ENGINEERING AND CONSTRUCTION ALTERNATIVES TO LINE CLEARANCE TREE WORK

by John W. Goodfellow

Abstract. Electric utilities routinely prune trees to maintain clearance between branches and overhead electric conductors. Alternative methods of overhead and underground line construction can reduce the impact of electric utility lines on trees. The greatest opportunities for incorporating alternative utility designs into the urban forest come at the time of original construction or when changes are made to the existing utility infrastructure.

Tree-caused outages are a major concern to the electric utility industry. In many areas, trees are the primary threat to service reliability. The industry has long engaged in extensive pruning and removal of trees that threaten overhead lines. Annual expenditures run in excess of $1.5 billion.

Electric utilities are in the business of selling reliable service. It is reliability that differentiates one company's product from another's. As the industry faces increased competition, reliability takes on new importance. As an industry, utilities also have an obligation to ensure the safety of their employees and the general public. Interference between trees and energized electric conductors is a threat to such safety. Finally, investor-owned utilities have a financial obligation to their shareholders. Construction and maintenance costs, including line clearance tree work, can be substantial.

Utility lines and construction techniques vary considerably. This paper focuses primarily on construction sites in the urban forest, and on 4 kV to 34.5 kV electric distribution lines (the most common type of "power line" found in urban and residential areas), which distribute power from substations to the consumer. High-voltage transmission lines are not included in this discussion. Many other types of utility lines are found in the urban forest, including telephone, cable TV, streetlight circuits, and traffic signal circuits. Because their tree/wire interaction is much less significant than with electric distribution circuits, these other types of facilities are not discussed in this paper.

Tree-caused outages occur when a tree contacts an energized conductor. This contact breaches the electrical integrity of the line, causing a fault or "short." Tree-caused faults occur because the tree provides a path to the ground or between phase wires of the electric system. Most tree-related outages happen when trees or branches break, the wind causes branch movement, the electric load on the line increases, or when high temperatures cause the conductors to sag. The purpose of utility line clearance tree work is to maintain adequate clearance between conductors and trees so that interference is avoided.

Opportunities for Change

The best time to address the adverse effects of trees on distribution lines is at the time of initial design. Other opportunities arise when the existing infrastructure is altered for road widenings, relocations, or upgrades to the electric system. It is the author's experience that only in exceptional cases can the cost of converting an existing system to an alternative type of construction be justified on the basis of reliability or avoided cost of future tree maintenance and repair. Where the existing system has depreciated and is operationally adequate, there is little or no financial incentive for a utility to pursue conversion. And, the question of who pays for the "improvement" must be addressed (the municipality, those customers directly benefiting from the project, or all rate payers?).

Overhead vs Underground Construction

Both overhead and underground electric distribution lines are commonly found in the urban forest. The dominant construction trend in urban areas is to place new urban and residential utility systems underground. Both categories of construction have their own unique characteristics. Generally, underground facilities in urban areas are more expensive to build. The materials used in underground construction are considerably more expensive, as is the effort required during construction. In addition, unlike overhead lines which are easily upgraded, underground facilities are usually designed and built with capacity to serve the probable future load. The current shift away from direct-bury to conduit construction methods allows greater flexibility to upgrade. However, initial costs are high due to increased material costs for the conduit pipe and vaults, and the increased labor required for pulling cable into the duct system. Increased costs and underused plant capacity are accepted trade-offs with underground system designs.

Differences in the practical aspects of underground and overhead construction can also be notable. Overhead construction tends to be predictable because most construction problems can be anticipated. Underground construction in urban and developed areas can be a challenge. Competition with other utilities for space underground can be as intense as that found in the world of overhead distribution lines, where wires and trees compete to occupy the same space. The variable nature of manmade urban soils is another challenge. Coarse fill of construction and demolition debris can create problems during underground trenching, and particularly for trenchless construction technologies discussed later in this paper. Finally, the cost of site restoration cannot be overstated. Restoration costs can be the greatest share of the total cost of an underground construction project. Mature landscapes, structures, and pavements can be very difficult and expensive to adequately restore. The impact of restoration issues is the greatest in open trench construction, is less for overhead projects, and can be negligible on trenchless underground projects.

Underground construction eliminates trees as a cause of outages. Although the resulting improvement in reliability can be dramatic, underground systems are not without their own problems. The life of some underground cables is considerably shorter than expected, and accidental dig-ups are common. While overhead outages are less frequent, underground outages often are longer in duration due to the difficulty of locating faults, and they are more expensive to repair. The faulted cable must be excavated and repaired, and the site restored, again at considerable expense.

