to reduce future damages. In this study, utility locators' perspectives regarding the damage causes and overall prevention process were collected, analyzed, and compared to excavators' perspectives and responses that were previously reported. Surprisingly, the results suggest that stakeholders' behaviors (i.e., human factor), rather than technology limitations or current policies, significantly contribute to a breakdown of the damage prevention process. Specifically, communication between stakeholders, excavators' behaviors, and locators' working conditions have been identified as crucial factors in the damage prevention process. There are few, if any, empirical studies that have recognized the human factor as a contributing element to utility damages. Thus, the findings will help improve future policy development. In addition, the clear and detailed description of damage causes and prevention processes will help stakeholders understand the contribution of their behaviors to the damage prevention process, which will result in a more reliable and workable process. DOI: [10.1061/\(ASCE\)CO.1943-7862.0001899](https://doi.org/10.1061/(ASCE)CO.1943-7862.0001899). © 2020 American Society of Civil Engineers.

Introduction

Underground utilities are the core of modern cities. Public services such as clean water, electricity, and telecommunications are delivered through millions of miles of underground infrastructure every day. The high demand for energy and improved quality of life increases the size and complexity of the invisible world of underground utilities (Siu and Lai 2019; Al-Bayati et al. 2019b). Furthermore, our nation's infrastructure continues to expand due to population growth (ASCE 2002). Damage to underground utilities leads to lack of public services (e.g., water, electricity, and sewer) and paralyzed modern cities. In addition, the impacts of damages include project delays, costly repair expenses, environmental damages, and fatal and nonfatal injuries (Al-Bayati and Panzer 2019a; Tanoli et al. 2019). For example, damage to a gas line during a horizontal drilling operation led to an explosion that killed two people and injured 25 while destroying a building and damaging a dozen buildings in North Carolina in 2019 (Graves 2019). While damages to underground infrastructure are not a recent issue, they have increased in recent years due to the substantial growth of the underground infrastructure (Metje et al. 2007; Al-Bayati and Panzer 2019a). There were roughly 956 damages to underground utilities per day in 2017 (DIRT 2017). Most of the damages to underground utilities happen during construction activities (Al-Bayati et al. 2019b).

An estimated 28 million and 1.5 million underground utility excavations are executed each year in the United States and the United Kingdom, respectively (CGA 2019b; McMahon et al. 2006). Roughly, 1.5% of these excavations involve damage to underground utilities (Al-Bayati et al. 2019b; McMahon et al. 2006). Damages often happen when underground utilities are not accurately marked before excavation starts (Li et al. 2015; Tanoli et al. 2019). Thus, accurate marking (i.e., locate) is a crucial prerequisite for safe excavations (Hyung and Dulcy 2004; Metje et al. 2007). Locators use a combination of maps and electromagnetic technology to locate and subsequently mark the underground utilities within the proposed excavation area. Locators may be hired directly by utility owners or locate companies that are contracted for the service. In the United States, construction firms are required by law to report planned excavation activities to one-call centers to request that owners of involved utilities locate their underground utilities within the excavation's boundaries (Al-Bayati and Panzer 2019b). One-call centers were initiated in the 1970s to serve as a communication channel between excavators and utility owners and have been supported by the states' damage prevention statutes. Accordingly, shared responsibility between the involved parties is crucial to successfully reduce the damages (Al-Bayati and Panzer 2019a).

Damage Root Causes

The root causes of damages are difficult to identify, and they vary based on the source of information (e.g., locators versus excavators) (Metje et al. 2015). The causes of damages could be categorized into the following: excavation practices insufficient, locating practices insufficient, and notification error. The contribution of these categorized causes is inconsistent within the published literature. In addition to the previous categorization, Metje et al. (2015) reported untraceable and abandoned utilities as contributing to damages. Furthermore, Siu and Lai (2019) suggest that the influence of nearby cables and metallic pipes (i.e., coupling effect) has a significant influence on locating accuracy. Untraceable and

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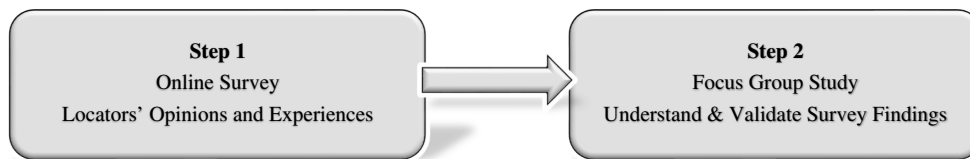


Fig. 1. Research methodology.

abandoned utilities and the coupling effect cannot be classified under the previously discussed categorization. Thus, they could be classified under a new category called “Others.” Al-Bayati and Panzer (2019a) investigated the excavators’ perspectives regarding the damage prevention practices with an aim to identify deficiencies and possible improvements. The study suggested that inaccurate locates are the second contributing cause of damages after the lack of utility depth information (i.e., technology limitation). The findings suggest several causes, such as the locators being in a rush or insufficiently trained, inaccurate utility maps, and broken tracer wires. Al-Bayati and Panzer (2019a) also revealed that the time required to locate underground utilities is often longer than the legislated time (e.g., three business days in North Carolina). The study revealed that more than 50% of the one-call requests were not within the legislated time requirement.

