Reducing Damages to Underground Infrastructure: Performance Evaluation of One-Call Notification Program

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Abstract: Reducing damages to underground utilities is one of the primary goals of construction stakeholders. The societal and economic impacts of such damages are substantial. To minimize potential damages to underground utilities, one-call notification programs have been created to coordinate efforts that aim to locate utilities before excavating. One-call centers are distributed throughout the United States and have been collecting damages data for years. However, few, if any, studies have evaluated the overall process of one-call centers and whether their services are adequately designed and efficiently delivered to utility owners and excavators. Thus, the present study aims to fill this gap in practice by investigating underground utility damages and evaluating the overall process. To achieve the aim of the study, two methods of data collection were adopted. Damage data from the state of North Carolina in 2017 were obtained to examine trends and frequencies of damages. In addition, a survey was developed and used to evaluate the overall process of one-call centers and identify deficiencies. Among other findings, the results suggest that damages to telecommunication and television (Tele/TV) lines are more frequent than other types of damages and that, overall, Tele/TV contractors are the primary contributors to most damages. The study also reveals that locate time is the most deficient component in the locating process. Findings from the present study are expected to help construction stakeholders and state agencies improve the locating process and management of underground utilities. **DOI: 10.1061/(ASCE)SC.1943-5576.0000441.**

Introduction

There were an estimated 439,000 occurrences of damages to underground utility networks in the United States in 2017, according to the Common Ground Alliance (DIRT 2017). The estimated damages have experienced a continuous increase since 2015 (i.e., 378,000 damage reports in 2015, 416,000 damage reports in 2016, and 439,000 damage reports in 2017). The reported damages often happen to the following underground utilities, in descending order of incidences: telecommunication and television (Tele/TV), natural gas, electricity, and water (Al-Bayati and Panzer 2019). According to Nelson et al. (2012), more than 35 million miles of underground utilities exist in the United States, and this number is growing every day. These dense utility networks are responsible for the well-being and continued economic strength of the United States. Yet damages to underground utilities are still a major concern (Talmaki and Kamat 2012), due mainly to the inaccuracy of identifying the exact location of these utilities (Young et al. 2016; USDOT 2018). If the location of utilities is not accurately identified, then each excavation activity has the potential to cause damage to underground utilities. As for the social and economic impact of these damages on the public, they can influence design and construction operations negatively, leading to delayed schedules and increased cost. Accordingly, damages to underground utilities cost society roughly $1.5 billion (DIRT 2016). Furthermore, these damages could result in significant fatal and nonfatal injuries. For example, an explosion caused by a damaged gas line killed 1 person and injured 11 others in Canton, IL in 2016.

One-call notification is a program initiated in the 1970s to coordinate communication between excavators and operators of underground facilities. The one-call center is generally a free service for excavators to inform underground utility owners of any called-in excavation activities that can affect their underground facilities. More formalized recognition was established through 1998's Transportation Equity Act for the 21st Century to reduce unintentional damage to underground utilities (TEA-21 1998). According to the act, accidental damages can cause significant disruption to public services such as hospitals and electrical power and are a leading cause of hazardous liquid pipeline accidents (Kolera and Bernold 2006). Accordingly, the act encourages states to establish one-call notification systems to serve as the connection between excavators and utility owners (i.e., operators) to mark underground utilities to prevent damages. TEA-21 established a 2-year program that provides grants for states that have a one-call notification system meeting the minimum standards to enhance the overall process. In March 2005, the Federal Communications Commission (FCC) granted three-digit dialing of 8-1-1, creating a universal number in the United States for the coordination of locating services for underground utilities. Currently, all states across the nation have their own 811 notification center to help excavators and operators coordinate digging underground safely. In addition, each state has its own regulations that require all individuals and entities (i.e., excavators) to call in and report information before excavating. The regulations vary from state to state. Table 1 illustrates some of the differences between states.

It is important to realize that a one-call center can only notify the utility owners who are members of the one-call center. This means

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Table 1. Sample of differences among one-call centers

State	Minimum advanced notice	Ticket life	Exempted—user type							Exempted—work types					
			Home owner	Road agency	Railroad	Sewer	Water	Municipal	Agriculture	Maintenance	Agricultural	Emergency repairs	Landscaping	Blasting	Razing or demolition
Michigan (MISS DIG 811)	3 WD	21 WD	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Arizona (AZ 811)	2 WD	15 WD	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes
New York (NY 811)	3 WD	10 WD	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
North Carolina (NC 811)	3 WD	15 WD	No	X	No	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes
Utah (Blue Stakes 811)	2 WD	14 CD	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Washington (811)	2 WD	45 CD	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes
Texas (Lonestar 811)	2 WD	14 WD	Yes	No	No	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes
Nevada (USAN 811)	2 WD	28 CD	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: WD = working day; and CD = calendar day.

that utility owners who are not members will not be notified. Therefore, utility owners must join the one-call center to protect their utilities. Young et al. (2016) conducted a study about the importance of one-call programs and concluded that the centers have significantly contributed to the damage reduction of underground utilities in the United States. In general, the current practice requires all individuals and entities to place a notice with one-call centers before excavation starts. The one-call center, in turn, will notify facility owners, who then mark their utilities within the proposed excavation area. The one-call process includes two main stakeholders who lead the marking of underground utilities. These stakeholders are the one-call center and utility owners. However, these two parts of the process will not be activated unless excavators call and place a ticket. Thus, the first step in the marking process is to notify the one-call center (Young et al. 2016; Al-Bayati and Panzer 2019). Recently, several studies such as Talmaki and Kamat (2012) and Ariaratnam and Proszek (2006) have investigated the root causes behind damages to underground utilities, as well as the state-of-the-art technology used to mark underground utilities. However, there has been little research conducted to evaluate the overall process that one-call centers and utility owners undertake regarding marking underground utilities before excavation starts. The present study aims to evaluate the overall process of one-call centers by answering the following research questions:

1. What are the trends of damages to underground utilities and their effects on utility owners and the public?
2. What are the current deficiencies in the overall process and practices?