Despite these issues, underground construction is often the only acceptable method for new construction in urban and residential areas. Regulation, franchise requirements, and operation tariffs establish this preference in many cases. Despite improvements in construction methods, technology, and materials, underground construction generally is more costly than a comparable overhead line. Increased coordination between all the utilities competing for space in joint occupancy trenches, and the sharing of trenching and restoration costs is reducing the economic impact of underground construction for all utilities. The current trend on large construction projects is for the developer or general contractor to provide the trench and restore the site. This reduces the utility's costs.

Overhead Design Alternatives

A variety of overhead construction designs alter the space requirements of distribution lines and their impact on trees. This discussion contrasts these alternatives with *open construction* (bare wire and crossarms) Even within this benchmark reference, variation can be found. The placement of the system neutral either up on the arm or below, and the proximity of the hot phases to trees can change the performance and reliability of open construction (Figure 1).

Alley or *wing arms* (framing a crossarm and braces off one side of the pole in an inverted "L" configuration), can gain several feet of side clearance. Adding a wing arm requires some conductor slack, and may also require a down guy to compensate for offset mechanical loads on the pole. Of course, the structural integrity of the adjacent tree will have a major influence on reliability. Clearance requirements between conductors and trees remain the same as for conventional open overhead construction (Figure 2).

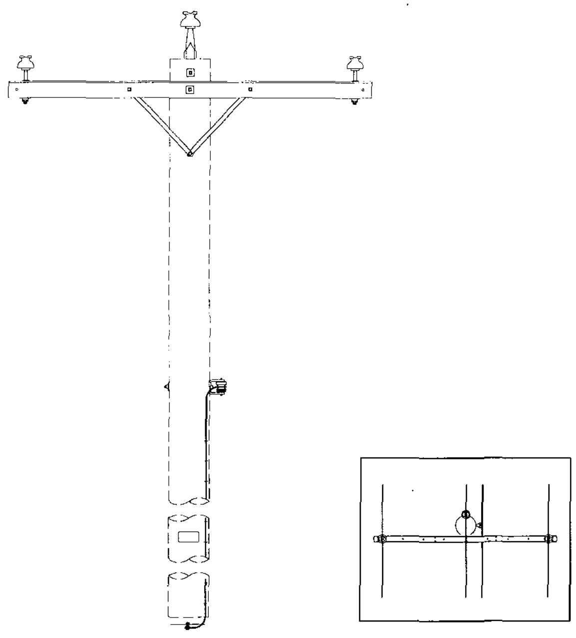

Figure 1. Open construction with bare wire and crossarm.

Distribution lines are sometimes rerouted around problem trees by simply jogging across the street with a pole or two and then back again.

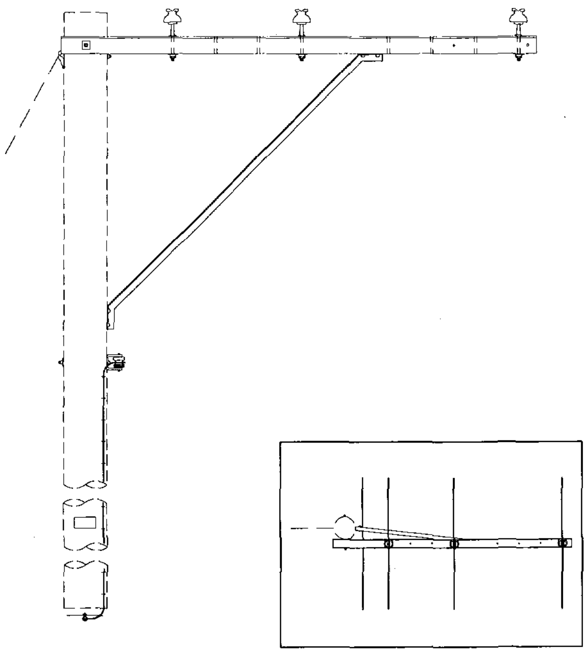

Figure 2. Alley or wing arm construction.

Obviously, this is a solution only if the land across the street has no tree problem.

Compact construction framing, which has seen increased popularity in recent years, moves the bare conductors closer together. This can reduce the clearance space required in the crowns of trees. However, the reduced spacing of the conductors may increase the probability of phase-to-phase outages. In other words, a smaller branch is capable of causing an electrical short between two wires (Figure 3).