Accordingly, this study aims to validate and further understand the root causes that significantly contribute to inaccurate and late locates from locators’ perspectives. Therefore, the root causes that have been suggested in Al-Bayati and Panzer (2019a) and Metje et al. (2015) have been reviewed and discussed. In addition, the study aims to understand the working conditions and challenges that underground utility locators face daily.

Research Methodology and Findings

Both quantitative and qualitative techniques were employed to further understand the causes of inaccurate and late locates as perceived by utility locators. To achieve the study goal, a partnership with the North Carolina 811 notification center (NC811) has been established. Accordingly, a survey was prepared to solicit the locators’ point of view. The research team reviewed the survey questions with a group of locators to ensure the survey is valid and easy to understand. After the survey data was collected and analyzed, a focus group study was designed to further understand and validate survey findings. Focus group interviews have unique features such as enabling in-depth discussion and allowing interaction among participants. Fig. 1 illustrates the research methodology and its purpose. The authors used a combination of qualitative and quantitative methods (i.e., mixed-method) to ensure the study findings were valid as suggested by Al-Bayati et al. (2019a). Furthermore, a content analysis has been conducted on the collected qualitative data (i.e., open-ended questions) to quantify the provided feedback and comments. Content analysis is a method that helps researchers to gain more insights and expand their understanding of text data (Krippendorff 2004). Finally, Western Carolina University’s Human Subject Institutional Review Board (HSIRB) reviewed and approved the research instrument and protocol.

Survey Findings

The survey was administered between March and May 2019, and 98 responses were received. The job titles of the respondents fell within the following categories: locate technician [44 (44.9%)],

locate manager [30 (30.6%)], and locate supervisor [24 (24.5%)]. The answers to the question about the participants’ experience indicate that 81 (82.6%) respondents have more than three years of experience; 14 (14.3%) respondents have between 1 and 3 years of experience; and 3 (3.1%) respondents have less than 1 year of experience. The educational background of respondents mostly falls within US high school [26 (26.5%)] and some college or beyond [68 (69.4%)]. The age of participants falls between 20 and 66 years [Mean (M) = 43.24, Standard Deviation (SD) = 11.1]. Finally, the respondents came from North Carolina [43 (43.9%)], New Jersey [10 (10.2%)], California [8 (8.2%)], South Carolina [6 (6.1%)], and other states such as Texas, Virginia, and Maryland [31 (31.6%)]. The respondents were also asked to provide information about their working conditions. Table 1 shows the working conditions of locators, including the number of working days per week and the number of locates, working hours, and miles driven per day. Most locators (i.e., more than 50%) work up to 10 h and drive more than 121 km (75 mi) every day. Comparing the number of locates per day presented in Table 1 with the years of experience reveals that more experienced locators can complete a higher number of locates per day; see Fig. 2.

Participants provided information about the type of underground utilities they often locate. The responses show that most of the participants [65 (66.3%)] locate multiple utilities including gas, telecommunication, and electric, followed by gas locators [25 (25.5%)], telecommunication [5 (5.1%)], and electric [3 (3.1%)]. Thus, it could be inferred that most of the survey participants work for locating contractors, not utility owners, because utility owners’ locators often locate one kind of underground utility. The participants were asked to order the utilities (i.e., gas, electricity, telecommunications, and sewer and water) based on the accuracy of the

Table 1. Locators working conditions

Characteristics	Number (%)
Locates per day	
15–20	40 (40.8)
20–30	40 (40.8)
30–40	11 (11.3)
More than 40	7 (7.1)
Working days per week	
1–4	4 (4.1)
5	56 (57.1)
6	32 (32.7)
7	6 (6.1)
Hours per day	
6–8	12 (12.2)
8–10	60 (61.3)
More than 10	26 (26.5)
Miles driven per day	
Less than 25 miles	6 (6.1)
25–50	22 (22.4)
50–75	29 (29.6)
More than 75	41 (41.8)

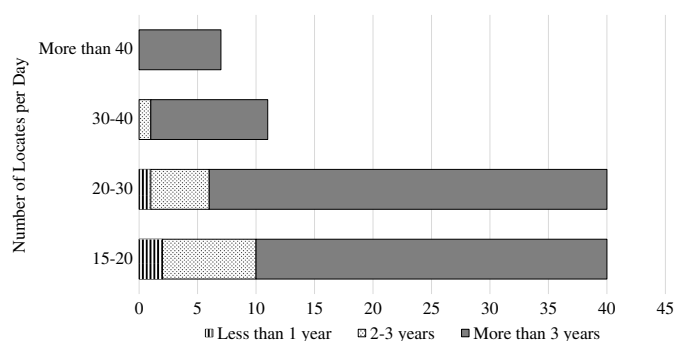


Fig. 2. Number of locates per locators' experience.