Methodology

A partnership with the North Carolina 811 notification center (NC 811) has been established to achieve the objectives of the research. As a result, the present study focuses only on the state of North Carolina as an example of the entire United States. In 2017, NC 811 collected information about 11,160 reported damages to underground utilities. The damage reports include information about the type of utility, the cause of damage, and other related information. After obtaining the data from NC 811, the research team conducted a follow-up survey with individuals who contacted NC 811 during 2018. The survey targeted first-time callers to solicit their feedback on the NC 811 process and accuracy of locating underground utilities.

Survey Results

The results of the analysis are categorized into two sections. Section one examines the damage trends based on the 11,160 damages reported to the NC 811 notification center. In this section, the 2017 damages to underground utilities in the state of North Carolina will be analyzed to identify potential trends among the damages. Section two examines the excavators and customers' feedback regarding the effectiveness of the process and accuracy of locating underground utilities provided.

Section One: Trends of Damages

In North Carolina, any person or entity performing earthwork is required by law to report planned excavation and related activities to the NC 811 notification center before 3 business days of the start of work. The NC 811 notification center then notifies the utility owners who are members of NC 811 about potential underground utilities within the excavation's reported boundaries. Two active

legal acts in North Carolina require the excavator to contact NC 811 and report requested information. These acts are the Underground Utility Safety and Damage Prevention Act (UUSDPA) and the Occupational Safety and Health Act of North Carolina (OSHA NC) (Al-Bayati and Panzer 2019). Furthermore, the UUSDPA requires the excavator or the contractor performing the work to immediately notify NC 811 and the facility operator or owner when damage happens to underground utilities. The responsibility of reporting the damages lies with the employer (i.e., the contractor). Thus, the employer must also provide the required time and training to his or her employees to ensure compliance with the requirements. The 2017 data set obtained from the 811-notification center shows that 2,169 damages (19.4%) in North Carolina were not associated with a locate request submitted to the center, hereafter called "no locate requests." Further examination of no locate requests indicates that most of these cases occurred in Mecklenburg County (23.10%), followed by Wake County (17.38%), Durham County (5.53%), and Guilford County (4.52%). This finding suggests education efforts regarding the NC 811 notification center and its services should be emphasized and improved in these counties. The education and awareness efforts of the NC 811 notification center can take a variety of forms, including advertising campaigns (e.g., billboards and television advertisements), onsite training by NC 811 educators, and online education about safe digging practices (i.e., PIPES Plus). Examining the no locate requests data by the nature of work performed indicates that damages without requests to locate were mostly associated with landscaping (25.15%), construction activities (23.08%), Tele/TV installation and repair activities (22.59%), and water installation and repair (10.9%). This finding highlights the specific sectors that the NC 811 notification center needs to target through more education and training. Accordingly, damage prevention training and education should focus on landscaping, construction, and Tele/TV firms, especially smaller-sized firms specializing in excavation and earthwork because most no locate requests were associated with landscaping, construction, and Tele/TV activities.

On the other hand, the geographic distribution of damages shows that the highest percentages of reported damages occurred in Mecklenburg County (26.09%), followed by Wake County (19.87%), Durham County (5.39%), and Guilford County (4.36%). This result is expected because these counties encountered many excavations in 2017. Excavation work has significantly increased in Mecklenburg, Wake, and Durham counties mainly because Google and AT&T chose these counties to be outfitted with fiber Internet services back in 2015. Thousands of miles of fiber cables were installed in these counties in 2015 and 2016. As work slowed down recently, fewer damages have been observed in these counties. Comparing the 2017 data with 2016 data shows a decrease in the number of damages occurring in most counties in North Carolina, except Guilford County; see Table 2. Guilford County was the only county that reported increased damages and increased no locate requests in 2017. Thus, it is imperative for NC 811 to improve education and awareness of its services in this county.

Table 2. Damage percentages of major counties in 2016 and 2017

	Percentage of damages			
Year	Mecklenburg	Wake	Durham	Guilford
2017	26.09	19.87	5.39	4.36
2016	33.35	21.46	6.62	3.96

Note: Counties with less than 4% of damages in 2017 are not presented.

Employer Type and Affected Services

An excavator is a person or entity engaged in excavation or demolition. There are several types of employers, such as contractors and utility owners, who may hire excavators to perform excavation or demolition. Based on the data analyzed, contractors caused the highest number of damages to underground utilities (78.7%), followed by municipalities (6.33%) and utility owners (4.07%). Employers who caused less than 3% of damages are considered within acceptable variations and therefore have been excluded from the discussion. Table 3 shows the number of damages per service type caused by the major employer (i.e., contractors, utility owners, and municipalities).