Covered overhead primary (COP) is a departure from the previously discussed bare wire designs. COP can serve as the conductor in either conventional crossarm construction or compact designs. Conventional bare conductor designs rely on physical separation and the dielectric strength of air to provide sufficient insulation. "Tree wire" COP conductors are covered with polyethylene. While usually not code-rated insulation, the covering does have some insulating

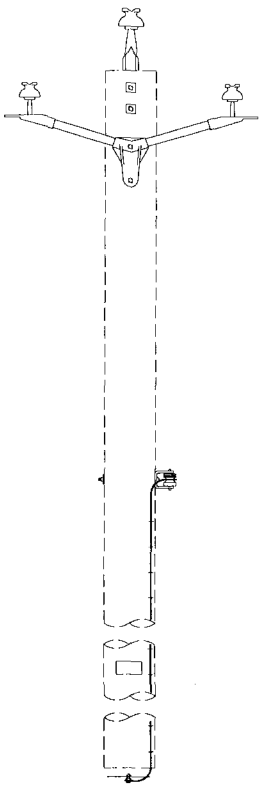

Figure 3. Compact construction.

qualities, so tree branches are much less likely to cause a phase-to-phase or phase-to-ground fault. But, because the insulation is unrated, an outage is likely if an offending branch remains in contact with the line over several days or weeks. As leakage current flows from conductor to the tree through the covering, the covering's dielectric strength is lost. Ultimately a fault will occur. Branches in contact with COP conductors need to be removed in a timely manner. Therefore, COP construction requires more frequent patrols, and line clearance tree work remains necessary. The industry's practice generally is to apply the same tree-conductor clearance requirements to COP as it would to bare wire construction.

Spacer systems manufactured by Hendrix (Figure 4) can be thought of as a combination of two ideas: covered wires and compact configuration. A spacer system brings the individual phase wires very close to each other, achieving a compact configuration that reduces the crown area of a tree affected by the distribution line. The conductors used in spacer systems have a thicker covering than tree wire. The increased covering thickness results in increased dielectric strength. Though not a rated insulation, spacer cable's ability to reduce tree-related outages is well recognized. As with other COP construction, the dielectric strength of the covering is lost through leakage at points of direct contact by trees The ultimate result will be a fault as the covering burns through. Line clearance tree work is still necessary. The industry is debating whether less tree/conductor clearance can be tolerated. A recent survey by the Edison Electric Institute indicated that the industry felt by a three-to-one margin that the same tree/conductor clearances required on bare wire construction should apply to spacer cable(Figure 5).

Because COP uses a covered conductor, the power system may be unable to sense a downed wire. With conventional bare wire construction, protective relays will sense a fault and operate protective sectionalizing equipment, de-energizing the faulted circuit. The same cannot be said with covered conductors. The probability increases

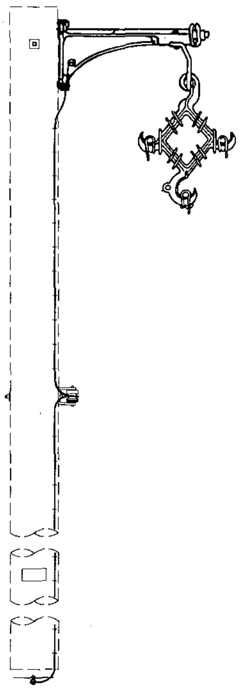

Figure 4. Aerial ("Hendrix") spacer system.

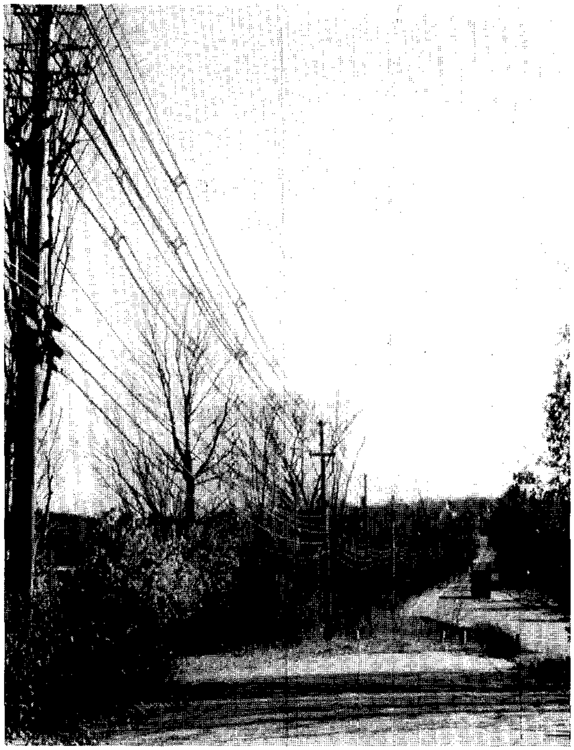

Figure 5. Four circuits of spacer system construction.

that lines could be down and energized. Because the covering on neither COP nor spacer cable can be considered insulation, a person may suffer serious injury when coming in accidental contact with the downed line.