Table 2. Descriptive data of utilities' locate accuracy

Utility	Mean	Standard deviation	Minimum score	Maximum score
Gas	2.05	0.97	1	4
Electric	2.04	0.8	5	5
Telecom	2.67	1.26	1	4
Sewer and water	3.29	0.99	1	5

locates, where 1 is often accurate and 5 is less accurate. Table 2 shows the participants' scores for each utility type.

A factorial ANOVA was conducted to determine if there is a significant difference between the scores of utilities' accuracy. The results indicate a statistically significant difference in the accuracy score based on participants' experience ($F = 33.387$; $df = 3,388$; $p < 0.001$). A statistically significant difference means that there is less than a 0.001 chance that the difference in scores could be attributed to random effects. However, the ANOVA test does not tell where the statistical differences lie. Therefore, Tukey's honestly significant difference (HSD) tests were conducted on all possible pairwise contrasts. The results revealed that the accuracy of locating gas and electrical is statistically significantly more accurate than others (i.e., score average is 2.045). Furthermore, the accuracy of telecommunication locates is statistically significantly better than sewer and water locates

(i.e., score average is 2.67). The following groups were found to be significantly different ($p < 0.05$):

- Group 1 (most accurate group): Gas locating accuracy ($M = 2.05$, $SD = 0.967$) and electrical locate accuracy ($M = 2.04$, $SD = 0.798$)
- Group 2: Telecommunication locating accuracy ($M = 2.67$, $SD = 1.26$)
- Group 3: Sewer and water locating accuracy ($M = 3.29$, $SD = 0.995$)

Table 3 illustrates a summary of the first four challenges per utility that locators provided through the survey's open-ended questions. The challenges have been ordered based on their frequency. These challenges will be further discussed during the focus group study to evaluate their validity and reliability.

Inaccurate Locates—Root Causes

Al-Bayati and Panzer (2019a) have suggested eight causes of locate inaccuracy. Accordingly, participants were asked to score the eight suggested causes of locates inaccuracy from 1 to 10, where 1 means totally disagree and 10 means totally agree. The suggested causes are as follows:

- Locators are in a rush due to the workforce shortage;
- Locators do not get enough training;
- Inaccurate maps;
- Some utilities were installed with looped lines that were not marked;
- Utility location gets obscured due to material interference;
- Utility location is unlocatable due to a broken tracer wire;
- Utility location gets obscured due to vegetation growth; and
- Locating equipment limitations.

Table 4 shows the average score for each cause based on locators' experience. A factorial ANOVA was conducted to determine if there is a statistically significant difference between the suggested causes based on participants' experiences. The results indicate a statistically significant difference in the score of causes ($F = 131.3$; $df = 7,776$; $p < 0.001$). Furthermore, Tukey's honestly significant difference (HSD) tests were conducted to evaluate the pairwise differences between the suggested causes. The results revealed that "the locators being in a rush due to workforce shortage" is statistically significantly the most contributing cause to locate inaccuracy (i.e., score average is 7.04) followed by "inaccurate maps" and

Table 3. Suggested challenges of locating underground utilities

Utility type	Suggested challenges	Sample of participants' feedback
Telecom	Number of lines (i.e., coupling effect) Poor maps Untenable materials Installation practices	"There is so many buried and more are being buried each day." "The prints are not good, access points are not always available, and there is so much of it in the ground."
Water and sewer	Untenable materials Damaged, corroded, or no tracer wire Poor signal strength Depth	"Cast/ductile iron doesn't allow good current flow. Clay pipes/no tracer wire." "Water is the harder cause of age, no tracer on plastic lines, or cut tracer line, hard to find old valves."
Gas	Damaged, corroded, or no tracer wire Untenable materials Poor maps Lack of access (unable to direct connect)	"The number of services in the scope of each ticket." "Gas can be hard because of broken or no tracer wires with plastic piping."
Electrical	Poor grounding Lack of access (unable to direct connect) Number of lines (i.e., coupling effect) Poor signal strength	"Everyone uses electric grounds; it makes isolating things difficult." "The communication companies ground through the transformers or power meters and put voltage on some lines."

Table 4. Inaccurate locate causes from the most to the less contributing cause

Group no.	Group no. (Al-Bayati and Panzer 2019a)	Cause	Score average
1	1	Locators being in a rush due to the workforce shortage	7.04
2	4	Broken tracer wire	6.67
	2	Inaccurate maps	6.42
3	1	Locators do not get enough training	5.83
	4	Utility location gets obscured due to material interference	5.27
4	4	Utility location gets obscured due to vegetation growth	4.54
	3	Utilities were installed with looped lines that were not marked	4.20
	N/A	Locating equipment limitations	4.09

“utility location is unlocatable due to a broken tracer wire.” Table 4 illustrates the groups that were found to be significantly different ($p < 0.05$). Table 4 also includes the causes’ order based on excavators’ experiences from Al-Bayati and Panzer (2019a). Locators’ scores seem to be partially different from excavators’ scores. For example, broken tracer wire contributes significantly to inaccurate locates according to locators’ perspectives (i.e., second group), while this issue contributes less according to excavators’ perspectives (i.e., fourth group). Locators also suggest that the training quality is the third contributing factor, not the first as excavators suggest; see Table 4. It is suggested that the locators’ perspectives regarding the causes of locate inaccuracy are more valid due to their work experience. The research team believes that comparing the perspectives of locators and excavators is crucial to identifying areas of misunderstanding, which in turn will help to improve education and damage prevention efforts.