Fig. 1 illustrates the percentage of damages to underground utilities per major employer. The overall results show consistency in the percentage of damages across the major employers. However, utility owners caused a higher percentage of damages to Tele/TV underground utilities than contractors and municipalities.

Turning attention to the type or classification of a facility, Fig. 2 illustrates the affected service types by the damages. The service types could be classified as transmission, distribution, and service lines. Transmission lines carry services such as electricity, clean water, and natural gas to distribution lines that then carry services to the customers through the service lines. The collected data indicated consistency in the affected service types across the key employers. The rate of damages by service types based on known data descends in the order of service lines, distribution lines, and transmission lines. It is evident that the damages to transmission lines represent a small percentage of the overall damages. Transmission lines are usually laid down deeper than other lines and are well marked in private rights-of-way (ROW). Even transmission lines that are not in private ROW are usually along busy roads, not in neighborhoods and around building facilities. To satisfy federal regulations from the Pipeline and Hazardous Materials Safety Administration (PHMSA), the Transmission Integrity Management (TIM) has required pipeline personnel to be present during excavation activities. Damages to transmission lines can lead to high-severity injuries and significant cost implications. Accordingly, transmission lines are always a high priority for owners to protect.

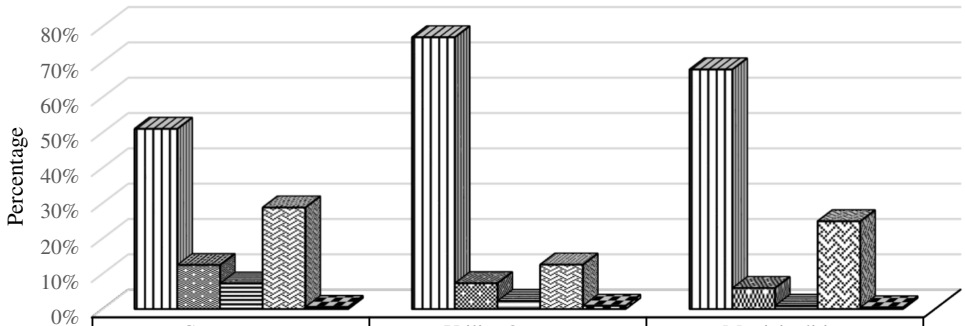
There is a need to investigate damages by work type to examine whether there is a type of work that contributes more to underground utility damages. Fig. 3 illustrates damages per work type. The illustration indicates that the highest damages happened while conducting Tele/TV work (29%), followed by water work (14%), construction work (12%), and natural gas work (11%). The illustration also shows that the highest percentages of natural gas damages happened while working on Tele/TV and construction works.

Positive Response Trends

A ticket is created after each notification received by the NC 811 notification center from an excavator. Accordingly, the NC 811 center transmits the received notification to the affected utility owners. Several transmissions are typically associated with each

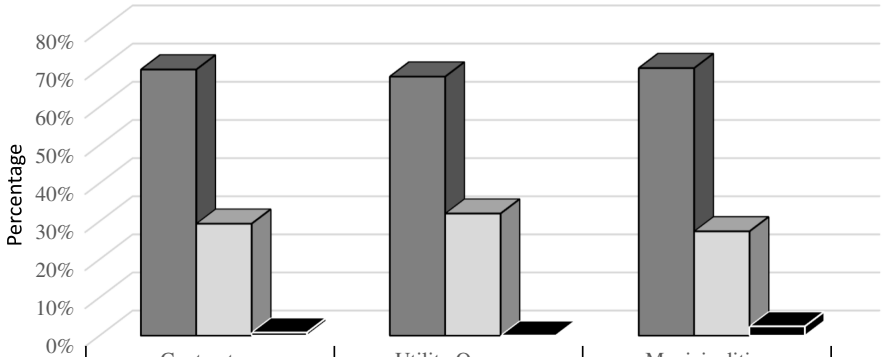
Table 3. Number of damages to underground utilities per major employer

	Employer type			
Damaged utility	Contractors	Utility owners	Municipalities	Total
Tele/TV	4,321	337	445	5,103
Electric	1,055	32	39	1,126
Water	611	10	6	627
Natural gas	2,434	55	163	2,652
Sewer	48	4	3	55
Total	8,469 (78.8%)	438 (4.07%)	656 (6.33%)	9,563



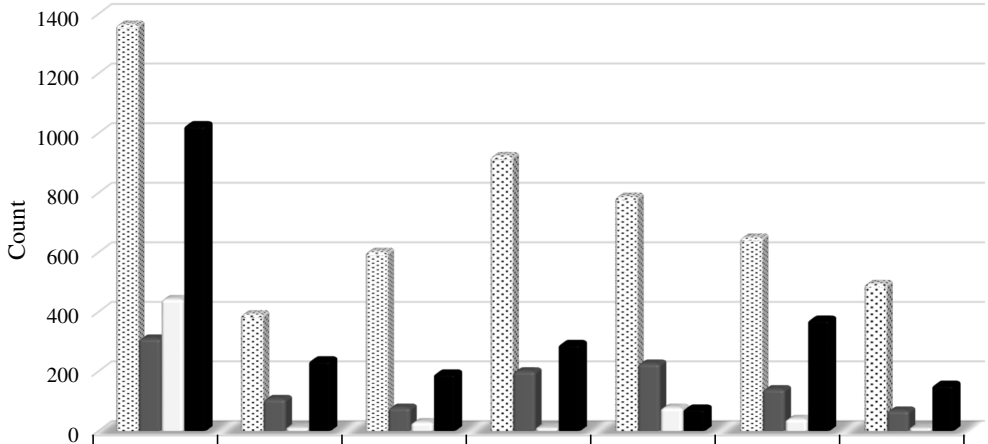
	Contractors	Utility Owners	Municipalities
Tele/CATV	51%	77%	68%
Electric	12%	7%	6%
Water	7%	2%	1%
Natural Gas	29%	13%	25%
Sewer	1%	1%	0%

Fig. 1. Damages to underground utilities per employer type.