Aerial cable systems, while having only limited application, deserve mention. Basically they can be thought of as underground cables strung overhead. Just like underground cables, they are shielded and have fully rated insulation. They typically are strung pole to pole, wrapped in a bundle, much like the triplex commonly used for residential services. Aerial cable has been used in heavily stocked urban forests where utility facilities are sited on back lot lines and alleys. Tree-caused outages are nearly eliminated. Clearances are only a concern from the standpoint of mechanical loading and abrasion (Figure 6).

Underground Installation Alternatives

Converting an existing overhead system to underground is expensive. Beyond the obvious issue of replacement of conductors, underground conversion requires other new plant equipment such as transformers and switches. This section describes several underground construction techniques.

Figure 6. Aerial cable system.

Cable plowing involves drawing a heavy knife or plow through the soil profile from the surface to the desired cable placement depth. Cables are fed into the void created behind the plow. The plow is capable of placing cables to depths in excess of 30 inches. Plowing distribution cables at depth requires substantial power and continuous access across the site by heavy equipment. This technique is best suited to rural areas where underground obstructions, including other elements of utility infrastructure, are minimal, and where site disturbance is acceptable. Because of these limitations cable plowing is unsuitable in most urban areas. It is, however, a cost effective method where it can be used.

Open trench underground construction is the most common method used in new urban and residential utility construction today. A trench is excavated using a backhoe or other mechanical trencher. Conduits or cables are placed in the trench, and the trench is backfilled. Both techniques, plowing and open trench, place the cables via direct excavation through the soil profile. Any intercepted tree roots are severed. Therefore, placement of the trench in relation to trees is critical. Open trenching can offer a joint utility trench occupied by electric, gas, telephone, cable television, and other utilities. Joint occupancy reduces the cost of construction to any one utility and confines the impact of underground utilities to a smaller area. A carefully designed trench route can minimize the adverse effects of trenching on trees (Figure 7).

Wheel trenching with a "rock saw" trencher in the street or at the shoulder of the road, can minimize the impact of underground construction on trees, particularly in well-established landscapes. This technique cuts a narrow trench through the soil profile, making this type of excavation suitable for the road shoulder or out in the street. It is particularly effective where restoration costs for established landscaping would be excessive. Again, the trench should be routed to avoid major tree roots (Figure 8).

Trenchless underground construction methods vary, but they can be divided into two groups:

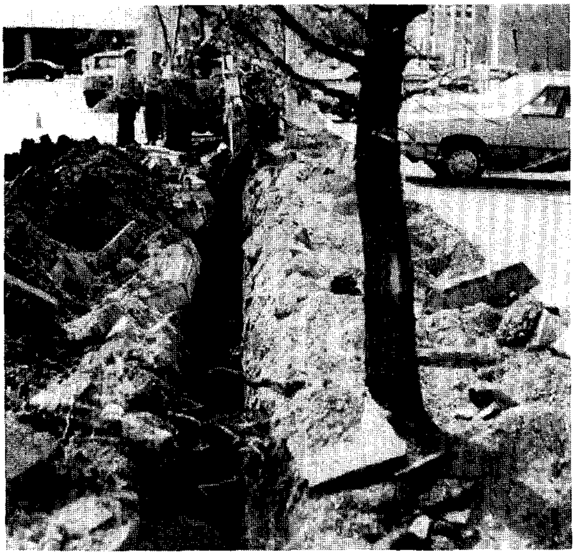

Figure 7. Open trench construction.

those technologies with limited ability to be directed, and boring methods with directional steerage control.

"Unguided" trenchless technologies include pneumatic "moles" that hammer their way horizontally through the soil, and steel rods that are driven by hydraulic rams through the soil. Both unguided methods work by compressing displaced soil out of the way. Conduit or cables are pulled in behind the rod or mole, into the void created as it is driven through the soil profile. Note that while these techniques are called "unguided," an experienced operator can direct the alignment of the

Figure 8. Wheel trench construction.

tunnel, especially with rod pushers, which have a fair degree of "steerability." Both techniques require the excavation of launching and recovery pits at the beginning and termination of the tunnel. Tunnel length is also somewhat limited compared to some of the guided boring techniques. However, both moles and rod pushers are well suited to short distances such as road crossings and tunneling under high-value trees (Figure 9).