Late Locates—Root Causes

Al-Bayati et al. (2019b) suggested that the time to complete locates is often more than the legislated time (e.g., three business days). However, the factors that contribute to late locates have not been previously identified. Therefore, the participants were asked about several potential factors that have been suggested by stakeholders and the executive director of NC811. The suggested factors are workforce shortage, inaccurate maps, tickets that should be survey/design, no white lining, and improper update tickets. Workforce shortage seems to be a significant challenge that contributes to late locates; see Table 5. The responses suggest that inaccurate maps are an issue locators face on a regular basis (26.6%), or at least from time to time (59.2%); see Table 5. A design/survey ticket should be created by firms or individuals during the design phase. Design/survey tickets are intended to be used when excavation is not taking place. The legislated time to respond to a design/survey ticket is

10 business days instead of the three full business days. In addition, a response to a design/survey ticket could be either a physical locate, provision of maps, or access to the maps provided by the utility. A large portion of the study sample indicates that excavation tickets are being requested instead of design/survey tickets on a regular basis (30.6%) or from time to time (44.9%); see Table 5. This could be a result of the fact that architectural/engineering firms wanting a physical locate. These firms understand that a locate is not an automatic guarantee with a design/survey request or they do not want to wait 10 days to get a response. This misidentification places an unnecessary load on locators. In North Carolina, the law requires that white lining around the proposed excavation area should be made by contractors when the area cannot be adequately described in the ticket. The white lining could be made with soluble white paint, white flags, or white stakes. White lining is very important to more clearly define the specific area that is to be excavated and helps facilitate accurate locates of the utilities within an acceptable time. Unfortunately, white lining seems not to be a practice that is performed as consistently as needed by the excavators; see Table 5.

After the utilities have been marked, a positive response that communicates the ticket status (i.e., locate request) to the excavator must be delivered by the utility or their contract locator. Once this step has been completed, construction firms (i.e., excavators) have 15 business days, which may vary per state, to complete their proposed excavation. Construction firms are required by law to update the ticket if there is a need for more time. Therefore, an update ticket should only be placed in a very specific condition where the 15 days is not enough time to complete the work. Participants were asked if they experience update tickets for work that has not been started or has been completed. The responses suggest that locators within the study sample regularly (53.1%) or sometimes (37.8%) receive update tickets for jobs that have not begun. This practice is done by some construction firms to ensure that they have a live ticket for the whole duration of the project. Similarly, the responses suggest that locators within the study sample regularly (36.7%) or sometimes (48%) receive update tickets for jobs that have been completed; see Table 5. Thus, this issue seems to be frequent and also places an unnecessary workload on locators and delays the locating of valid tickets.

Clearly all the suggested factors that contribute to late locates seem to be valid. Additionally, the survey asked participants to elaborate on the reasons behind the late locate through an open-ended question. The participants provided the following reasons, ordered by frequency:

1. Lack of time due to the following:
 - Number of tickets, ticket fluctuation/seasonal, and
 - Lack of staff (e.g., lack of experience, lack of training, high turnover rate).
2. Communication issues, such as the following:
 - Incorrect or improper information on the ticket (e.g., address, contact, scope/size/white lining, instructions);

Table 5. Factors that increase locating time

Factor	Never	Rarely	Sometimes	Often
Workforce shortage ^a	8 (8.2%)	16 (16.3%)	53 (54.1%)	21 (21.4%)
Inaccurate maps ^a	1 (1%)	13 (13.3%)	58 (59.2%)	26 (26.5%)
Tickets that should be survey/design	7 (7.1%)	17 (17.3%)	44 (44.9%)	30 (30.6%)
No white lining	1 (1%)	6 (6.1%)	32 (32.7%)	59 (60.2%)
Update tickets where the work has not begun	(1%)	8 (8.2%)	37 (37.8%)	52 (53.1%)
Update tickets where the work has completed	0 (0%)	15 (15.3%)	47 (48%)	36 (36.7%)

^aThis factor contributes to inaccurate locate as well; see Table 4.

