Underground Fiber Report

Research Report: Underground Fiber Life Cycle

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EXECUTIVE SUMMARY

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The UTC Fiber subcommittee serves as a platform for utility industry professionals and executives to address present and future challenges related to fiber optic networks. The primary objective is to facilitate the exchange of experiences and expertise, aiding utilities in effectively planning, designing, constructing, and managing their fiber networks. The subcommittee conducts regular surveys to collect data and develop optimal strategies for resolving common fiber optic network issues. This report encapsulates the outcomes of the latest fiber network survey, delving into network specifics and proposing solutions for prevalent concerns.

During spring 2021, the subcommittee devised a comprehensive survey focusing on the lifecycle of underground fiber networks. This survey reached out to UTC members representing 268 utilities across North America, with responses coming from 28 distinct companies, accounting for approximately 25% of the utilities surveyed. This report maintains the organizational structure employed in previous UTC publications, encompassing the lifecycles of ADSS and OPGW systems. The report is partitioned into nine sections, covering: 1) Assessment of Underground Fiber Infrastructure; 2) Fiber Optic Transmission Requirements; 3) Cable Structure; 4) Network Deployments; 5) Fiber Types, Vaults, and Splice Cases; 6) Trends Impacting Deployment; 7) Fiber Utilization and Best Practices; 8) Addressing Specific Challenges; and 9) Failures and Mitigation. Key findings from the underground network lifecycle report are summarized below.

Baseline Assessment

1. Roughly 45% of responding utilities disclosed the usage of fiber optic cables exceeding 20 years in service.
2. An overwhelming 82% of utilities indicated possession of fiber networks spanning 100 to 500 miles, with about half of these reporting either less than 100 miles or 500 miles of fiber.
3. On average, underground fiber networks displayed an age range of 11 to 15 years. Notably, one-third of these networks' oldest segments were over two decades old.
4. More than 61% of utilities lease excess fiber capacity to external entities, while an impressive 80% employ underground fiber for internal applications such as SCADA, tele protection, surveillance, and DWDM traffic.
5. Intriguingly, 57% of utilities utilize underground fiber for long-haul connections between cities and towns, surpassing the 53% using it within metro areas.
6. A significant majority (93%) install underground fiber optic cables within dedicated conduits rather than duct banks or direct burial.
7. The main driving factor for deploying underground fiber was the demand for new connectivity and the absence of alternate communication options (e.g., wireless) (79%). A range of other reasons were reported, spanning from addressing existing fiber issues to FTTX/Smart Grid expansion, increased fiber counts, broadband enhancement, IP Transition, Municipal Regulation, and Cellular integration.

8. All respondents engaged contracted teams for underground fiber construction projects, while only 43% utilized internal construction teams.
9. For splice work on underground fiber projects, 68% preferred contracted crews, with the remaining 86% opting for internal splice teams.
10. Fifty percent of respondents positioned their underground fiber networks within public Right of Way (ROW).

FAILURES AND MITIGATION

1. Failures and related issues emanated from various sources, with fiber cuts from excavation accounting for 40%, followed by human error (22%), rodent damage (20%), right of way clearing (14%), and other factors (4%).
2. Fiber attenuation problems were reported by over 25% of respondents. Splicing issues represented 29% of the causes, whereas rodent damage (18%), jumper cleaning (12%), bend losses (12%), faulty installations (9%), aging (8%), water penetration (7%), and miscellaneous causes (5%) constituted the remainder.
3. Dig-ins primarily resulted from location inaccuracies without prior alerts, often coinciding with road upgrades and culvert adjustments.
4. Fading color codes and reduced fiber strength were the primary contributors to fiber aging issues.
5. A substantial 68% of utilities reported no fiber failures within the preceding 12 months.

Disclaimer

The working group has diligently endeavored to ensure the thoroughness, accuracy, and clarity of the information presented in this paper. However, the content is based solely on survey results, and as such, is provided "AS IS," potentially containing errors or omissions.

Section 1 – Assessment of Underground Fiber Infrastructure

- Age of Deployed Underground Fiber

Out of the twenty-seven individuals who participated in the survey, 45% have experienced the installation of their underground fiber networks for a minimum of twenty years, while 26% have seen their underground fiber in place for at least sixteen years. This cumulative percentage of 71% highlights that nearly three-quarters of the respondents possess more than fifteen years of operational insight.

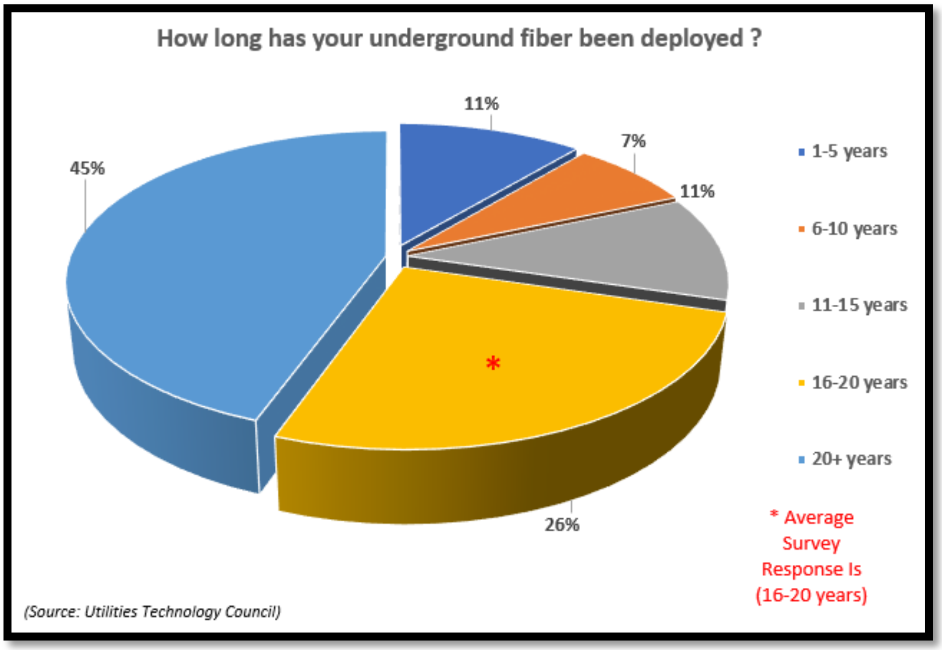


Chart 1

The survey findings also reveal that among the respondents, the average age of their deployed underground fiber falls within the range of 16 to 20 years.

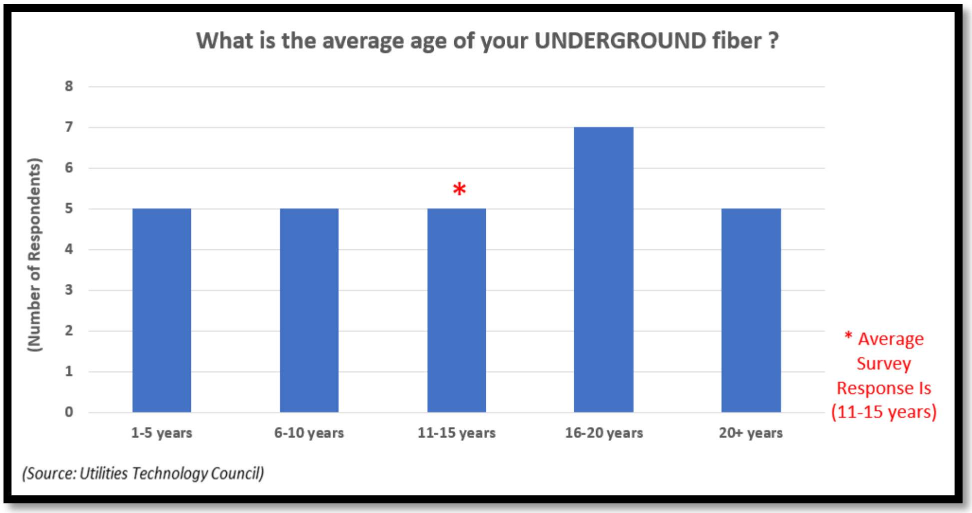


Chart 2

Notably, participants conveyed that their underground networks tend to consist of relatively recent installations, as a maximum of one-third of their deployments are made up of the oldest cables.

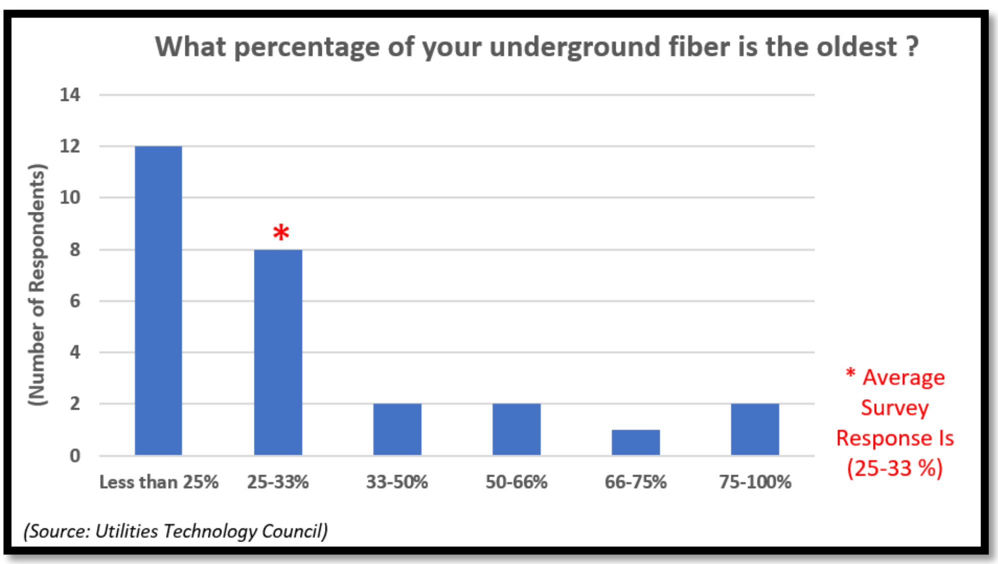


Chart 3

- Size of Underground Fiber Deployments

Among the respondents, twenty-four individuals shared the total extent of fiber cable that represents the mean age of their underground fiber deployment.

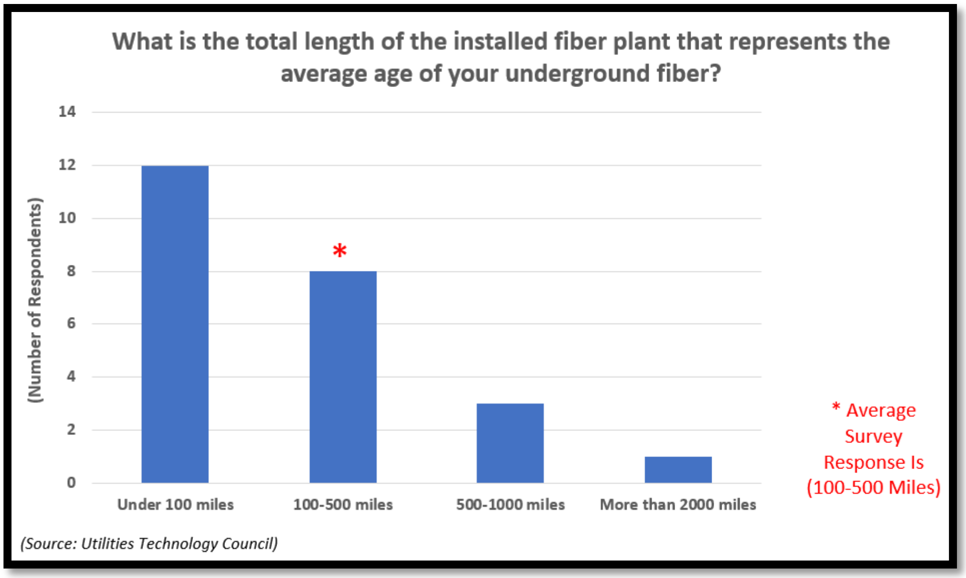


Chart 4

Intriguingly, the average survey response also indicated that the collective extent of their underground fiber deployment falls within the same range (100-500 Miles) as the total length of their averagely aged fiber cables. This suggests that most participants pursued a strategic fiber deployment plan, implementing most of their fiber within a similar timeframe.