Guided boring trenchless technology represents the state of the art in underground construction. It differs from unguided methods in that the tunnel is bored, meaning soil is excavated, typically using a mechanical cutting head and or a high-pressure fluid jet. This technology includes boring rigs that are highly steerable, allowing an experienced operator to "fly" the cutting head through the soil profile, effectively avoiding obstacles. However, it is standard practice to "pot hole" or excavate, at sites where the boring head intercepts other elements of the underground infrastructure or other obstructions. Launching and recovery pits are also necessary. As with the other trenchless technologies, conduit or cable is drawn into the tunnel. The success of trenchless boring is highly dependent on soil structure. The presence of aggregate (natural or manmade) material can dramatically reduce production or make the technology impractical (Figure 10).

Appendix, Table 1 gives the pros and cons of engineering solutions for underground distribution lines. Table 2 gives the same foroverhead distribution lines.

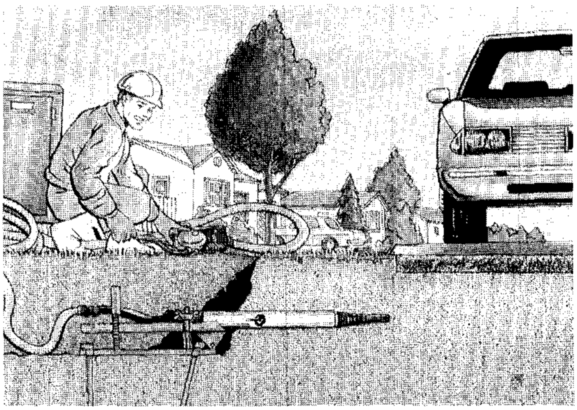

Figure 9. Unguided trenchless construction -- mole method.

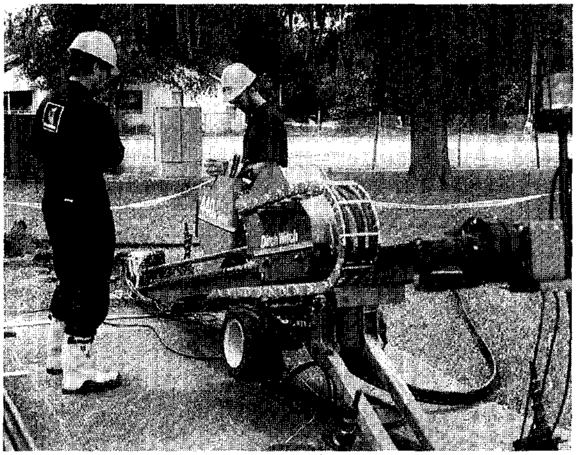

Figure 10. Guided boring construction.

Conclusions

The opportunity to consider alternatives to bare open wire overhead lines is greatest at the time of original construction, or at times when the system is changed for other reasons. Urban and utility foresters are encouraged to recognize these windows of opportunity.

The construction alternatives presented here more often than not will come at a premium cost. At times, these costs may be justified. On the other hand, we have a responsibility to recognize that heroic efforts to preserve trees and the associated expense may not be appropriate in all cases.

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Résumé. Les entreprises de services électriques élaguent de façon cyclique les arbres dans le but de maintenir une zone de dégagement entre les branches et les conducteurs électriques aériens. *Des méthodes alternatives de construction* des lignes électriques peuvent réduire l'impact des lignes sur les arbres. La meilleure opportunité pour introduire des schémas alternatifs demeure au moment de la construction originale ou lorsque des changements sont réalisés sur l'infrastructure existante du réseau.

Zusammenfassung. Die Elektrizitätsgesellschaften schneiden regelmäßig Bäume zurück, um Freiraum zwischen den Ästen und den elektrischen Überlandleitungen zu gewähren. Alternative Methoden der Verlegung von Leitungen können den Einfluß der Leitungen auf Bäume reduzieren. Die größte Gelegenheit zur Durchsetzung alternativer Gestaltung ergibt sich im Moment der Leitungsneuverlegung oder wenn die existierende Infrastruktur verändert wird.