Table 6. Improvements suggested by the study sample

Suggestion	Frequency (%)	Suggestion sample
Better communication		
Contractor: White lining, detailed ticket, contact information, report broken tracers and utilities, and on-site representative	39.7	“Excavators being specific as to which utilities aren’t located when calling in 3 h notices because we get a lot where gas has been marked, but excavators are needing phone, TV, and power located.” “Clearer marking instructions and white lined excavation areas!!” “More fluent conversations between contractor and locator and accessibility to talk to someone on-site instead of office personnel that have no idea about on-site work being done.” “The one thing that the one-call folks have that I do not is access to proprietary utility maps. There is no reason those maps should be proprietary—if I had access to those, I would be able to do a much better job and would not need to rely on one call.” “Utilities required to send maps to excavators.”
Utility owners: Accurate maps and access to the maps and records		
Better enforcement and 811 overall process: Create better laws and fines for the abuser	21	“Stopping the abuse of the system by the contractors. Since it’s FREE they call in fake emergency tickets, Tickets they’re bidding on (design).” “Area of excavation better described on the ticket or white lining instead of the entire property. To save us time from having to contact the contractor.”
Ticket area size and workload	14.4	“Tickets being shorted to 5 address adjoining not 1/4 mile and if both sides of the road then a ticket for each side.” “Less ticket volume requested per locator.”
Others: Public awareness, staff recruiting, training certification, better compensation for locators, and manageable workload	24.9	“A state or national certification would make the employees feel like they are in a real trade.” “The utilities should be willing to pay for quality locating.” “PHMSA and state regulators need to mandate certification for all locators.”

- Incorrect ticket type (e.g., false emergency tickets, making the locate occur far before the start date, false updating tickets including calling for sites already completed); and
- Poor communication with field personnel (e.g., lack of access, contractors do not visit the site before placing a locate request).

3. Size of the area assigned to a locator (i.e., management issue).
4. Weather.

The causes previously provided are rarely mentioned in the literature. For example, there are few, if any, studies that have identified the incorrect or improper information on tickets and poor field communication between excavators and locators as a cause for longer locating time. Finally, the participants were asked about potential enhancements that would improve the overall locating process and reduce damages to underground infrastructure. A total of 132 improvements have been suggested. Overall, the suggestions are meant to overcome the challenges that provided previously by participants. Table 6 illustrates the suggested improvements based on their frequency.

Focus Group Findings

It is crucial to gather data from multiple replication studies that examine the same topic to gain confidence in the findings (Abowitz and Toole 2010; Al-Bayati et al. 2017). Thus, two focus group meetings were conducted ($n = 10$) to further investigate and validate the survey findings. In addition, the topics discussed in the meetings were based on the observations of the corresponding author who observed a locator while he was doing his normal activities for a day in Asheville, NC. The two meetings took place in Cullowhee and Greensboro, North Carolina in June 2019. The research team ensured that the employers of focus groups’ members represented both utility owners and locating contractors. The locators were employed by utility owners (50%) and locating contractors (50%). The job titles of the participants are locators (60%), supervisors (30%), and locators’ director (10%). The participants’ experience ranges between 3 and 26 years ($M = 14$, $SD = 9$). Liamputtong (2011) recommended having a person from the same group during focus

group studies. Thus, the executive director of North Carolina 811 was the mediator of the two focus group meetings.

Inaccurate Locates—Root Causes

The participants discussed the causes of inaccurate locates per utility type. In general, the participants agreed on the challenges identified through the survey; see Table 1. It was stated many times in the two meetings that damaged tracer wires are often a challenge that contributes to inaccurate locates as shown by Metje et al. (2015). Damage to tracer wires occurs because of the age of the wires and also the fact that many contractors/excavators do not report damages to tracer wires at the time they occur. Participants suggest that most excavators do not know the importance of tracer wires. Therefore, these damages do not get reported to the utility owners. Another reason that has been suggested is that excavators do not want to delay construction activities when they damage a tracer wire, not a utility pipe. Tracers’ damages could be perceived as low-risk damages by excavators. Low- and high-risk damages have been suggested by Al-Bayati and Panzer (2019a). Largely, low-risk damages (e.g., telecommunication and TV damages) have no monetary potential impacts on construction projects’ schedule and budget, unless they damage fiber-optic telecommunication lines. Therefore, low-risk damages are acceptable by construction practitioners and often not reported. The participants also indicated that while the maps provided by the utility owners are often accurate, abandoned or inactive lines that are present in the same area do not show up on the maps. Once removed as a taxable asset, services that are abandoned in place are removed from the maps as well. Thus, abandoned and inactive services compromise map accuracy, create confusion for excavators, and can result in damages to underground utilities.