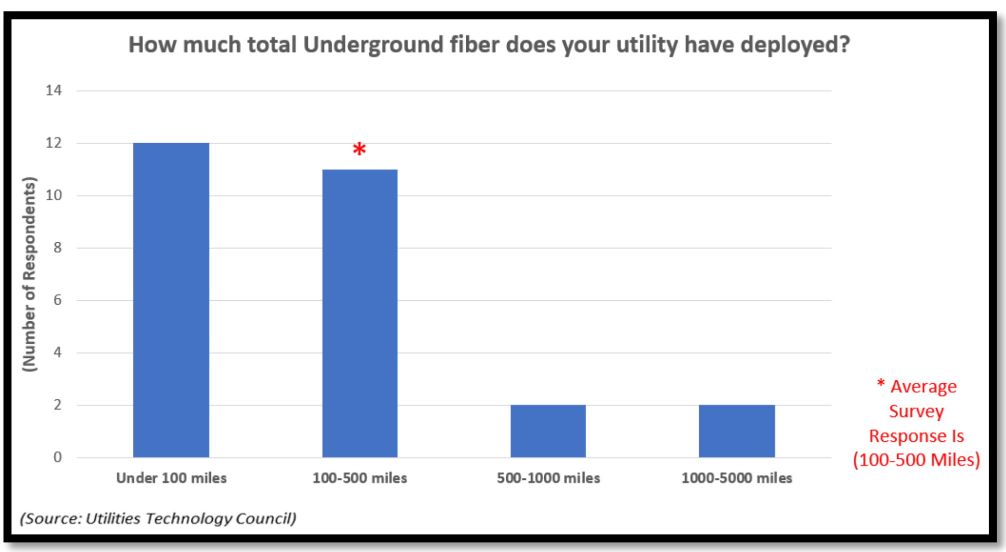


Chart 5

- Size of Fiber Deployments in Public vs Private Right-of-Way

With respect to how much fiber respondents have deployed in both public and private rights-of-way; survey results indicate there is a somewhat balanced deployment in each.

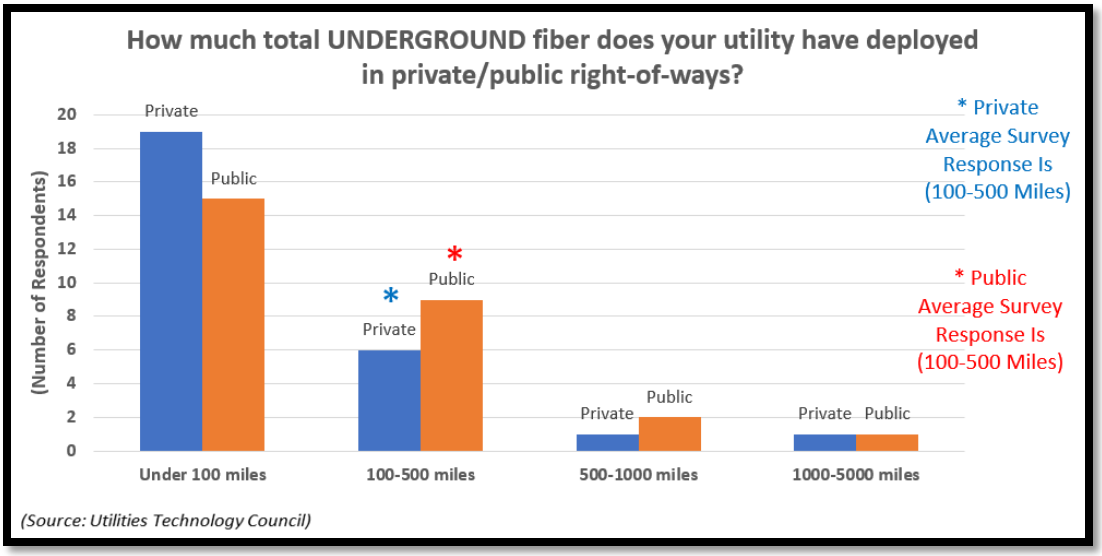


Chart 6

- Average Length of Underground Cable Runs

Lastly, survey results indicate that the average length of underground fiber cable runs are between 1000 and 5000 feet.

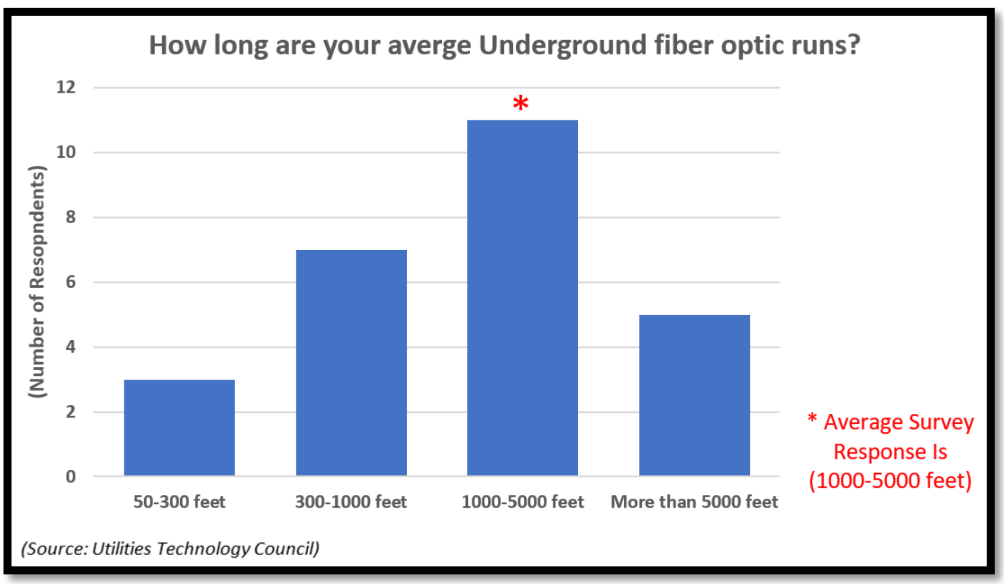


Chart 7

Section 2 – Fiber Optic Transmission Requirements

In the year 2020, the global landscape was significantly shaped by the ramifications of the Covid-19 pandemic, leading to the widespread adoption of remote work enabled by the vast network of single-mode fibers in place. Though unplanned for this scenario, the existing fiber optic communication systems exhibited remarkable efficiency, predominantly relying on legacy SONET/SDH systems capable of achieving transmission levels of up to ten Gigabits per second (OC-192).

The pandemic underscored the vital need for seamless communication, regardless of geographical distance. The ongoing deployment of optical fiber technologies continues to offer a viable solution. The prevalent use of virtual video conferencing has become a societal norm, and technologies like Fiber to the Home (FTTH), Fiber to the Business (FTTB), and Fiber to the Antenna/Cell Tower (FTTA) are instrumental in enhancing access to the extensive bandwidth afforded by optical fiber. The versatility of single-mode fiber is also facilitating increased utilization of mobile phones and personal devices with advanced capabilities. For the transmission of 5G cellular signals, single-mode fibers are indispensable for interconnecting cell radios. Depending on the number of radios on a tower, it's not uncommon to find fiber counts of 24 single-mode fibers per radio.

Forward-thinking service providers can curtail future construction expenses by adopting larger fiber/cable counts, with current fiber counts reaching as high as 6,912 fibers. For pre-existing installations, wavelength division multiplexing (WDM) technologies offer effective remedies for fiber capacity limitations. Dense WDM (DWDM) can accommodate hundreds of wavelengths, each capable of transmitting up to four hundred Gigabits per second.

The realm of high-speed transmission equipment is already addressing data rates of 800 Gigabits per second within data centers, and this technology is poised to extend to long-haul and metropolitan networks. At these elevated transmission speeds, meticulous fiber characterization of the existing infrastructure will be imperative to adhere to service level agreements (SLAs) stipulating signal quality. All systems operating at 100 Gb/s and beyond will incorporate forward error correction (FEC) and coherent detection within the transmission equipment, with a heightened focus on the optical signal-to-noise ratio (OSNR). As transmission rates continue their upward trajectory, the existing ITU-T G.692 and G.694 optical spectrum WDM allocations will face challenges, necessitating consideration of future channel spacing.

To ensure optimal performance of optical fibers themselves, a heightened emphasis will be placed on mitigating factors like polarization mode dispersion (PMD), chromatic dispersion (CD), and optical return loss (ORL). PMD's impact can be mitigated through FEC, while CD can be managed through dispersion compensation techniques. The most pronounced concern arises in systems operating at 40 Gb/s using traditional on-off keying (OOK), where the effects of CD and PMD are most pronounced. Addressing ORL will require the replacement of older installed connectors featuring legacy (PC, SPC) terminations with lower reflectance UPC or APC fiber end face polishes.

Section 3 – Cable Structure

1. Baseline Assessment of Utility Underground Fiber
    a. Age
    b. Mileage
    c. Rights-of-Way (public v. private)
    d. Average length of run / Average Age
2. Requirements for Fiber-optic Transmission
    a. ITU-T G.652-G.657
    b. Multi-mode fiber
    c. Other (including sensor fibers)
3. Fiber Cable Structure

There exists a wide variety of fiber optic cable types employed in underground installations. These encompass loose tube structures in both stranded and central tube designs, which can be either dielectric or armored. Loose tube cables are composed of an outer jacket encompassing buffer tubes that accommodate cable expansion and contraction with temperature fluctuations while safeguarding the internal fibers. Each buffer tube adheres to the ANSI TIA-598-D Optical Fiber Cable Color Code standard, with color-coded internal fibers and ribbons. These cables typically range from 2 to 432 fibers.

Tight buffer cables, designed for indoor settings, feature individual strands of 900-micron coated fibers. Larger fibers possess a more substantial protective coating and are grouped within a single cable sheath, typically separated by aramid yarn. Tight buffered cables have lower fiber counts, up to 144 fibers, and are commonly used in building risers or plenum applications as required by the National Electric Safety Code (NESC). Note: Local Authorities may have other requirements for depths which may be greater than the NESC requirements.

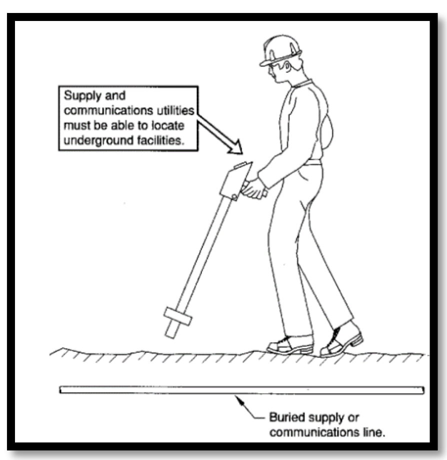
Flat ribbon cables come in stranded or central tube designs, offering fiber counts to 3,456. These fibers are grouped in sets of 12, each with individual markings for identification. Ultra-high density fiber cables are engineered to maximize fiber density while minimizing form factor. They often incorporate rollable ribbons, partially bonded for easy collapsing. These cables are notably smaller and lighter due to their circular form, compared to traditional flat ribbon rectangles. Partially bonded ribbon cables are usually gel-free, with diverse central tube, stranded, or slotted core designs. Some versions may even feature reduced 200-micron diameter coated fibers. These 200-micron coatings are also utilized in higher-density loose tube micro-duct cables and flat ribbon cables. Ribbon cables typically include a bar and block pattern code for identification. Ultra-high-density cables range from 432 to 6,912 fibers and are spliced together in multiples of 12, forming groups of up to 36. Ribbon cables offer advantages in terms of quick splicing and mean time to repair (MTTR) in case of damage.

Survey respondents confirmed the deployment of all cable types. The predominant choice was loose tube, present in 96% of respondents' systems. Notably, 71% of respondents reported underground fiber installations of over 15 years, making loose tube's outdoor durability a logical choice for utility networks. Tight buffered cables were used by 29% of respondents, primarily in substations and switch centers. Ribbon cable adoption was less common, at 11%, and ultra-density cables saw a 7% usage rate.

Various methods exist for installing underground fiber optic cables, with direct burial and conduit placement being the most prevalent. The utilization of innerducts and newer micro-ducts with micro-duct cables allows high fiber counts in smaller diameter cables. Micro-duct cables are designed for "jetting" into micro-ducts and often have lower tensile strength compared to standard loose tube cables. Direct burial involves placing cables directly in the ground via trenching, commonly employed in rural areas. This method is cost-effective but lacks retrievability, requiring new cable installation in case of damage. Conduit deployment is more common in infrastructure-rich areas and can involve semi-flexible HDPE innerduct or rigid PVC conduits. Micro-ducts subdivide ducts for efficient underground resource usage, requiring specialized micro-duct cables. Most respondents (93%) used conduit-installed fiber, often within dedicated communications conduits. Armored cable usage followed at 39%, indicating direct buried deployments. Micro-duct usage stood at 28%, possibly reflecting the demand for higher fiber counts in recent years.