Appendix. Table 1

The Pro's and Con's of Engineering Solutions - Underground Distribution Lines

Alternative	New Constr. cost relationship	Retro Fit Issues	Operational Issues	Safety Considertion	Net effect on Reliability	Impact on Trees
OH Wing Arm	100-105	Requires sufficient conductor slack. May require additional guying	Access from pole reduced, may require use of a bucket truck	No significant difference	No Significant difference	Clearances change spacially (+ or - 4 ft.)
OH Re-route	105-125	Requires new pole, additional conductor, and guys	No significant difference	No significant difference	Reduction or elmination of tree related conflicts	Elimation or conflict shift to alternate site?
OH Compact Configuration	95-110	Electical clearance codes may require new poles. Shorter spans	Reduced phase spacing can restrict working clearances	Reduced working clearances	Can result in reduced reliabilty due to phase-phase outages	Potential reduction in total crown area affected due to tighter spacing
Covered OH primary a.k.a. "Tree Wire"	110-120	Increased mechanical loads may require hardware/pole upgrades	Work practices such as use of working grounds are more difficult. Requires regular patrols. Coating requires increased work for splices and taps	Reduced ability of system protection to detect downed and energized conductors. Presents a risk to public safety.	Reduction in branch failure caused phase-phase faults.	Not considered a means to eliminate line clearance tree work.
Aerial Spacer Cable a.k.a. "Hendricks System"	120 - 200	Increased mechanical loads likely to require some hardware and pole upgrades.	Dramatically reduced phase spacing and conductor coating may increase working difficults. Requires regular patrols. Covering requires increased work for splices & taps	Reduced ability of system protection to detect downed of energized conductors. Heavy conductor covering reduces potential risk.	Significant reduction in branch failure caused phase-phase faults	Reduction in total crown are affected due to tighter spacing Debate over reductions in clearance required
Aerial Cable (true cable)	200+	Increased mechanical loads will require significant hardware and pole upgrades	Insulation requires increased work for splices and taps. Work it like UG cables. May require outage to make taps.	Reduced ability of system protection to detect downed & energized conductors. Rated insulation reduces risk of adverse effect on public safety	Dramatic reduction in branch failure caused phase-phase faults	Reduced clearance requirements. More a mechanical than electircal clearance issue.

Cost relationship is provided as a general relative cost. No cost units are implied. The intent is to provide a comparative cost reference. All values are stated as related to bare overhead 3 Ø distribution primary (100)

Appendix. Table 2.

The Pro's and Con's of Engineering Solutions - Overhead Distribution Lines

Alternative	New Constr. cost relationship	Retro Fit Issues	Operational Issues	Safety Considertion	Net effect on Reliability	Impact on Trees
UG, cable plow	200+	Entirely new plant including transformer, secondary & services may be required. Impractical in developed areas	Limital application as plant and UG infastructure becomes more complex	None	Elimination of tree as a significant cause of interruption	Highly variable dependent on where cable is plowed in relation to trees root system
UG, open trench	200-400+ *highly dependent on site restoration costs	Entirely new plant including transformer, secondary, services may be required. Site restoration may be a major expense. High level of site disturbance	Excellent opportunity to share expensed with other utilities Joint trench requires high level of coordinations and coopertion. Note: trench excavation may not be utility's responsibilty	None	Elimination of tree as a significant cause of interruption	Highly variable , dependent on where trench is dug relative to trees root system.
UG, wheel trench	200-300 *highly dependant on site restoration costs	Entirely new plant including transformer, secondary & services may be required. Increased difficulty when significant other UG infrastructure is present	Requires cooperation by gov't agency w/jurisdiction over streets and public ROW	None	Elimination of tree as a significant cause of interruption	variable, generally low to no adverse impact
UG trenchless unguide push rod or mole	300-400+	Entirely new plant including transformer, secondary & services may be required	Generally requires significant disturbance at launch & recovery pits. Highly dependant on soil conditions. Pits required at direction changes & "pot holes" at utility crossings. (best suited to short runs) Low production rates	None	Elimination of tree as a significant cause of interruption	Little to none provided launch & recovery pits sited properly.
UG trenchless guided bore	200-400+	Entirely new plant including transformer, secondary & services may be required	Highly dependant on soil conditions "Pot holes" at ulility corssings. Low production rates. Less suited to high plant instensity installations	none	Elimination of tree as a significant cause of interruption	Little to no adverse impact.

Cost relationship is provided as a general relative cost. No cost units are implied. The intent is to provide a comparative cost reference. All values are stated as related to bare overhead 3 Ø distribution primary (100)