Fig. 3 illustrates the main challenges per utility type when combined, based on participants’ feedback. Each type of utility has unique as well as common challenges. These challenges must be included in training materials for both excavators and locators to improve the overall understanding of damage prevention efforts. For example, it is common practice to place water and sewer deeper than other utilities, which makes them harder to locate. Abandoned lines

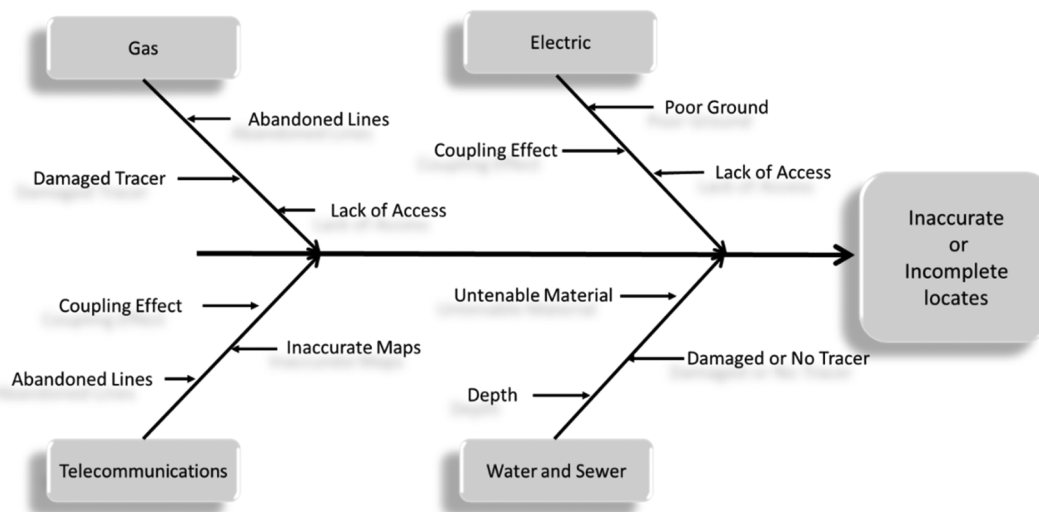


Fig. 3. Suggested challenges to utility locates.

and damaged tracers often seem to be a challenge within telecommunication and gas utilities, respectively. Finally, when locating electrical utilities, the contact point for the induction of a signal on the utility line is the common ground from a meter box. Locators do not access the inside of the box and directly connect to power. Therefore, the common ground that they use to induce a signal is the same ground typically used by the other facilities. As a result, the poor ground and potential interference with other facilities using the same common ground are among the main challenges.

Finally, Al-Bayati and Panzer (2019a) suggested that the accuracy and visibility of locates placed by utility owners' locators are more likely to be more accurate than the accuracy of contractor locators. This suggestion was discussed during the focus group meetings. The discussion reveals that the work pressure among locators who work for locating contractors is higher than locators who work for utility owners. This is because locating contractors are paid per locate, which requires them to do as many locates as they can. In addition, they do not have full access to utility GIS systems like locators who work directly for utility owners.

Late Locates—Root Causes

The participants were asked to rate, on a 1–10 scale, the reasons that were identified through the survey section of this study. The participants confirmed the identified reasons and ranked the incorrect ticket information (e.g., address, contact, scope/size/white lining, instructions) as the number one contributing factor followed by the lack of staff. Additionally, poor planning by the excavator, lack of communication with field personnel (i.e., excavators), incorrect ticket type, and weather have been confirmed, respectively. The discussion revealed that incorrect information provided on tickets by excavators is a frequent issue. Overall, the incorrect information provided by participants confirmed the information received through the survey, which includes incorrect information on tickets, incorrect ticket type, and poor communication with field personnel. However, the open discussion with locators revealed the importance of the communication between locators and excavators on overall damage prevention.

Participants expanded their discussion about incorrect ticket types, specifically false emergency tickets. An emergency is an event involving imminent danger to life, health, or property, the interruption of essential utility services, or the blockage of transportation

facilities, including highways, railways, waterways, or airways that require immediate action. There is no specified accelerated time frame for a response to an emergency ticket. However, most utilities and contract locators respond with priority to emergency tickets. Therefore, placing false emergency tickets to avoid waiting time of regular tickets seems to be a frequent issue. In North Carolina, placing false emergency tickets is a Class 3 misdemeanor. Therefore, the participants recommended that NC 811 should reference the legal consequences of false emergency tickets to all excavators who request an emergency locate, in the hope of reducing insincere requests. In addition, the participants discussed the consequences of not having white lining performed by the excavator in advance of the locate. Locators are required by law to mark the whole site described in the ticket instead of only the excavation area when there is no white lining. Thus, the participants suggested that a better workflow will be achieved if the white lining becomes a mandatory requirement, especially for commercial jobs.

The electromagnetic (EM) technique is the primary method that has been used for years to locate underground utilities (Siu and Lai 2019). There are many methods to utilize EM, but the most commonly used method is the direct connection method (CGA 2019a). The direct connection method requires the locator to directly connect the equipment to the metallic part of the utility or a tracer wire along with the utility and place a ground stake perpendicular to the utility to close the circuit (CGA 2019a). The participants have confirmed that the electromagnetic technique is the primary method they use to locate underground utilities. Access to the utility is crucial for locators to deliver high-quality locate within the legislated time. Fences and pets are the major causes of limited access that have been reported by participants. Code 40 is one of the positive response codes in North Carolina that can be used by locators to indicate that they could not gain access to the property. Al-Bayati et al. (2019b) identified the most frequent codes used in North Carolina, where Code 40 rarely occurred. Consequently, the locators who have participated in the focus group meetings seem not to be aware of Code 40, which could be a result of the fact that the systems used by locators use different codes that are then converted to the codes accepted by the one-call center. Participants also suggest that having communication with a contractor representative (CR) could help overcome the white lining issue as well as the challenge of not having access to the job site.