Section 4 – Network Deployments

1. Deployments
    a. Long-haul, metro, FTTx, and other
    b. Fiber counts (36-48; 96-144; 144-288; 288-432; 432-864; 864-6,912)
    c. Depth (-18; 18-24; 24; 36; 48; 60; others)
    d. Configurations (alone, dedicated conduit w/transmission, dedicated conduit w/distribution, joint trench, micro-duct)
    e. Locates (Trace wire, Tone able mule tape, tone able mylar, armored jacket on cable, above-ground markers, cable with trace wire, other).



The Fiber Deployment section of the survey described the network's architectural elements and the applications of underground fiber. This encompassed scenarios like long-haul, metro, or FTTx, along with fiber count, depth, configurations, and locate capabilities.

From chart 8 below, it's evident that most utilities use underground solutions for long-haul and metro situations, while approximately a third apply them for fiber-to-the-premises or similar subscriber services. This usage pattern aligns with the mix of overhead connections utilized for each of these areas.

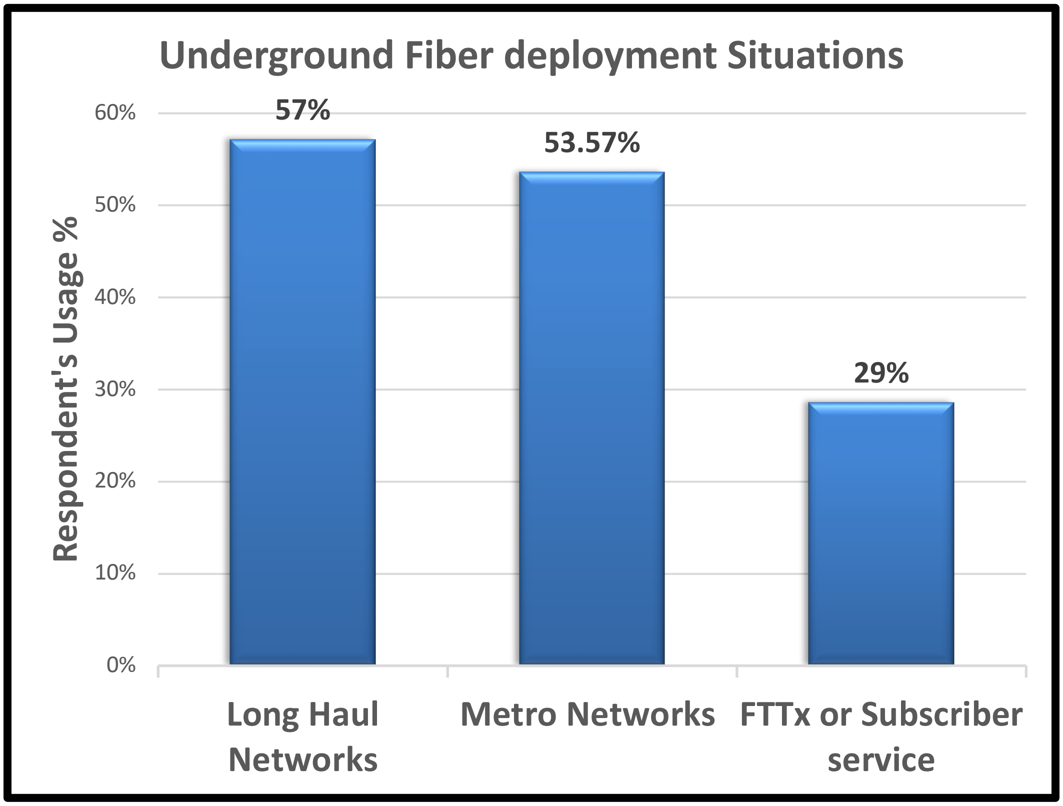


Chart 8

*Note respondents could select multiple answers if they had multiple environments in their network.

The underground cables exhibit a similar fiber count pattern as observed in the overhead study, with the median count falling around 36 to 48 fibers per cable. There's a gradual tapering on both sides of the median, with around half of the responses indicating fiber counts of 24 and 144. The correlation between the age of deployment and smaller fiber counts is evident, as reflected in other sections of the report.

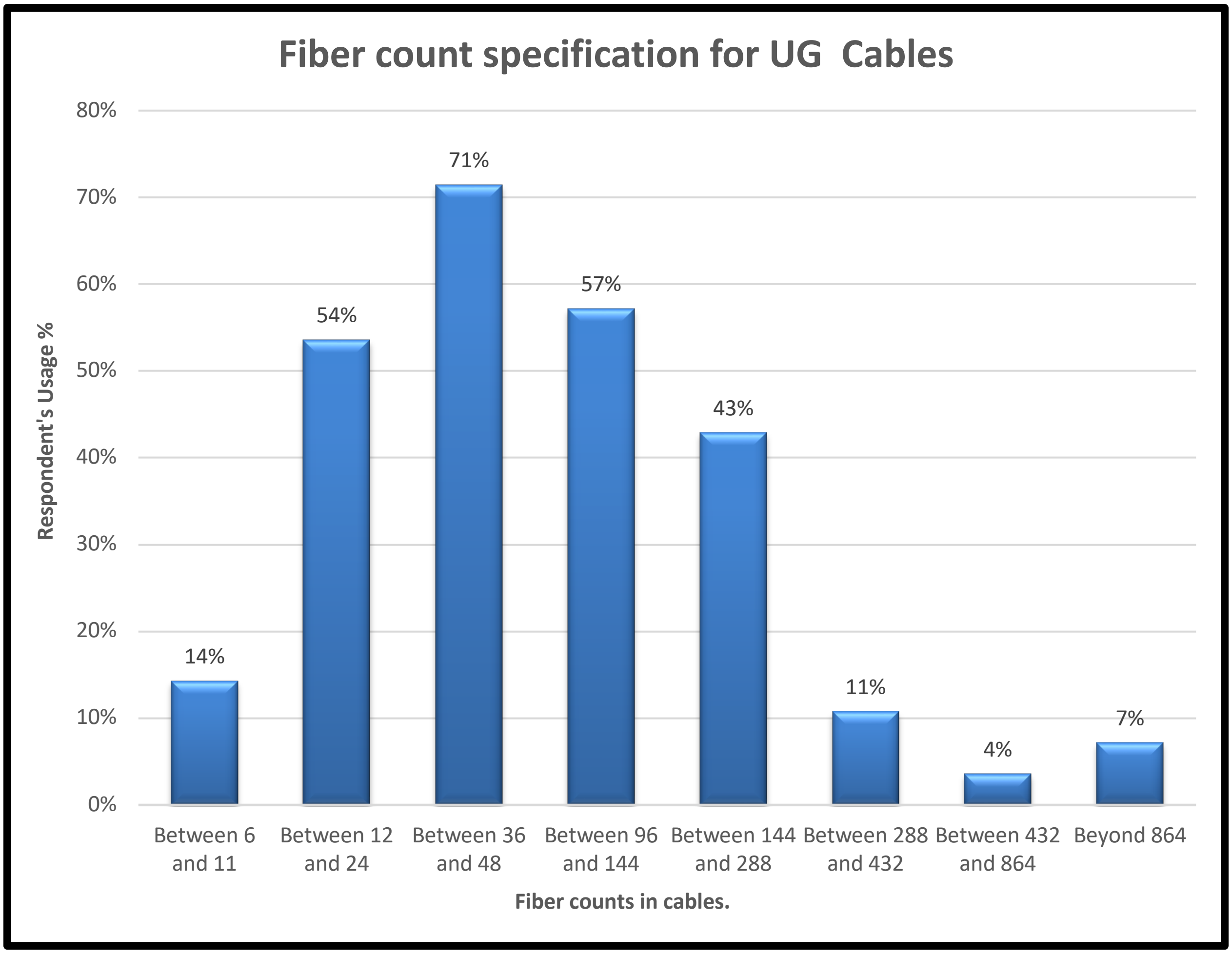


Chart 9

* Note respondents who utilize multiple fiber counts reported as such, so totals exceed 100%.

When it comes to the depth of installed underground fiber optic systems, a predominant 68% of responses (Chart 10) align with a depth of 36 inches. This trend is consistently observed across various regions in the US, where most ground disturbances tend to occur above this level.

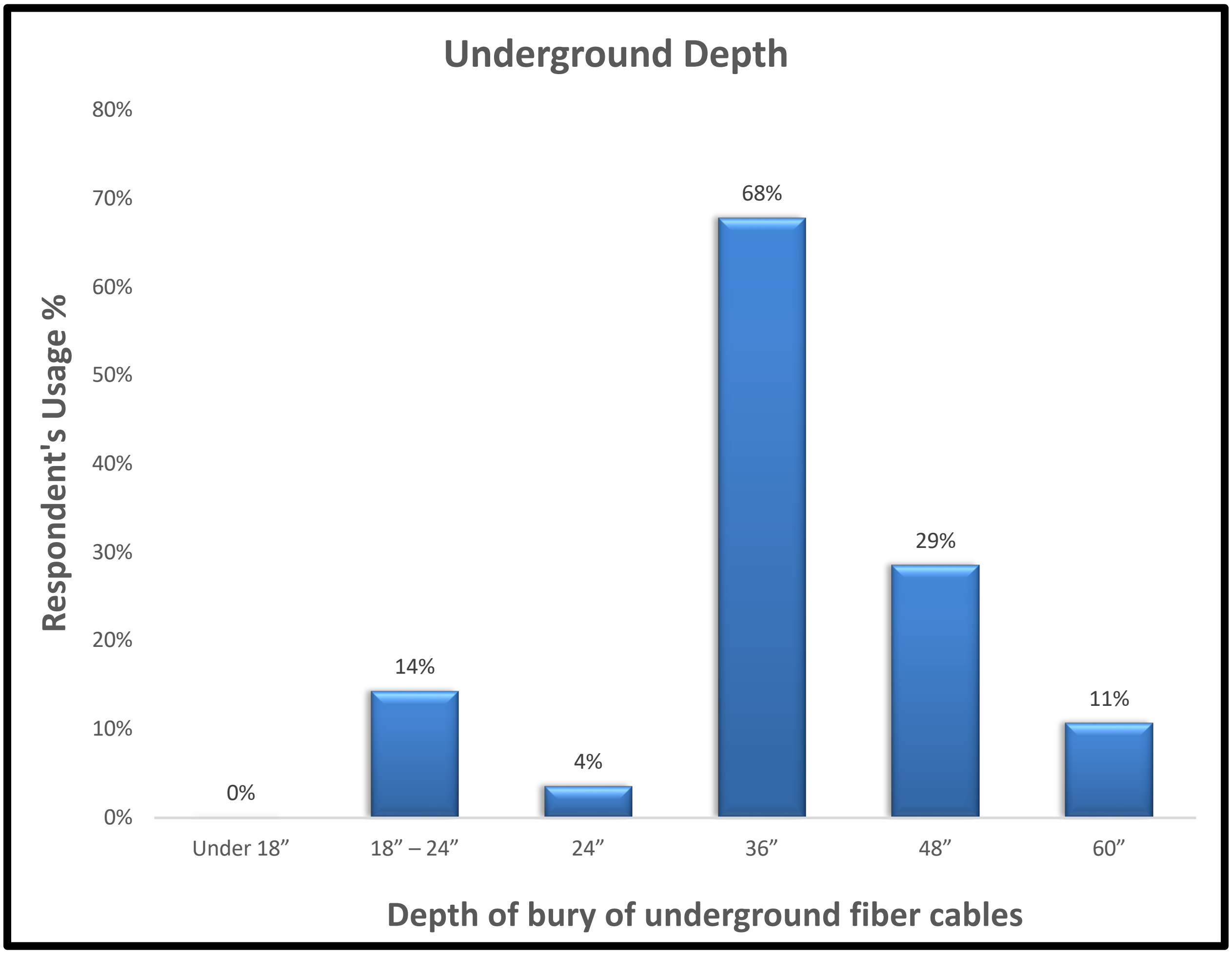


Chart 10

* Note utilities could bury legacy plant at a deeper depth than current standard so totals exceed 100%.