	Contractors	Utility Owners	Municipalities
Service	70%	68%	70%
Distribution	29%	32%	27%
Transmission	1%	0%	2%

Fig. 2. Affected services per type of employer.



	Tele/ CATV	Sewer	Electric	Water	Natural Gas	Construction	Landscaping
Tele/CATV	1365	393	603	924	788	651	495
Electric	311	108	79	201	227	141	69
Water	444	12	30	12	79	41	11
Natural Gas	1028	238	194	293	76	375	156

Fig. 3. Damages per work type.

Table 4. Count and percentage of transmissions and tickets in 2017

County	Transmissions (%)	Tickets (%)
Mecklenburg	1,804,028 (22.3)	317,369 (16.6)
Wake	1,344,797 (16.6)	282,032 (14.8)
Guilford	454,160 (5.6)	97,892 (5.1)
Durham	355,230 (4.4)	73,657 (3.9)
Forsyth	271,000 (3.3)	67,990 (3.6)

ticket, roughly a 5:1 ratio. Out of the 100 counties in the state of North Carolina, 55.2% (i.e., 4,229,215) of the 2017 transmissions were placed in the following five counties: Mecklenburg, Wake, Guilford, Durham, and Forsyth; see Table 4. Positive responses to the NC 811 notification center are a requirement under the law and a means for the members of NC 811 to provide information to excavators regarding the location of underground utilities. The most frequent positive responses during 2017 were Code 10 – no conflict, the utility is outside of the stated work area (153,494; 33.8%), followed by Code 20 – marked (150,892; 33.3%), Code 80 – member's master contractor is responsible for locating facilities (35,621; 7.8%), Code 999 – member has not responded by the required time (28,759; 6.3%), and Code 60 – locator and excavator agreed and documented marking schedule (28,214; 6.2%). The various numbers of days that have been needed to provide positive responses in 2017 are presented in Fig. 4. The results indicate that 48.5% of positive responses required more than the regulatory period, which is 3 business days in the state of North Carolina. The time needed to mark the proposed excavation (i.e., Codes 10 and 20) shows a similar trend. Based on the presented results, there is a need to further investigate the causes that led to the noncompliance with the 3-business-day statutory requirement.

When a positive response is not delivered after waiting for 3 full days, an excavator shall place a 3-hour notice (3Hr). According to North Carolina's Damage Prevention Act [Section 87-122. (c)(2)], excavators shall not begin excavation or demolition until a 3Hr notice has been made. The presence of a 3Hr typically means something was performed incorrectly during the process of locating underground utilities or a positive response was not provided (Code 999). Comparing the overall number of 3Hr notices and Code 999s in these five major counties indicates that the 3Hr notice was not fully used. For example, the percentage of Code 999s per transmission in Mecklenburg County was 10.2%, whereas the percentage of 3Hr notice per ticket in the same county was only 2.08%. This discrepancy suggests that a high percentage of uncompleted locate requests were not followed by 3Hr notices; see Fig. 5. Durham County seems to have the lowest percentage of 3Hr notices when compared to the percentage of Code 999s. The other important observation from Fig. 5 is that the percentage of Code 999s in Durham County was the highest (21.4%), followed by Mecklenburg County (10.19%), and Wake County (7%). The high percentage suggests a shortage in locators in these three counties, especially Durham County. Thus, there is a need to hire more locators in these counties. In addition, the high percentage of Code 999s could

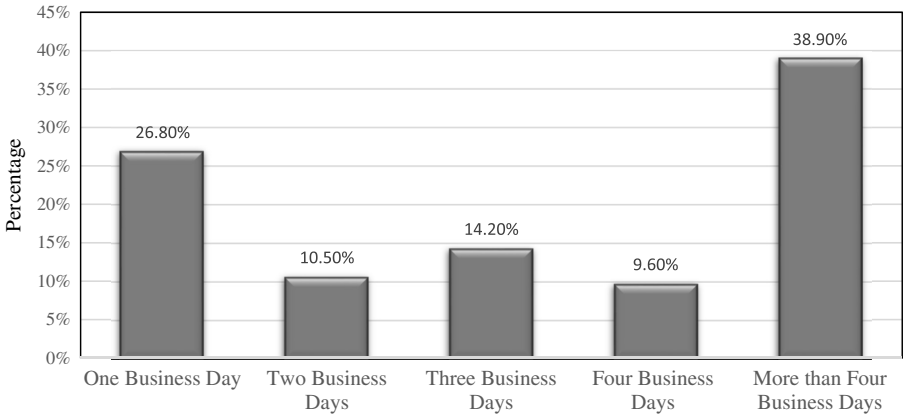


Fig. 4. Frequency of number of days needed for positive responses.