Finally, the weather was discussed by participants as a factor that can delay locating; locators cannot locate during the rain because the rain washes marks away. Excavators are instructed to request a destroyed marks ticket when marks vanish due to weather. However, participants indicate that 3 h notices increase after bad weather because marks are removed by the rain. A destroyed marks ticket is allowed the same three full business day response time as a regular ticket. Therefore, some excavators may be requesting 3 h notices instead of a destroyed marks ticket for a faster response. It is necessary to request the right ticket type in order to be in compliance with the law, and consequently to not overload the system with short notice requests. Also, requesting an incorrect ticket type may influence the contract locators' compensation as contract locators often do not get paid for 3 h notices. Thus, more education is required for both excavators and locators about the specific use of different types of tickets and the positive response codes that should be utilized by the locators.

Discussion

It is crucial to assess the current damage prevention efforts and practices in order to improve the overall process. The current literature often focuses on damage prevention technology and the physical conditions of underground infrastructure. Accordingly, the main contribution of this study is highlighting the human factor that contributes to underground infrastructure management in the United States. Specifically, understanding and identifying the required and desired behaviors of the stakeholders will certainly improve the process efficiency. At the same time, it is critical to understand how deviations (i.e., undesirable actions) from the desired behavior of stakeholders can compound issues such as delayed and incomplete locates. Undesirable actions can quickly create a snowball effect that compromises the damage prevention efforts. For example, the study reveals that abusing the one-call notification system by placing false emergency tickets or incorrect ticket types (e.g., placing 3 h ticket instead of destroyed marks ticket or update ticket when the work has not started yet) is a common practice that significantly increases the locators' workload. This unnecessary amount of notifications creates system noise. The effect of the system noise would not be limited to longer locating the time, but rather could create a compounding effect that leads to many undesirable scenarios such as the following:

- When excavators believe that they will not receive response in the required timeframe, they may place locate tickets weeks in advance to hopefully obtain marks when they are actually planning to dig.
- Excavators may lose confidence that the locates will be completed on time. In this case, the excavator may place a series of tickets with the hope that some of the work will be located within time, and those will be the jobs they move the crews to work on.

Conversely, locators can also contribute to system noise. For example, locators have used positive response codes such as Code 60 (i.e., the locator has spoken to an excavator and arranged a schedule) and Code 32 (i.e., the locator was unable to reach the excavator, and there is need to speak with them), when in fact those actions did not take place. As a result, the process must be built on a foundation of trust among stakeholders that each party handles their portion of the responsibility. Table 6 shows the desired behavior of the stakeholders (i.e., utility owners, locators, excavators, and one-call centers). When a party does not feel that they can trust the other, or abuses the system with their undesirable actions, the potential for the creation of noise occurs.

The size of the area that the locator needs to mark has been identified as a challenge for locators; see Table 6. An excavator may call both sides of the road for a possible road bore. In this case, the excavator should be white lining the specific area of boring. Otherwise, locators have to locate the whole area, which requires a considerable amount of unnecessary time and effort. Thus, white lining is crucial for the prevention damage process. White lining has been recommended as one of the best practices in CGA's best practices guide (CGA 2019a). Based on the study findings, the authors believe that white lining should be a mandatory practice. Similarly, it is a common practice that excavators request a whole property to be marked when the excavation is taking place in a small portion (e.g., front easement or left side of the home). Thus, the excavators should be specific regarding the ticket area. Similarly, the law should be specific and reasonable regarding the ticket area. For example, the existing law in North Carolina requires that the size area not exceed one-quarter mile or five contiguous addresses. Overall, the law should ensure that the proposed area satisfies the stakeholders' needs and limitations, especially the locators. As a result, the shared responsibility among stakeholders, including one-call centers, is a critical factor in ensuring the system reliability and workability. Shared responsibility calls for teamwork among stakeholders that creates a smoother work process has been suggested by Farnsworth et al. (2016). Beyond the human factor role, the inaccuracy of locates will always present a possibility that construction firms should consider. The inaccuracy could be a result of a wide range of issues such as the coupling effect and abandoned utilities (Metje et al. 2015; Siu and Lai 2019; Al-Bayati and Panzer 2019a). The abandoned utilities are not just compromising the locate accuracy; they also confuse excavators by giving them false confidence that they have uncovered the marked underground utility and they can use a mechanical excavator to complete their task. Excavators are required by law to avoid using a mechanical excavator until they physically expose the underground utilities using hand tools. Abandoned utilities are caused by utility owners removing them from maps at the time they are taken out of service. There have been proposals that abandoned utilities must be marked. However, this has been recognized as an impossible task if the records no longer exist.