Notably, the primary driving force behind construction projects appears to be the installation of underground fiber. This is underscored by the fact that 93% of responses indicated that fiber is placed independently, without co-location with other cables. Furthermore, 75% of responses are related to distribution duct banks, while an additional 39% are situated within Transmission duct banks. This distribution is influenced by the prevalence of installed Distribution duct banks compared to Transmission duct banks due to their differing scale and cost considerations.

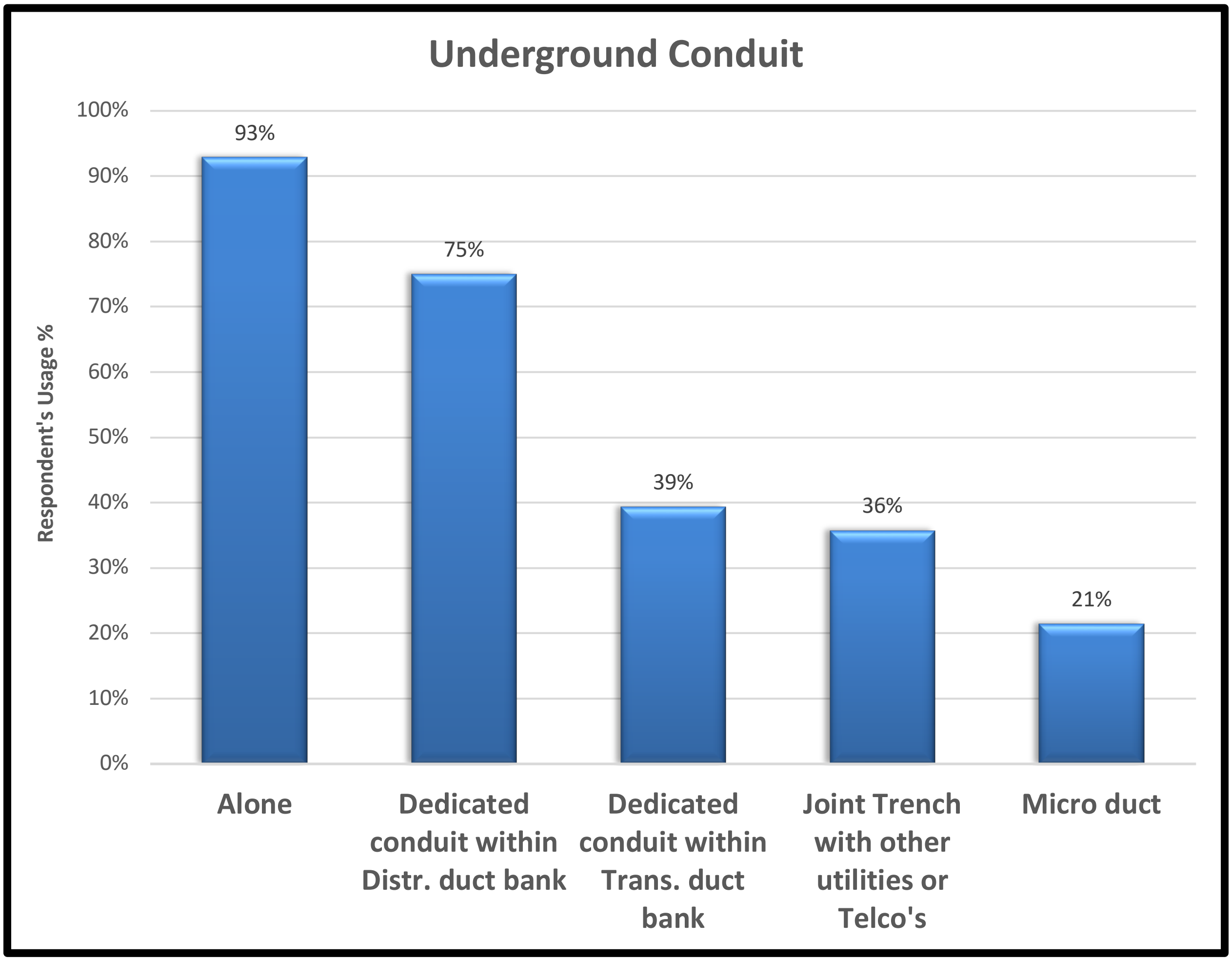


Chart 11

* Note that respondents may have multiple duct variations in their underground plant and could answer accordingly. Therefore, totals exceed 100%.

Swiftly identifying cable damage locations is of utmost importance for maintaining cable systems effectively. A comprehensive chart below showcases various solutions to achieve this goal, along with the corresponding percentage of responses from participants. It's worth noting that the responses encompass a variety of methods, indicating that utilities might employ a combination of these techniques across different installations, thus making their usage non-mutually exclusive.

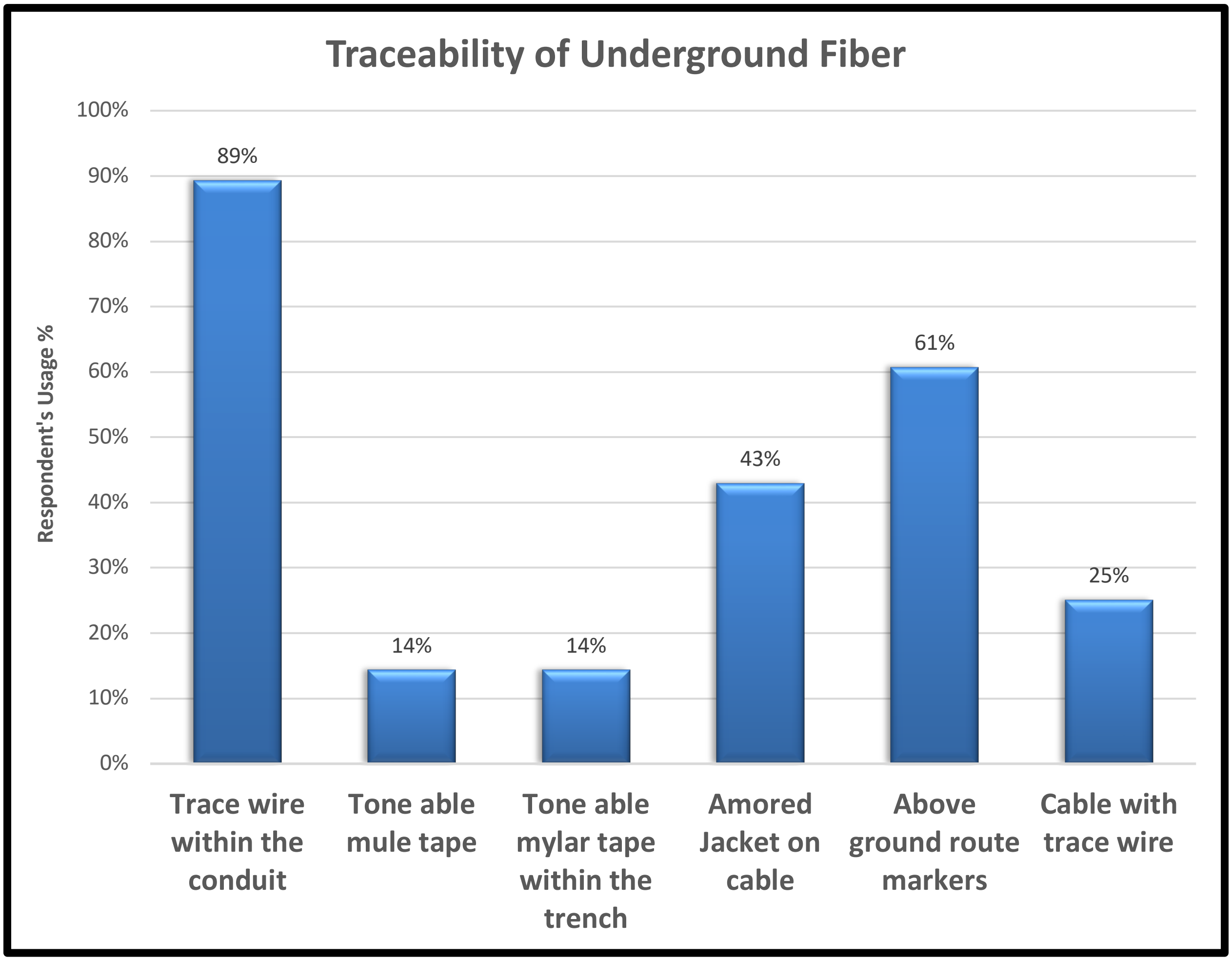


Chart 12

* One thing to note is that the responses are not mutually exclusive, such that a utility could be using all the methods across various installations, therefore totals exceed 100%.

Section 5 – Fiber Types, Vaults, and Splice Cases

1. Fiber (AFL, INCAB formally Brugg, Teldor (Israel), Corning, OFS, Superior Essex, Prysmian (formally Pirelli), Chromatic, Draka (formally Alcatel), SFPOC (China), Taihan (Korea), Sumec, Wasin, Sumitomo, Local Market provider, Other (please specify)
    a. Oldest Age of fiber (AFL, INCAB formally Brugg, Teldor (Israel), Corning, OFS, Superior Essex, Prysmian (formally Pirelli), Chromatic, Draka (formally Alcatel), SFPOC (China), Taihan (Korea), Sumec, Wasin, Sumitomo, Local Market provider, Other (please specify)
2. Vaults (Hubbell, Quazite, Old Castle, Charles Industries, Unknown, Other (please specify)
3. Splice Cases (PLP, Coyote, AFL, TYCO, Raychem, 3M, Corning, CommScope, Hubble, Unknown, Other (please specify))

Underground plant typically is comprised of cable, vaults, and splice cases. Because these are major components in everyone's underground plant, information was gathered in the survey about them. This section of the survey asked respondents about what cable manufacturers their utility used, as well as the brand of vault and splice enclosures their utility used. The first question asked was what the oldest cables were used in the plant. Out of the manufacturer pick list, eight individual manufacturers were selected. The top three were AFL, OFS and Corning as shown in chart 13 below.

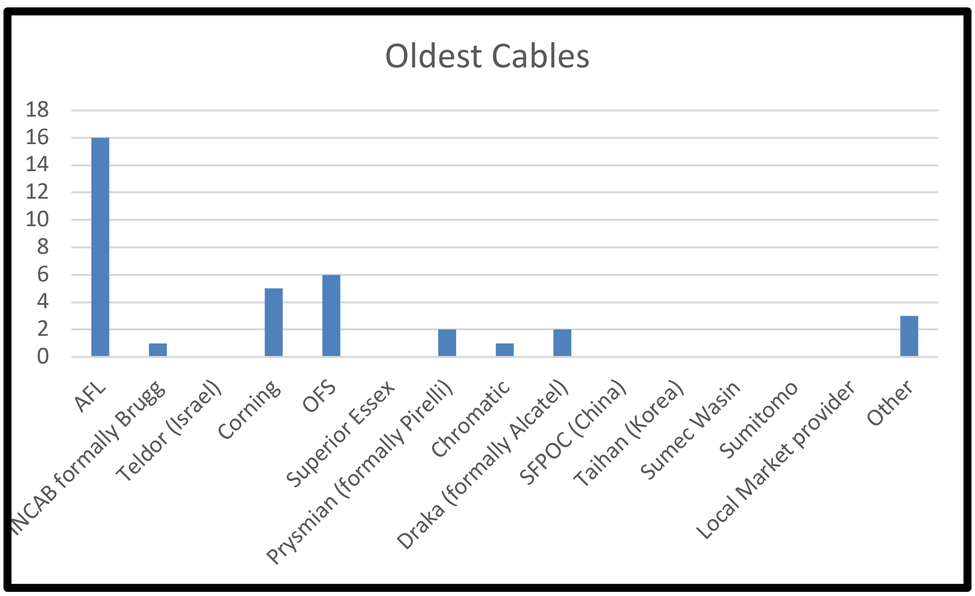


Chart 13

Out of the common industry cable manufacturers nine were noted as being used most in respondents underground, not including an unknown category. This survey shows the top three manufacturers were AFL, OFS, and Prysmian. Chart 14 shows the distribution of manufacturers. Given this data it would appear at least in this sample the two most used cable manufacturers were AFL and OFS being the oldest and most used cables.