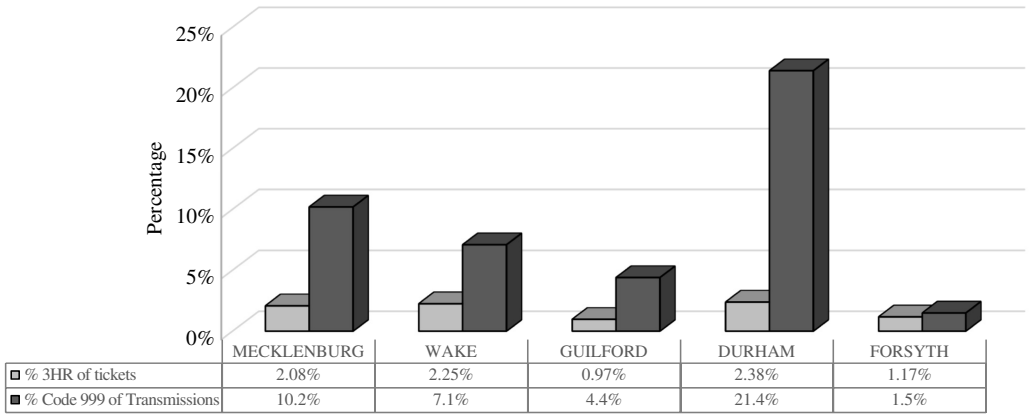


Fig. 5. Percentages of 3Hr notices and code 999.

Pract. Period. Struct. Des. Constr., 2019, 24(4): 04019018

be attributed to the low participation in NC 811 by utility owners in Durham County.

Section Two: Follow-Up Survey

A follow-up survey was developed by the researchers to evaluate the notification process and services provided by the NC 811 call center. After the research team developed the survey instrument and its protocol, it was submitted to the Human Subject Institutional Review Board (HSIRB) at Western Carolina University for review and approval. After approval, the survey was distributed to the participants. The survey targeted individuals who contacted the NC 811 notification center in the preceding 3 months to assess their experience with the process used, trends of damages, and overall locating time and accuracy of underground utilities. Approximately 20,000 email requests were sent, and 958 responses were received, yielding a response rate of 4.79%. After analyzing the responses, it was found that 707 participants (i.e., 73.8%) were first-time callers, whereas 251 (26.2%) participants were not. Fig. 6 illustrates the frequency of contacting NC 811 by non-first-time callers. The participants who completed the survey were distributed as follows: 753 homeowners (78.65%), 75 construction practitioners (7.83%), 18 agriculture practitioners (1.90%), 10 manufacturers (1.00%), and 102 other individuals (10.60%). The data collected did not show whether the homeowners who participated in this survey had performed the excavation by themselves or hired an independent excavator to perform the work.

The next step was to ask the participants about their evaluation of the NC 811 service provided. Overall, the participants seemed to be satisfied with the ease of placing tickets and the notification process. Approximately 94% of the participants stated that their experience with NC 811 was easy and convenient. Likewise, the accuracy of the locating marks seemed to satisfy the individuals who participated in the study. Of the participants, 834 (87.9%) stated that the locating marks provided by the NC 811 service were accurate. Concerning the utility owners or locators, the results indicate that they are oftentimes unable to complete the locating process within the specified time, which is 3 business days. According to the survey, 361 participants (37.7%) stated that the locating service was not fulfilled within the specified 3 business days. This percentage is consistent with the percentage in the 2017 data discussed herein before. On the other hand, the results from the survey indicate that a large percentage of the participants used an inaccurate method to check the locating status. Individuals who place a ticket with one-call centers are required by law to ensure that all underground utilities have been marked by checking a positive response using phone, website, or email. However, based on the survey results, 601 (62.73%) participants had only checked the excavation area when determining the locating status. Checking the excavation area alone does not provide adequate information for an excavator to determine if all utilities have been marked. This deficiency is considered a violation of article #87-122. (a)(2) of the Damage Prevention Act in North Carolina. The Damage Prevention Act requires excavators to confirm the positive response through NC 811 before work starts. Fig. 7 illustrates the number of days needed to locate underground utilities.

Quality of Service Provided

This section discusses the assessment of the level of professionalism and quality of the process used by the NC 811 notification center, as well as the accuracy, completion time, and professionalism of locators who often work for utility owners. The participants rated each of these aspects using a 1–10-point scale, where 1 represents an unsatisfactory status and 10 represents a complete satisfactory status for the process used and services provided. Fig. 8 illustrates the average values of five aspects (i.e., professionalism and the process of NC 811, as well as the accuracy, completion time, and professionalism of locators). The results indicate that the level of professionalism of the NC 811 center was higher than the other aspects evaluated. A t-test was conducted to assess the statistically significant difference in the variances between the NC 811's level of professionalism and quality of the process. The test result indicates a statistically significant difference in variances between these two aspects ($t = -4.931$, $df = 1{,}914$, $p < 0.001$). Thus, the professionalism of NC 811 in handling the requests is better than the experience of the entire "Call before you dig" process, according to the participants' feedback. Each component of the process may require further investigation to identify the deficiencies in the process. Identifying the deficiencies in the process would help suggest the proper corrective actions.