Recommendations

The significant influence of stakeholders' behavior on damage prevention must be included in the current awareness and educational efforts. Thus, there is a need to adopt an approach in which co-operation, education, and training are the primary focus. One-call centers provide outreach awareness training to excavators and locators upon request. Thus, awareness materials should be improved to include the needed knowledge and negative impacts of undesirable actions to ensure the success of damage prevention efforts and reduce the system noise. Similarly, utilities owners and locating contractors should improve their educational programs to reflect the findings of this study. The following are the topics that should be incorporated into the current awareness materials:

1. Excavators awareness training: The awareness should include information about the process of damage prevention, the types of tickets that excavators can utilize, the consequences of placing incorrect or false tickets, and the limitation of the current process (e.g., coupling effect, abandon lines, broken tracers, and weather impact). The importance of clear communication (e.g., contractor representative and white lining) with locators and the one-call center should be the core of awareness and educational efforts. The excavator should fully understand the

process and the possible negative impact of placing an incorrect ticket type. For example, while locators indicate that broken tracers contribute significantly to inaccurate locates, many excavators seem not to be aware of the tracer wires; see Table 4. Thus, it is expected that they will not report the damaged tracers, even though there are typically no financial penalties for breaking a tracer. Therefore, the educational material should clearly explain the importance of reporting damages to tracer wires.

2. Locators awareness training: The awareness should include information about the process of damage prevention, the meaning of the codes used for positive responses, the consequences of incorrect positive responses, the limitation of the current process and how to reduce its impact, and the importance of clear communication with field personnel and utility owners. For example, the study revealed that inaccurate maps negatively impact the accuracy of locates. Thus, it is crucial to open a communication channel between locators and utility owners to report inaccurate maps in order to update them.

The current working conditions of locators seem to be an important factor in damage prevention. Lack of time seems to be the first contributing factor to inaccurate locates; see Tables 4 and 5. Al-Bayati and Panzer (2019a) suggested hiring more locators to overcome the lack of time. However, this study reveals that the lack of time could be a result of insufficient communication or incorrect information provided by excavators. Thus, it is important to improve overall communication between locators and excavators to reduce the overall locating time. Excavators should visit the site before placing the ticket to ensure that the site is accessible as well as to white line the excavation area. In addition, it is vital to have an active enforcement process to reduce abuses of the system. Additionally, further requirements should be enforced to better manage broken tracers and abandoned utilities.

The identified best practices and undesirable actions should also be incorporated into states' damage prevention acts (i.e., one-call state statutes). Although one-call statutes vary from state to state, there are common themes. Thus, further investigation should be conducted to achieve a national agreement on the best practices that stakeholders place into state laws to reach an acceptable level of damage prevention requirements. The national agreement should be built based on excavators' and locators' feedback as well as one-call centers' abilities. In addition, the Pipeline and Hazardous Materials Safety Administration (PHMSA) should consider the findings of this study while conducting its evaluation program. Currently, PHMSA evaluates the national damage prevention centers concerning the enforcement of incidents occurring on gas pipelines (PHMSA 2019). Finally, ASCE 38-02 (ASCE 2002) provides a standard for defining four quality levels of utility locates through subsurface utility engineering (SUE), which is a branch of engineering practice. While these four levels are mostly based on an engineer's involvement, the standard does not clearly highlight the importance of the cooperation needed to provide higher quality performance. According to Anspach and Scott (2019), civil engineers are responsible for managing associated risks while working around underground utilities. Thus, there is also a need to incorporate the findings of this study into ASCE 38 to improve the performance of civil engineers who are responsible for managing underground utilities.

Conclusion

It is crucial to sustain the underground infrastructure to ensure the continuity of modern essential services. The current process to preserve the underground infrastructure during construction work

depends on timely and accurate locates. However, the delayed response time and lack of accuracy have been identified as significant shortcomings of the current damage prevention efforts. This study investigates the locators' perspectives with intent to reveal the current challenges and undesirable actions that compromise the needed timely and accurate locates. Accordingly, quantitative and qualitative research instruments have been designed and utilized. The findings strongly identify the communication between stakeholders as a crucial factor to accurate and timely locates. Additionally, the study provides a clear understanding of the causes and undesirable actions that could lead to inaccurate, incomplete, or delayed locates. Furthermore, the study compares the findings with previously reported excavators' perspectives. Among other findings, the comparison indicates a difference in perspectives between excavators and locators regarding white lining. Accordingly, the study highlights the value of educational material that describes the damage prevention practices and process, especially the shared responsibility concept. The awareness and educational material should clearly and easily communicate the desirable actions to reduce system noise. Also, the findings will certainly aid future policy development initiatives. Therefore, the contribution of this study is vital and will improve the overall management of underground infrastructure.

Data Availability Statement

Data generated or analyzed during the study are available from the corresponding author by request. Information about the *Journal's* data-sharing policy can be found here: [http://ascelibrary.org/doi/10.1061/\(ASCE\)CO.1943-7862.0001263](http://ascelibrary.org/doi/10.1061/(ASCE)CO.1943-7862.0001263).

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