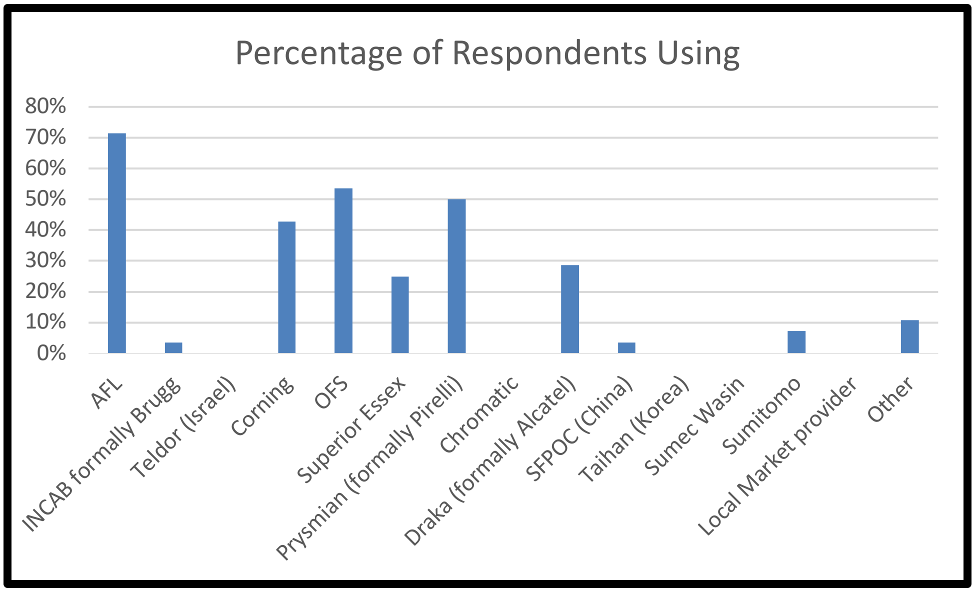


Chart 14

A survey of vault manufacturers was the next category with four major manufacturers leading the responses.

Chromatic dispersion and polarization dispersion testing occurs for transmission levels exceeding 10 Gb/s to assess optical dispersion levels. While the effects of PMD are mitigated at speeds of 100 Gb/s plus, Chromatic dispersion still exists. Fiber characterization should occur to identify all fibers characteristics for CD, PMD and ORL to identify the best/worse fibers for future high speed transmission.

Chart 15 indicates frequency of use among respondents. This means multiple types are often used in the underground over time. An unknown category indicated 15% of the handholes were not known. Old Castle, Hubbell and Quazite were the top manufacturers being used the most shown in Chart 15. It's important to note here that Quazite is now a Hubbell product so this would indicate that Hubbell overall is a strong competitor in this space.

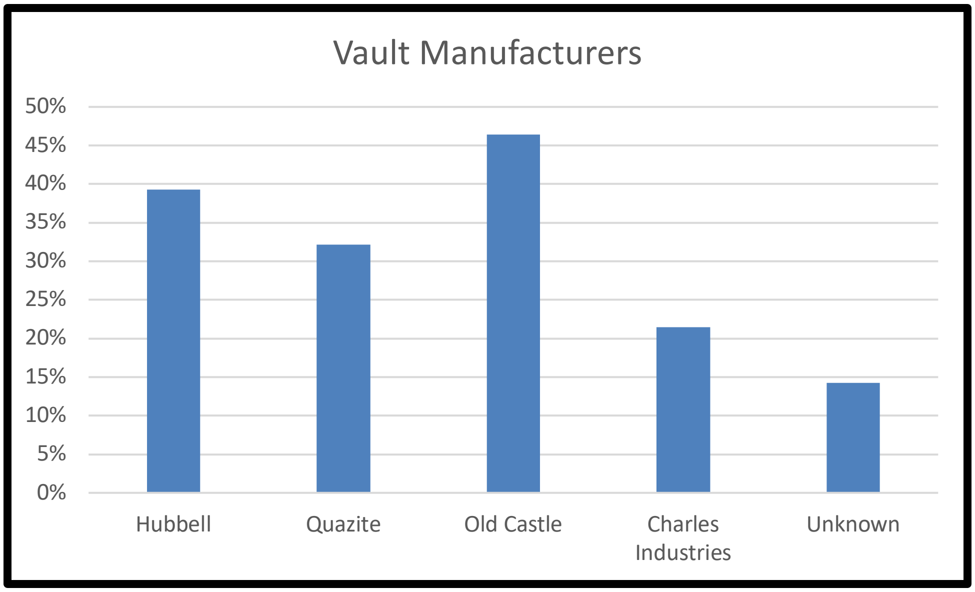


Chart 15

Lastly the survey asked about what kind of splice enclosures were used and chart 16 shows frequency of use among the respondents. The top three here were Tyco, Coyote and PLP. It's important to note that Raychem was bought by Tyco, Tyco bought by CommScope, PLP bought Coyote, and Windsor bought by Hubble. Considering this, CommScope and Coyote are the largest leading manufacturers.

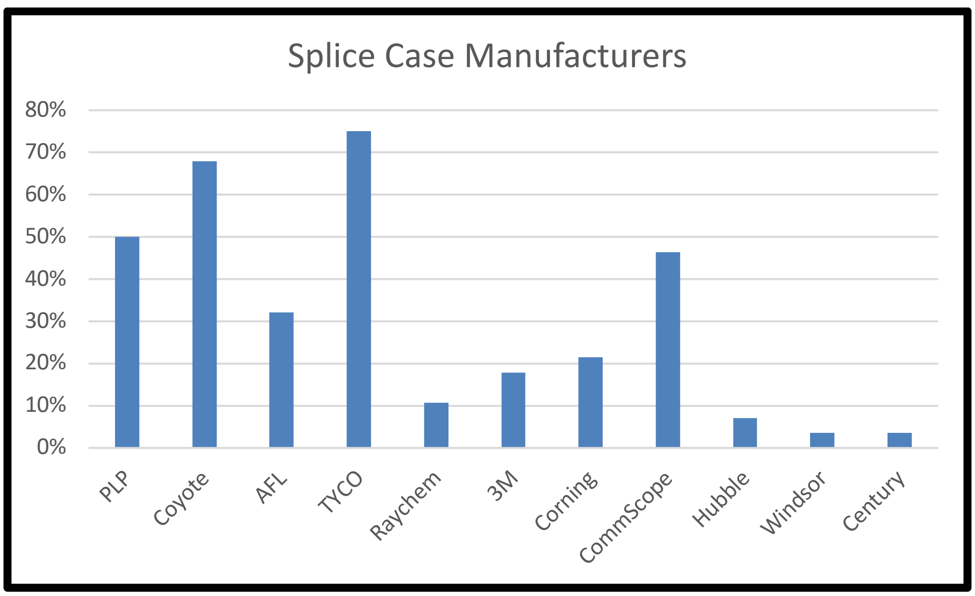


Chart 16

There are many popular manufactures in the industry. Many innovative designs exist for cable, vaults, and splice enclosures. An engineer has many choices to make when selecting these most common parts of the network. Reviewing all these responses the leading selection is AFL cable, spliced with the Raychem/Tycho/CommScope enclosures stored in Old Castle vaults. This is like what was observed in the July 2020 ADSS Fiber Life Cycle report that found the most common cable manufacturer was AFL and the splice case selection was tied with Coyote (PLP) and Tyco, so there are common threads between the underground and overhead plant for these components.

Section 6 – Trends Impacting Deployment

Trends/Drivers Affecting Deployment

1. Reliability - An in-depth analysis of fiber break statistics in both overhead and underground scenarios is essential to understand the comparative reliability of each approach. Focusing on the underground realm, it's important to examine the reliability of conduit, direct burial, and micro trench deployments. This evaluation could lead to the establishment of a quantifiable "cost of reliability" factor that considers factors such as maintenance, repair, and downtime costs associated with different deployment methods.

2. Cost - Exploring average costs associated with conduit, direct burial, and micro trench deployments, while considering varying soil conditions, is crucial. The economic aspect of deployment plays a pivotal role in decision-making. Understanding the cost implications of different methods and soil types can guide utilities towards optimal choices that balance both reliability and financial efficiency.

3. Undergrounding of Other Utilities - With the escalating impact of climate change and intensifying storms, the drive to improve reliability and enhance the aesthetics of urban landscapes has led to increased advocacy for undergrounding various utilities. Addressing the concerns raised by the public for both reliability and beautification requires a comprehensive approach that aligns with the broader goals of urban development and resilience.

4. Broadband and 5G Expansion - The current push for infrastructure development, exemplified by initiatives like the Build Back Better Infrastructure funding, underscores the expansion of broadband and 5G networks. The race for 5G network superiority and the transformation of communication infrastructure are driving utilities to consider fiber deployment strategies that facilitate efficient broadband delivery and cater to the increased demands of 5G technology.

5. Deployment Scenarios and Priorities - The deployment landscape is marked by various scenarios and priorities that guide the replacement and augmentation of underground fiber:

a. The expansion of Fiber-to-the-X (FTTx) footprints remains a top priority, as it brings high-speed connectivity to homes and businesses.

b. Supporting Advanced Metering Infrastructure (AMI) network collectors is crucial for utility automation and efficient energy management.

c. Carriers' efforts to retire TDM and copper circuits are driven by the need for modernization and improved efficiency.

d. The privatization of previously leased circuits aligns with regulatory compliance, particularly the North American Electric Reliability Corporation (NERC) Critical Infrastructure Protection (CIP) standards.

e. The demand for redundant control circuits from Independent System Operators (ISOs) shapes deployment strategies to enhance grid resilience.

f. The competitive race for 5G network superiority intensifies the urgency of robust fiber deployment strategies.

g. Public demand for reliability and beautification compels utilities to deploy fiber solutions that cater to both functional and aesthetic needs.

6. Top Priority Reasons for Replacement of UG Fiber - Among the driving forces for the replacement of underground (UG) fiber, several top priority reasons stand out:

a. Addressing optical faults that impact network performance and reliability is a paramount concern.

b. Rectifying conduit faults ensures the integrity of the entire fiber system.

c. Infrastructure projects that mandate relocation drive the need for fiber replacement.

d. Resolving fiber characterization issues becomes crucial to unlock the maximum benefits of Dense Wavelength Division Multiplexing (DWDM) technology.

e. Augmenting fiber count supports growing data demands and evolving communication needs.

7. Impact of Advanced Modulation Formats - The evolution of advanced modulation techniques plays a pivotal role in addressing the challenges of higher transmission speeds. As bit rates escalate, the demand for wider bandwidth intensifies, which necessitates a transition from conventional on-off keying (OOK) modulation. Advanced modulation formats leverage the entirety of a light wave's parameters—amplitude, phase, and polarization state—to carry information. These formats enhance spectral efficiency, improve noise characteristics, and enhance tolerance to chromatic dispersion (CD) and polarization mode dispersion (PMD). Furthermore, coherent detection and digital signal processing capitalize on advanced modulation's benefits, permitting electronic compensation of CD and PMD. The shift to forward error correction (FEC) at transmission speeds of 100 Gb/s and beyond introduces unique challenges in optimizing signal-to-noise ratios and spectral efficiency to ensure high-performance transmission.

8. Fiber Plant Resilience and Reliability - Ensuring the resilience and reliability of the fiber plant remains a paramount concern for utilities. With the increasing reliance on fiber-optic networks for mission-critical services, utilities are compelled to adopt engineering and design strategies that safeguard against service disruptions. Diverse routing, redundancy, and backup power solutions are integral elements of this strategy, designed to prevent single points of failure and minimize the impact of fiber cuts. Furthermore, the deployment of backup power sources at critical network nodes enhances operational continuity, particularly during power outages or catastrophic events. These efforts align with utilities' commitment to maintain uninterrupted services, safeguarding critical infrastructure and ensuring customer satisfaction.

9. Shifting Landscape of Communication Services - The landscape of communication services is undergoing transformative shifts, driven by technological advancements, and changing consumer behaviors. As the demand for high-speed data, reliable connectivity, and IoT applications continues to surge, utilities face the challenge of accommodating these evolving requirements. The proliferation of Fiber-to-the-Home (FTTH) applications and the expansion of Fiber-to-the-X (FTTx) footprints underscore the need for robust and scalable underground fiber deployments. Utilities are compelled to develop agile and adaptable networks capable of meeting the diverse needs of residential, commercial, and industrial users, while simultaneously accommodating the demands of emerging technologies like 5G and smart grids.