Correspondingly, a one-way ANOVA test was conducted to assess the statistically significant difference between the three aspects of locating (accuracy, completion time, and professionalism). The ANOVA result indicates a statistically significant difference between the three aspects of locating ($F = 9.665$, $df = 22{,}871$, $p < 0.001$). This means that at least one of the aspects is significantly different. To determine the source of variation, a post hoc analysis was conducted on the three possible pairwise contrasts (professionalism versus timeliness, professionalism versus accuracy, and accuracy versus timeliness). The following pairs of groups were found to be significantly different ($p < 0.001$): professionalism versus timeliness and accuracy versus timeliness. That is,

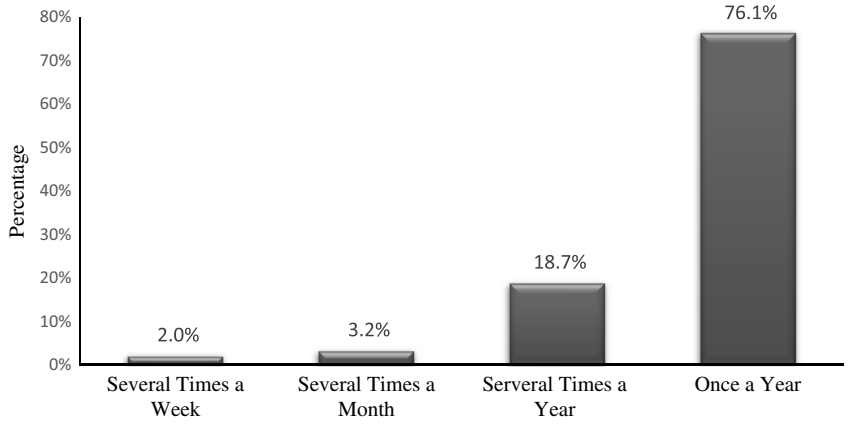


Fig. 6. Frequency of contacting NC 811 of the study sample.

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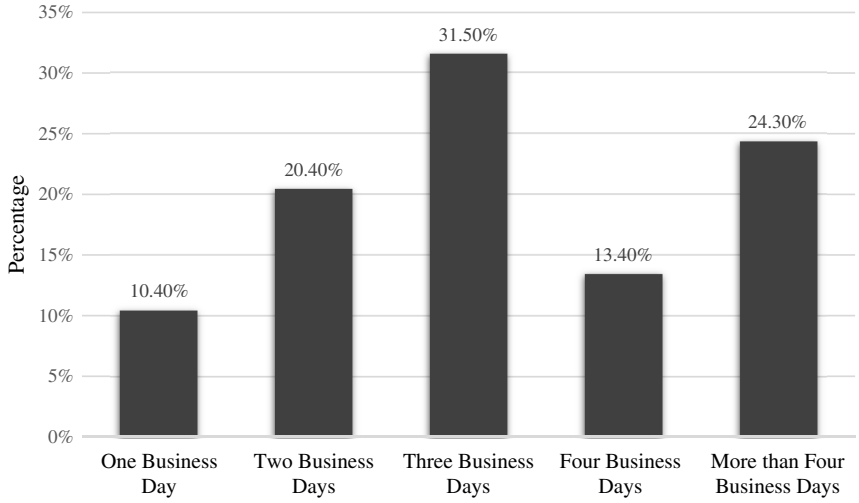

Fig. 7. Locate times based on participants' experience.

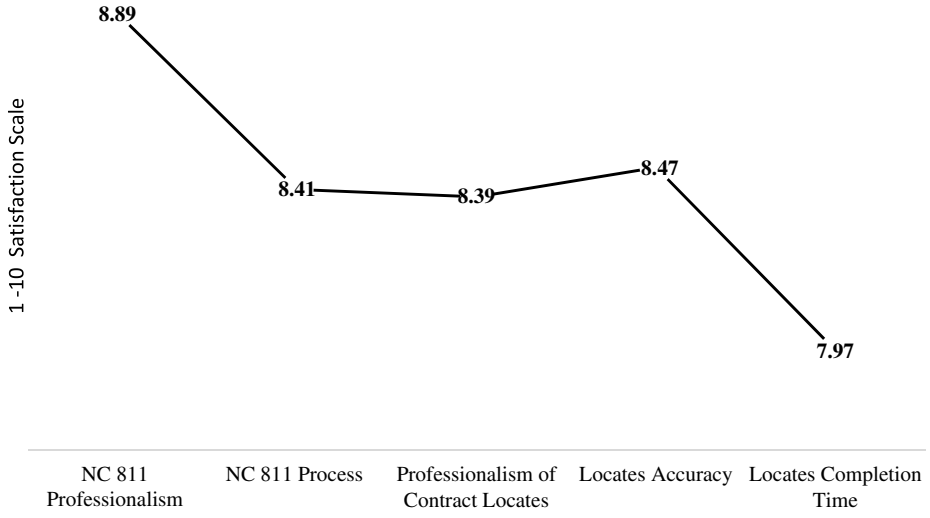

Fig. 8. Assessment of services provided by NC 811 and locators.

the level of professionalism and accuracy of service provided by the locators were rated statistically higher by the participants than the time needed to provide the service. This finding is again consistent with the results of the damage analysis. Overall, this finding strengthens the need for reconsidering the time required to locate underground utilities.