10. Integration of Smart Grid Technologies - The integration of smart grid technologies into utility operations introduces a new layer of complexity to fiber optic network deployments. Smart grid systems rely heavily on secure and high-speed communication networks to enable real-time data exchange and grid management. Consequently, utilities must design their underground fiber networks with the specific needs of smart grid applications in mind. Ensuring low latency, high reliability, and the ability to support a multitude of devices and sensors becomes imperative. This trend drives utilities to invest in advanced fiber optic technologies that can facilitate seamless integration with smart grid infrastructure and support the demands of next-generation power distribution and management systems.

Section 7 – Fiber Utilization and Best Practices

1. Fiber Leasing - As utilities venture into leasing dark fiber to commercial entities, it's imperative to comprehend the heightened expectations of commercial fiber customers. These customers demand uninterrupted service, making proper upgrade planning crucial to mitigate concerns. From a technical and operational perspective, the challenges of fiber leasing and dark fiber relate primarily to fiber lifecycle management and customer/contractor access for maintenance, repair, and replacement. Once customers establish network routes, altering them becomes less desirable. Therefore, a replacement plan should consider evolving technology needs and may entail upgrading fiber for enhanced performance. Service level agreements gain significance, as customers are sensitive to any fiber anomalies affecting their services due to bandwidth or power degradation. Regarding underground fiber, rapid response times during fiber cuts are crucial for carriers to facilitate seamless switching during catastrophic events. While fiber leasing and dark fiber offer revenue opportunities, utilities must acknowledge the accompanying technical requisites and responsibilities.

2. Duct Exhaustion - The demand for larger fiber counts has immediate repercussions, particularly in terms of duct exhaustion. Addressing this challenge involves various approaches within the communication industry. These encompass higher fiber count cables employing smaller diameter fibers. In high-count cables, the fiber coating diameter may reduce from 250 µm to 200 µm. Alternatively, cable structure modifications can yield reduced outside diameters, leading to the emergence of "micro duct" cables. These cables are specifically designed for blowing or "jetting" techniques during installation. Supporting these cables are micro-ducts, which offer added flexibility. In cases requiring flexibility, Maxcell flexible innerduct can provide a suitable solution.

3. Engineering, Design, and Permitting - Most surveyed utilities adopt a combined approach, utilizing both internal and external resources for designing, engineering, permitting, and constructing their underground fiber optic networks. Reliability, resilience, and legal/regulatory adherence are pivotal aspects driving utility fiber engineering, design, and permitting. Utilities deploy well-defined processes that incorporate reliability-enhancing characteristics like diverse routing, redundancy, and backup power. Network design minimizes single points of failure and often employs ring configurations to facilitate traffic rerouting during fiber cuts. Networks are also equipped with backup power at critical points to ensure operational continuity. All these design aspects must comply with rights-of-way and permitting stipulations. Obtaining necessary rights for deploying fiber and obtaining permits from local zoning authorities, particularly for street cuts, are vital steps. Non-compliance can result in fines and penalties.

4. Tools or Methods for Fiber Placement - Surveyed utilities rely on a comprehensive array of tools when designing and engineering their underground fiber optic networks. These tools encompass topographic studies, environmental impact assessments, research on state, county, and township requirements, land rights, rights-of-way, public utility easement details, and engineering and survey data, which culminate in construction drawings.

5. Guidelines:

Who?

a. Utilities have primarily developed guidelines internally, often seeking input from fiber optic material manufacturers. Some utilities involve engineering consultants or partner companies in guideline development.

What?

a. These guidelines encompass a broad spectrum of underground fiber optic construction requirements, including diverse fiber types, specifications for boring or trenching, as well as details about vaults, splice cases, and conduit.

6. Micro-duct Practices - Standard splice closures are adapted with smaller entrance ports and fittings for micro-duct cables. Micro-duct cables are typically rated at 300 lb. tension, in contrast to standard Outside Plant (OSP) cables, which are rated at 600 lbs.

7. Type of Traffic - Utilities employ their underground fiber optic networks for a range of applications including mission-critical traffic such as Tele-protection, SCADA, Security, and IT, transmitted via IP/MPLS, SONET, and DWDM networks. Some utilities also utilize their networks for Fiber-to-the-Home (FTTH) applications.

8. Installation - While some utilities use internal crews for specific tasks, all surveyed utilities rely on contracted construction crews for trenching, boring, and installing conduit, vaults, and fiber optic cables. Some utilities note that internal crews perform work within substations.

9. Splice Crews - Splice crews can be internal or contracted, but they should possess proper training in splicing techniques. Core alignment splicing methods are recommended for achieving the lowest splice values. Ribbon or rollable ribbon fibers can be spliced using fixed V-groove splicers.

10. Testing:

When?

a. Bi-annual testing of dark fibers during extreme temperature conditions establishes attenuation benchmarks and assesses environmental stress effects.

How?

a. Bi-directional optical loss testing at 1310/1550 nm establishes end-to-end baseline attenuation.

b. OTDR testing at 1310/1550 nm examines length, attenuation, splice locations, connector reflectance, and optical return loss (ORL). Enhanced testing at 1625/1650 nm offers improved stress loss identification.

c. Chromatic dispersion and polarization dispersion testing occurs for transmission levels exceeding 10 Gb/s to assess optical dispersion levels. While the effects of PMD are mitigated at speeds of 100 Gb/s and higher, chromatic dispersion still exists. Fiber characterization should occur to identify all fibers characteristics for CD, PMD and ORL to identify the best/worst fibers for future high-speed transmission.

d.

e. Transmission rates up to 40 Gb/s employ on-off keying (OOK) modulation and require chromatic dispersion and polarization mode dispersion (PMD) characterization.

f. Transmission speeds of 100 Gb/s and higher use forward error correction (FEC) and coherent detection, mitigating PMD effects but not chromatic dispersion due to the nature of advanced modulation formats.

Distinguishing Between OOK and Advanced Modulation Formats

The disparity between On-Off Keying (OOK) modulation and advanced modulation formats stems from the escalating bit rates in data transmission. At a 10 Gigabits per second (Gbps) bit rate, OOK modulation easily accommodates within 50 Gigahertz (GHz) Dense Wavelength Division Multiplexing (DWDM) channels. However, as the bit rate surpasses 40 Gbps, the laser's spectral width broadens, causing it to overlap adjacent DWDM channels. This overlap introduces crosstalk and degrades the modulated signal, revealing a fundamental truth in signal transmission. Higher bit rates necessitate broader bandwidth for successful transmission. Nonetheless, innovative solutions exist to maximize data throughput without substantially expanding the required bandwidth, achieved through advanced modulation techniques. These new schemes are essential for effectively handling long-distance transmissions.

Advanced modulation formats bolster spectral efficiency by harnessing the entirety of a light wave's attributes for data carriage—amplitude, phase, and polarization state. Notably, advanced modulation formats exhibit enhanced noise characteristics, along with heightened tolerance to Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD). Furthermore, the incorporation of coherent detection and digital signal processing fully leverages the advantages of advanced modulation formats. This technological synergy unlocks capabilities hitherto inaccessible in systems relying on direct detection. With this approach, CD and PMD can be electronically compensated for, obviating the need for dispersion compensators along fiber spans and avoiding the latency increase these elements can introduce.

In any transmission line, including optical fiber, the limiting factor for data transmission capacity is noise. The Signal-to-Noise Ratio (SNR), quantified as the power ratio between signal power and noise power—typically in decibels—holds pivotal importance. Optimizing the optical signal-to-noise ratio across the entire transmission system becomes crucial for achieving optimal performance beyond 100 Gbps over substantial distances.

The fundamental underpinning of all advanced modulation techniques revolves around encoding multiple bits into symbols, forming a stream of these symbols for transmission. This innovative approach translates into a smaller set of symbols representing a larger array of bits. During transmission, the slower symbol rate, referred to as baud rate, dictates the bandwidth rather than the bit rate, leading to a more efficient utilization of available resources.

Section 8 – Specific Issues

Fiber Splicing, locates, maintenance plans, and tracking tools.

This section of the Underground Fiber Report discusses what utilities are doing in the areas of splicing underground fiber, who they are using to do fiber locates, what type of fiber maintenance program they have, and the type of tools or methodology they use to track fiber routes and connectivity.

Every utility company in the survey uses non-reflective fusion splicing as its main method to splice fibers. Fusion splicing is the preferred method to splice fiber optic strands for long-term or temporary emergencies to minimize the impact of light loss budgets on the system. A few companies use reflective mechanical splicing in certain situations. Examples are short runs inside substation yards, as a last alternative splicing method due to critical time to restore fiber paths to minimize immediate system down-time, and this method may be required due to limited physical fiber cable/strand length availability. No other splicing methods were mentioned by the survey participants.

On the question of who does underground fiber locates for utilities, the results were evenly distributed between internal personnel, outside contractors, and a combination of both as shown in Chart 17 below. To accomplish underground fiber locates, 30% of the utilities used internal personnel, 40% of the utilities used outside contractors, and 30% of the utilities used a combination of internal personnel and outside contractors. Please note that each of the methods to locate fiber comes with its advantages and disadvantages. Cost to do the locates, having internal personnel available, ensuring you are getting good locates from contractors, landowner relationships, and multiple locate trips are some of the challenges that are included in the decisions made by utilities as to which direction companies choose for fiber locates. One problem identified by approximately 50% of the utilities in the survey was the lack of a ground wire to accomplish underground locates. Locating of underground cables should be a part of engineering the cable installation to ensure that locating does not become a problem later. Making multiple trips to do locates and having someone on site for the actual dig was a reoccurring issue for utilities. The last issue listed were last minute locate calls identified as emergency locates but when the locate was done on site there was no evidence of an emergency and it many cases the person calling in requested an emergency status due to poor planning and scheduling.

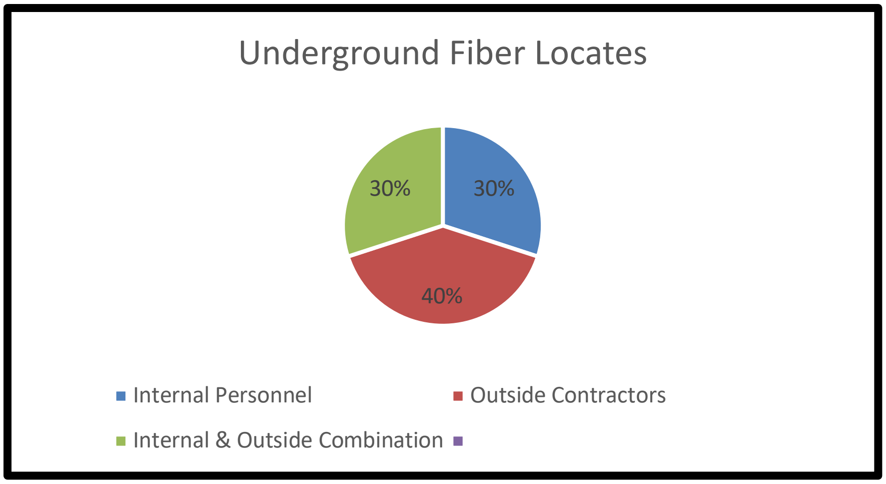


Chart 17

The results of the survey for preventative maintenance fiber testing of fiber cable were very interesting as most utilities taking part in the survey do not have a preventative fiber maintenance program. As depicted in Chart 18 below, 54% of the utility companies did not have a program, 7% had a one-year testing program, 10% had a two-year program, 8% had a 5-year program, and 21% of the utilities did not respond to this question. One company did partial testing each year and tested all fibers over a three-year period. One company commented they are starting a program to monitor on a 5 to 10-year basis. One question from this section for later review is why so many companies do not have a preventative maintenance fiber testing program or are they using other methods to verify they are not having premature fiber issues.

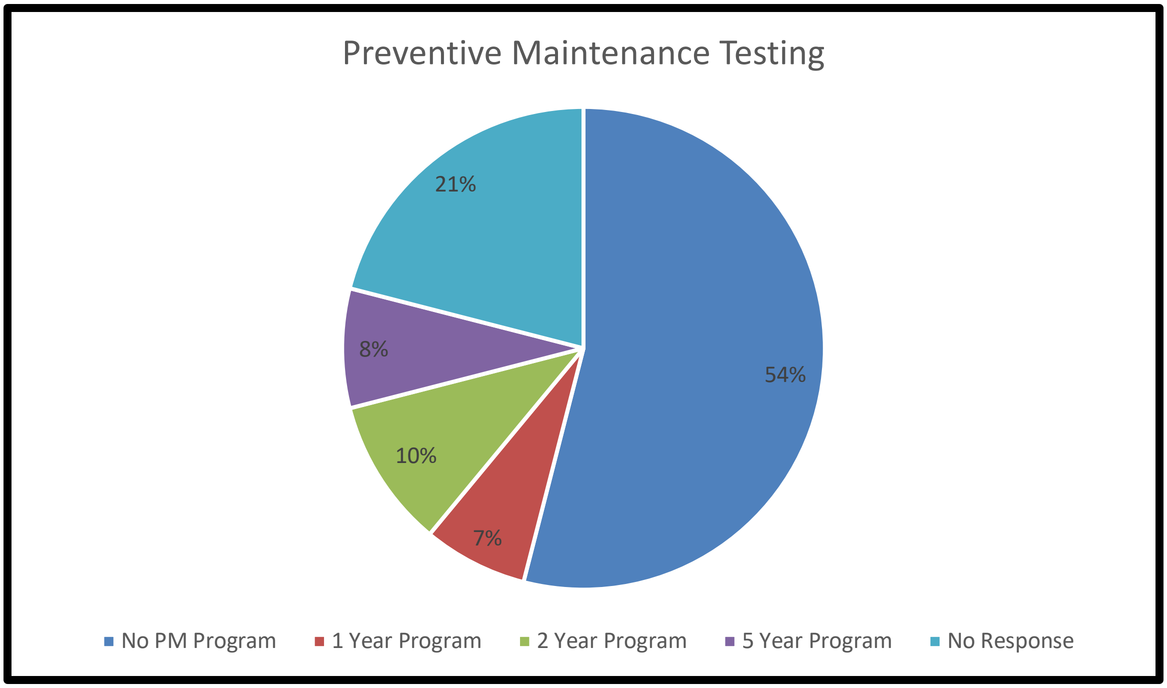


Chart 18

Every utility that participated in the survey used one or multiple tools or methodology to keep track of their fiber routes and connectivity. Most of the utilities (90%) used multiple tools or methodology for routes and connectivity. Of the utilities that used only one tool or methodology, GIS mapping or Google Earth Overlay were the tools of choice. The chart below shows the different tools or methodology utilities use to track fiber information with GIS modeling mapping tool (71%) and CAD drawings (68%) being the most popular. Google Earth Overlay is the third most widely used tool at 54%. Of the utilities using multiple tools or methodology, 52% used two different types and 48% used three or four different types.

Use of a tracking tool with test equipment to locate a failure event on the network.
While it is often easier to locate damage from the surface as due to backhoe fade, other issues may be more challenging when the surface has not disturbed. At this point one may use the test equipment as an OTDR to provide an approximate glass strand length at which an event has occurred. It is important to set up the OTDR to have the correct Index of Refraction as specified by the glass manufacturer's specification. Next one needs to accommodate for maintenance coil length as required to manage splice or termination points, vertical & horizontal run variations through buildings, and maintenance "slack" coils located at handholes or maintenance holes along the route. Finally, one must account for the Helix Factor or Helicity of the fiber strands length vs. the cable sheath length. This helix factor is the spiraling of the fiber strands within the cable and can vary between 1-4% depending on the cable structure and fiber count.

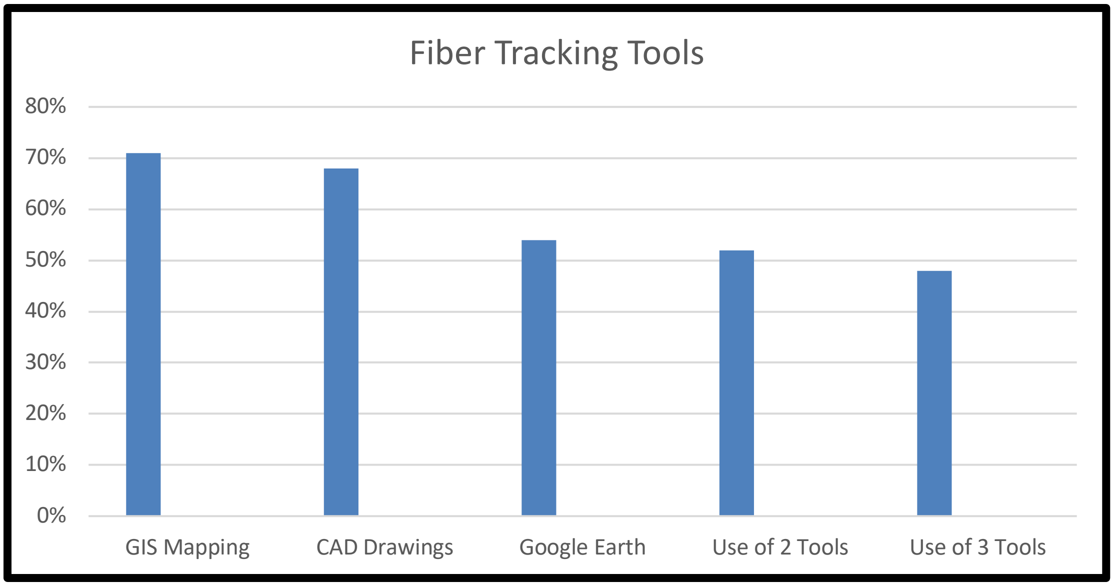


Chart 19

Environmental Impacts on Underground Fiber Construction

When constructing underground facilities, environmental impacts need to be taken into consideration to limit future construction problems or delays to one's plans or project. The following areas need be reviewed: wetlands and waterways; threatened and endangered species; archeological sites and historic structures; stormwater (the number of exposed soils); and possibly invasive species surveys issued. Generally Federal, State, and Local jurisdictions need to be contacted for these matters. Areas to consider may also include future possibilities of erosion and landslides.

Wetlands may be defined by the types of vegetation growing in an area. There are many types of wetlands i.e., forested, marsh, bog; and there are varying degrees of quality of the wetland i.e., degradative, and pristine. Depending on the state, wetland regulations can vary i.e., some states include hydric soils as wetlands. A waterway is any convenance that has enough water in it at any time of the year that will float a boat, such as a kayak. The streams that do not have water year around are called intermittent waterways. A waterway is defined by its bed and banks.

Threatened and endangered species are defined by the Fish & Wildlife Service. If a species is listed as "endangered," there are rules regarding avoidance. If working within a species' habitat cannot be avoided, the Endangered Species Act requires obtaining an incidental take permit. There may be periods throughout the year that construction cannot proceed due to procreation and migration activity. This may not be limited to animals but may also include plants.

There may be locations where one must not use open-cut/trench but must use boring methods with limited approved bore-pit location to minimize ground surface disturbances. There may be locations where no underground construction is allowed. For example, archaeological burials do not allow directional drilling nor the use of Hydrovac trucks. Another example is the federal trigger requiring stormwater permitting for erosion control which is 1 acre of exposed soil. Local entities may have lesser amounts that trigger permitting requirements.

Section 9 – Failures and Mitigation

Underground Fiber Failure Analysis

As we investigate underground fiber failure analysis, we will first look at the problems and challenges utilities have witnessed in underground fiber installations. Many of the utilities surveyed (65%) experienced cable installation problems. Utilities also experienced challenges with splice cases (14%) and splicing of the cables (14%) during the installation phase of installing fiber.

Utilities are presented with a variety of installation problems and challenges for their underground fiber projects. We start with cable installations. Utilities witnessed direct bury fiber problems due to plowing in ground not suitable for direct bury fiber. Gravel roads that had been filled in with backfill that included discarded barbed wire and metal pieces caused the fiber cable to be chafed and several fibers were broken. Ditches where a high volume of water run-off during storms caused wash outs and led to fiber being exposed and, in some cases, damaged by debris in the ditches. Cable problems occurred from contractors and utility crews pulling the cable with too much tension, which stretched the fiber cable and lead to breaks and other physical problems. This usually occurred where fiber was being installed in long conduits and/or difficult runs. A few utilities experienced problems with the actual fiber cable from the manufacturer. One problem was poor quality jacket materials that led to seasonal expansion/contraction of the cable resulting in broken fibers or micro-bends. A second similar problem was experienced with the migration of fibers within the buffer tubes, which caused problems with micro-bends and/or macrobends at splice points.

Problems occurred in the location of vaults, conduits, and fiber cable in rights-of-way. Conduits placed in the wrong locations led to additional time and expense to move it to the correct locations. Vault locations not marked properly resulted in crushed vaults or vaults being covered up and then hard to find. Pedestals located in low areas where they later were submerged in rising water events revealed poor fiber installation planning. Ducts should be foamed after installation because utilities experienced rodent issues in conduits that were left open. A similar problem was not sealing up vaults to keep rodents from getting into the vault and chewing up the cables. Some utilities experienced issues when they crossed main highways in getting the cable to the right locations for vaults. Legal issues also came up due to DOT right of way challenges (being too far off road) and having the wrong easement language in agreements.

Splicing and splice cases made up approximately 28% of installation problems. Most of the problems with splicing were due to splicing crews getting into a hurry to finish a splice job so they could meet installation timelines. Another issue was not keeping the work area clean, which caused fiber contamination when splicing. There were also challenges with splicing underground fiber with OPGW and ADSS, which will be covered later in this section of the report. Splice case issues were usually due to crews not sealing up the splice enclosures correctly. This was a failure in not following manufacturer instructions to seal or to seal and pressurize the cases properly. As we will see in the failure section later, rodents are a big problem, and not sealing up splice enclosures properly can lead to rodents doing catastrophic damage to the fiber. Water problems are an issue stemming from improper splice enclosure sealing. Water can cause the fiber to become brittle and fail over time. Water and/or moisture issues can be immediate or long-term challenges. Be sure to follow the manufacturer instructions when sealing up fiber splice enclosures. Some lessons learned by utilities in this section include 1) making sure to go big on vaults, so there is enough room to work in the vaults; 2)planning for ease of accessibility for splice cases, which alleviates some safety concerns; and 3)being able to place and store extra slack coils (fiber storage loops) has been a lifesaver when something does get damaged with a backhoe dig-in.

One last item on installation challenges was to ensure internal employees and contractors are well-versed in dealing with landowners. One utility commented that contractor issues with a landowner resulted in higher unplanned costs for surface soil remediation due to how the contractor dealt with the landowner.

Next in this section we look at issues when splicing, prepping, and storing fiber while working with different types of fiber (OPGW, ADSS, Underground).

First, we look at splicing different types of single mode fiber. Problems identified included 1) gains and losses where the fibers were joined (much more than when only one type of fiber was used); 2) higher than normal losses; and 3) matching-up the fiber in the splice machines when fusion splicing. Some utilities did comment that newer fusion splicer technologies have eliminated most of the slicing issues. Mechanical splices displayed most of the aforementioned issues when used to splice different types of fibers together. Brittle fiber issues were mentioned as a problem, and we will address those issues in a later section on failures and aging.

Second is the issues with transitioning from underground fiber at a splice enclosure to OPGW or ADSS. You may be prepping different types of fiber cable (Underground, OPGW, or ADSS) and bringing these different fiber types into the same splice enclosure at a splice site to complete an installation. Working on different types of cable when prepping is a challenge as each has different prepping methods and requires different tools to do the prepping. Making sure you have a procedure on site for each is helpful in eliminating human performance errors. Each of the fiber types (UG, OPGW, and ADSS) have different entry connectors into the splice encloses, so it is important to have the correct ones. Utilities reported issues with different slack lengths when working with the different types of cables. Some additional pre-planning of fiber storage inside and outside of the splice enclosure can aid in this issue. Most of the comments in this area of the survey dealt with the difficulty of working with OPGW, whether it was to secure the OPGW, bringing it into the splice enclosure, or having adequate room in the splice enclosure. Proper planning can help address these issues by establishing how the OPGW or ADSS will be secured and ensuring your splice enclosure has adequate room for the type of fiber you are storing in it. Not addressing the storage ahead of time can lead to problems with bent loose tubes or fibers and eventually breaks in the fiber splice enclosures.

Fiber Attenuation/Failures

We will break down the fiber failures and fiber attenuation into their own areas as fiber failures will cause loss of fiber signal but there are other issues that will cause fiber signal attenuation without the fiber failing.