NC 811 Effort to Improve Awareness

The follow-up survey also investigated the most effective method that can be used to educate the citizens of North Carolina about NC 811 services. The awareness efforts take different forms, such as billboards, TV advertisements, and radio commercials. Fig. 9 illustrates the most effective methods of education based on the perceptions of the 512 individuals who answered the question of interest. The results suggest that 58.8% of respondents stated that media, which includes television, radio, and internet advertisements, is the most effective method of awareness, followed by billboards (33.4%) and print advertisements (7.81%). Print advertisements include advertisements published in magazines, telephone directories, and utility bills. These results can help shape future awareness efforts of one-call notification centers across the United States.

Discussion and Recommendations

The trends of damages revealed in this study are consistent with the national trend in the United States reported by the Common Ground Alliance (CGA); see Fig. 10. The challenges and opportunities to reduce the overall damages could be similar. Therefore, the suggested techniques and improvements from the findings of this study could be used nationally. That being said, one must be careful when generalizing the results beyond the study sample. Each state has different weather conditions, rules, regulations, and so forth that make it unique.

The overall results indicate that the one-call program efficiently and effectively contributes to better management of underground utilities. Most participants evaluated the program as user friendly and stated that the accuracy of locate requests is acceptable. Furthermore, the results of both the 2017 damage analysis and

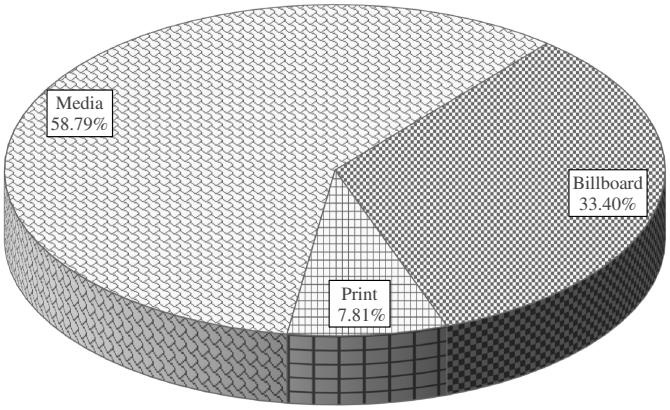

Fig. 9. Most effective awareness methods.

the follow-up survey suggest that the issue of not performing the locates within the 3 full working days is a challenge. The rough percentage of locate requests that are not fulfilled within the 3 working days is 48%, according to the NC 811 database. This challenge influences the excavation time completion, excavation crew safety, and integrity of underground utilities (Hanna et al. 2013). Locating time scores the lowest among the services provided by locators, including accuracy and overall professionalism. Thus, utility owners should investigate the causes of locate delays and take the appropriate corrective actions. Excavators who wait for the 3 working days and receive incomplete markings are required by the law to place a 3-hour notice. After that, the law allows excavators to proceed with care if utility owners have not performed their legal duties to mark. Accordingly, excavators should not be held liable for damages to underground utilities when no positive response has been provided. However, excavators are always required by law to proceed with care, which means not only must they uncover the underground utilities through hand digging, but they must also protect the utilities through the life of the excavation (Al-Bayati and Panzer 2019). On the other hand, further investigation into 3Hr notices would be helpful to understand why, in Durham County, for example, excavators are underusing the 3Hr notice. Another important issue the survey revealed is that a large percentage of respondents (62.73%) indicated that they determined the locate status solely through a physical site check. Excavators must ensure that all utilities have been marked via the one-call center's channels, such as the website or a phone call. Thus, this deficiency should be carefully addressed by the one-call center's educational personnel.

The reported damages to NC 811 had significant impacts on the social and economic aspects of the state of North Carolina and its citizens. It is expected that similar trends exist in other states across the United States. One of the most surprising results is that work on Tele/TV cables or lines contributed most to damages to underground utilities in 2017. This is especially unexpected given that the depth of the Tele/TV cables is typically less than that of other utilities (Richards and Anderson 1987). This unexpected result can be a result of the increased use of horizontal directional drilling (HDD) for Tele/TV cables. HDD has recently become the most common method for installing new underground utilities due to its minimal impact on the surface area and its competitive cost (Ariaratnam and Proszek 2006). That being said, using HDD to install Tele/TV cables may place the cables deeper than customarily expected. This additional installation depth may cause damages to existing underground utilities. Accordingly, one-call centers should target Tele/TV contractors through educational programs that focus on the identified issues. Furthermore, the data show that service lines were damaged more than distribution and transmission lines, which highlights another area that could be targeted by one-call centers. Likewise, the data analysis suggests that more than 50% of damages with no locate requests have occurred in only four counties, Mecklenburg, Wake, Durham, and Guilford. This finding, in particular, could help NC 811 focus on these counties by locating more resources to improve the NC 811 awareness. Thus, one-call centers across the United States should conduct similar studies to identify areas where more resources are needed.

Damage to underground utilities can be minimized by improving the stakeholders' awareness of the one-call notification program. Raising awareness can be facilitated in different ways. One of the ways is through increased billboards or media advertisements, as recommended by the study participants. The researchers believe that a combination of methods, including billboards and media advertisements, is critical for raising awareness of the importance of locating existing underground utilities before excavating. In addition, awareness efforts should focus on firms' types that need the 811 services most based on the study findings.