Fiber attenuation can be caused by several issues, and as we will see in this section, other than splicing issues, no one issue stands out. Chart 20 below shows the spread of the issues as reported by each utility that participated in the survey. One of the top issues utilities experienced that caused attenuation problems was bad splice issues (29%). The issues can be the actual splicing or storing the spliced fiber. Rodent damage was a second leading cause of fiber issues (18% of utilities reported having this issue) which can start with degraded signal and finally loss of light signal or may fail as the damage happens. Jumper cleaning problems were reported by 12% of the utilities and 12% reported bend loss issues with the fiber. Faulty installations were reported by 9% of utilities, aging by 8%, water penetration by 7%, and others made up 5% of issues reported by utilities. One can see the human element in many of these attenuation issues, such as not storing fiber properly, ensuring splices meet manufacturing requirements, cleaning fibers properly, and sealing up splice enclosures per manufacturer instructions. One underground attenuation issue that did not show-up as a factor in OPGW and ADSS is aging of the fiber. Utilities identified it as an issue, which we will look at in more detail.

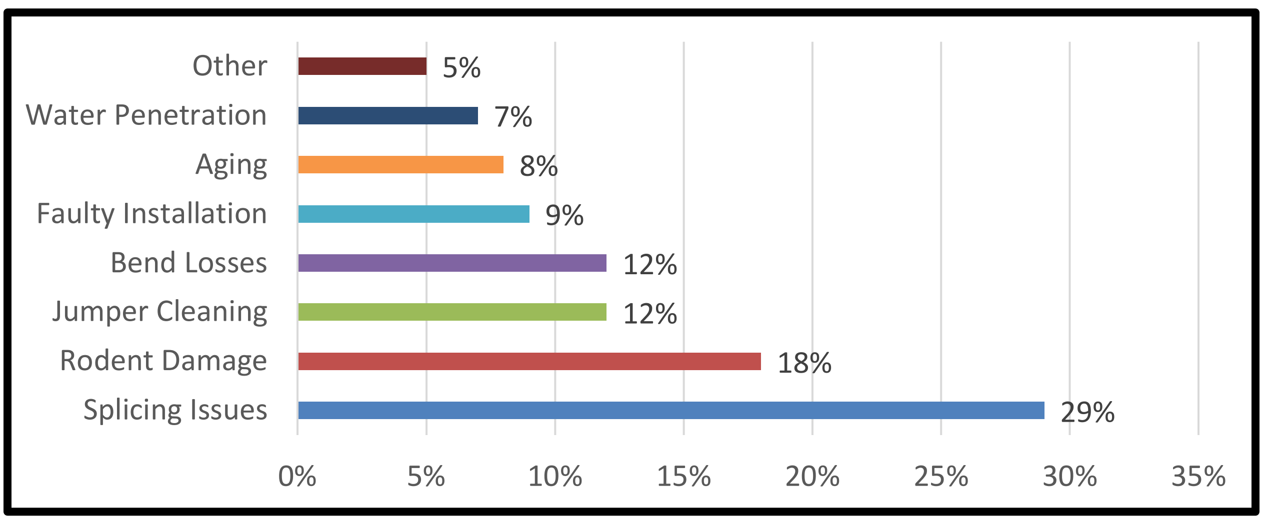


Chart 20

Fiber aging was identified by seven of the participating utilities. Of those seven utilities, three had underground fiber installed for over 20 years and two for 16 to 20 years. Utilities that identified fiber aging as a problem listed color-code fading (38%), loss of fiber strength (26%), and breakage (18%) as the top three issues. Increased attenuation was at 12%, and other made-up 6%. 50% of the utilities reported no aging issues.

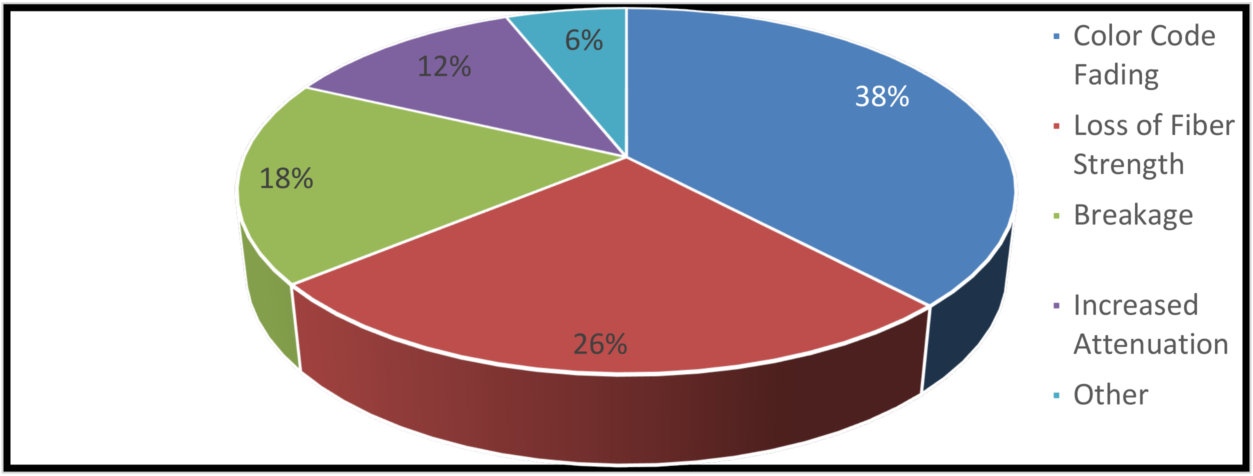


Chart 21Utilities identified dig-ins as the most prevalent fiber failure issue. The survey showed dig-ins were reported by 40% of the utilities participating in the survey. While some dig-ins happened with utility workers on-site during the dig, most happened with no locates being performed and no advanced warning of someone digging in the area. Some of these dig-in issues were the results of county road upgrades, moving of culverts, and other companies burying fiber where utility fiber was already located. Human causes (other than digging) and rodent issues were the next largest factors of fiber failures. As depicted in the graph below, human causes were reported by 22% of utilities and rodent issues by 20% of utilities. Human causes included gun shots, driving over above ground splice locations, and cutting cables coming into above ground splice enclosures. Rodents caused issues by chewing at the base of riser cables coming into splice enclosures, getting into the splice enclosures or vaults, and chewing on cables, or chewing through buried underground cables (pictures of rodent damage are included below the graph. Right-of-way clearing made up 14 % of the issues, and the others 4%.

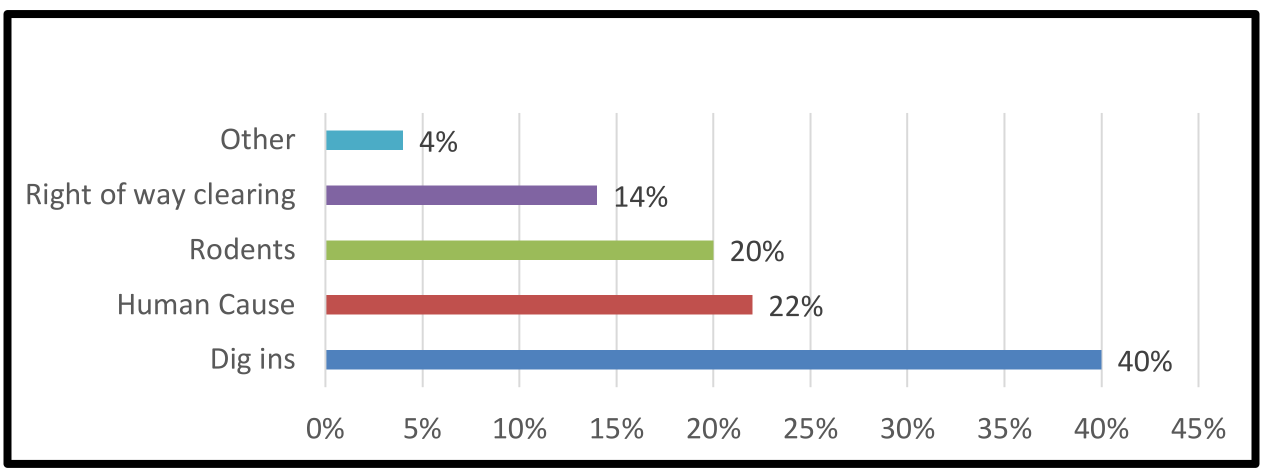


Chart 22

An important component in dealing with fiber failures or other fiber issues is the system restoral time from failure to repair. Extended repair times (system downtime) have been a problem for 46% of the survey participants, while 54% of the utilities did not list extended fiber system repair times as a problem. Some of the causes of extended repair times included not having material on-hand to facilitate repairs, availability of contractors to work emergency repairs, and having sufficient internal resources to do the repair work (engineering and field work). The use of self-healing ringed fiber networks does have a dramatic effect on system downtime for the communication network and does lessen the impact that fiber failure issues have on network customers. The good news on the issues of fiber repair is that 68% of the participant utilities experienced less than 5 fiber repairs in the last 12 months, and 14% had not needed to do any fiber repairs in the last 12 months. There were 11% of the participating utilities that did experience more than 5 fiber repairs in the last 12 months, and 7% did not know how many they had experienced in the last 12 months.

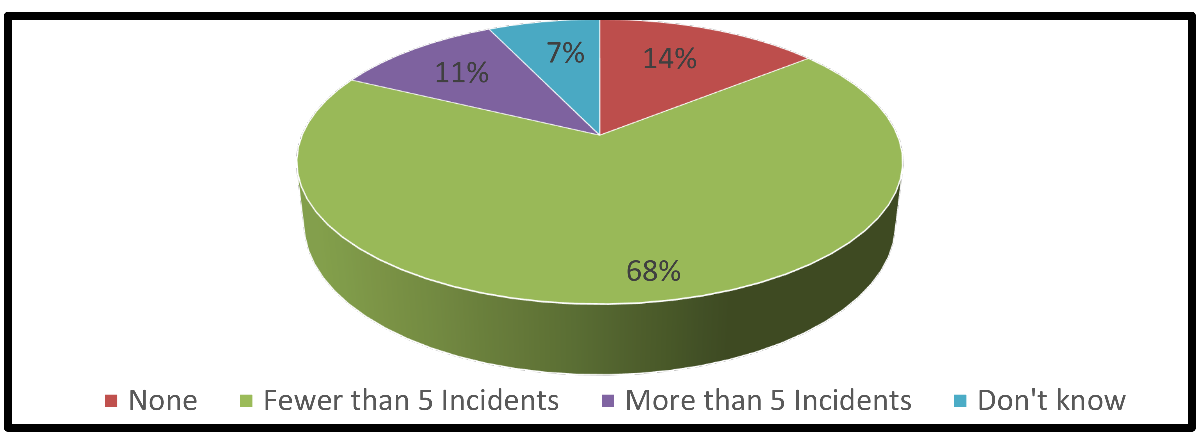


Chart 23

The human element plays a major factor in fiber failures and fiber attenuation issues for underground fiber. While rodents and mother nature contribute to the failure and attenuation issues, the human element can be traced to most fiber failure issues and fiber attenuation issues. Dealing with the human element is an important part in keeping your fiber network operating optimally.

Below are additional Pictures of underground cable damage and underground cable installation.

In conclusion, the exploration of underground fiber optic deployment and its associated practices reveals a landscape shaped by diverse factors and considerations. As the technological demands of the modern world continue to evolve, utilities are tasked with adapting their approaches to ensure reliable, high-speed, and resilient communication networks. The findings in this study shed light on key trends and drivers influencing the deployment of underground fiber, emphasizing the critical importance of reliability, cost-efficiency, and adaptability in the face of changing communication needs.

The transition from traditional on-off keying modulation to advanced modulation formats serves as a clear illustration of the intricate relationship between technological advancements and the necessity for enhanced data transmission capacities. With the demand for higher bit rates, the adoption of advanced modulation becomes paramount, optimizing spectral efficiency, noise characteristics, and the tolerance of dispersion effects. These advancements, in tandem with coherent detection and digital signal processing, underscore the industry's commitment to delivering robust and efficient communication solutions.

Moreover, the insights into fiber plant resilience, the integration of smart grid technologies, and the shifting landscape of communication services underscore the dynamic nature of the underground fiber deployment domain. As utilities grapple with the challenges of duct exhaustion, permitting complexities, and diverse fiber placement methods, it is evident that strategic planning, engineering foresight, and collaboration with both internal and external stakeholders are essential for successful deployment.

In essence, the deployment of underground fiber optic networks stands at the intersection of technological innovation, operational resilience, and the pursuit of optimized communication services. This study's findings illuminate the multifaceted considerations utilities must navigate to create networks that not only meet current demands but also lay the foundation for future growth and transformation. As the digital landscape continues to evolve, the lessons drawn from this examination will undoubtedly play a pivotal role in shaping the strategies that ensure seamless and efficient communication for years to come.