Conclusion

This study examined the trends of damages to underground infrastructure and the overall process to reduce these damages, relying

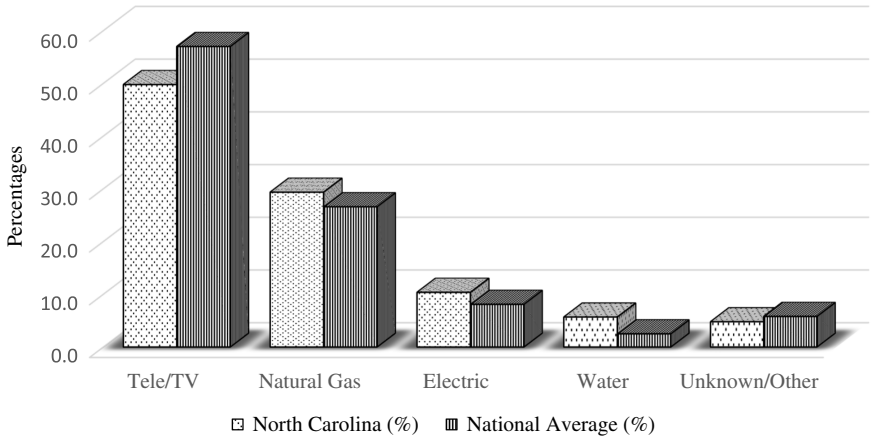

Fig. 10. Percentages of damages to underground utilities per facility type.

Pract. Period. Struct. Des. Constr., 2019, 24(4): 04019018

on data obtained from the North Carolina call center. The findings showed that a similar trend of damages to those that occurred in NC had been reported nationally. This similarity makes it possible to use the study findings nationally. The trends highlighted a need to target a particular type of excavators (i.e., Tele/TV contractors) to reduce the overall damages. Likewise, it was concluded that the notification process is essential to reduce damages to underground utilities. The overall results indicate the current notification process is efficiently and effectively contributing to better management of underground utilities. Overall, the process is well organized and convenient in its use by excavators. The findings also highlighted several opportunities to improve the current process between excavators and utility owners through education (e.g., the necessity of the 3Hr notice and checking for a positive response) and awareness (e.g., using most effective awareness methods and targeting specific geographical areas).

On a different note, delay in locating underground utilities was highlighted as one of the primary challenges that could impact the management of underground infrastructure. To minimize the delay of locating underground utilities, increasing advanced notice time should be considered as a potential way to address the high rate of unfulfilled locating requests. This action, however, may require that excavators wait longer to receive responses, which could, in turn, delay the start of construction operations on a project.

References

Al-Bayati, A. J., and L. Panzer. 2019. "Requirements and practices of underground construction activities: A review of recently updated act." *J. Legal Affairs Dispute Resolut. Eng. Constr.* 11 (3): 04519008. https://doi.org/10.1061/(ASCE)LA.1943-4170.0000300.

Ariaratnam, S. T., and J. J. Proszek. 2006. "Legal consequences of damages to underground facilities by horizontal directional drilling." *J. Prof. Issues Eng. Educ. Pract.* 132 (4): 342–354. https://doi.org/10.1061/(ASCE)1052-3928(2006)132:4(342).

DIRT (Damage Information Reporting Tool). 2016. "DIRT analysis and recommendations 2016." Accessed August 12, 2018. http://commongroundalliance.com/DIRT-2016-report.

DIRT (Damage Information Reporting Tool). 2017. "DIRT analysis and recommendations 2017." Accessed August 12, 2018. http://commongroundalliance.com/media-reports/dirt-report-2017.

Hanna, A., A. Shapira, M. El Asmar, and C. S. Taylor. 2013. "Impact of crew scheduling on project performance." *Pract. Period. Struct. Des. Constr.* 18 (1): 35–44. https://doi.org/10.1061/(ASCE)SC.1943-5576.0000121.

Kolera, B. T., and L. E. Bernold. 2006. "Intelligent utility locating tool for excavators." *J. Constr. Eng. Manage.* 132 (9): 919–927. https://doi.org/10.1061/(ASCE)0733-9364(2006)132:9(919).

Nelson, C. M., R. H. Iwasaki, R. K. Arulraj, and M. E. Ayers. 2012. "SHRP 2 tools for underground utility location, data collection, and analysis." Accessed November 28, 2018. http://www.trb.org/Main/Blurbs/166876.aspx.

Richards, P. J., and A. P. Anderson. 1987. "Microwave images of subsurface utilities in an urban environment." In *Proc., 8th European on Microwave Conf.*, 33–37. Piscataway, NJ: IEEE.

Talmaki, S., and V. R. Kamat. 2012. "Real-time hybrid virtuality for prevention of excavation related utility strikes." *J. Comput. Civ. Eng.* 28 (3): 04014001. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000269.

TEA-21 (Transportation Equity Act for the 21st Century). 1998. "One-call notification." Accessed November 28, 2018. https://www.fhwa.dot.gov/tea21/sumsafe.htm#ocn.

USDOT. 2018. "Subsurface utility engineering." Accessed November 28, 2018. https://www.fhwa.dot.gov/programadmin/sueindex.cfm.

Young, V., E. Rochon, and A. Mihailidis. 2016. "Exploratory analysis of real personal emergency response call conversations: Considerations for personal emergency response spoken dialogue systems." *J. NeuroEng. Rehabil.* 13 (1): 97. https://doi.org/10.1186/s12984-016-0207-9.