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Distribution Grid Resiliency: Vegetation Management

2015 TECHNICAL REPORT

Distribution Grid Resiliency: Vegetation Management

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We Energies	Kelley Knoerr
Xcel	Fletcher Johnson

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American Electric Power Service Corp.	Charles V. Talley
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Abstract

This report describes the results of the vegetation management (VM) task of EPRI's three-year distribution grid resiliency (DGR) initiative. The VM task objectives were to 1) better understand the mechanisms of vegetation-caused damage to distribution infrastructure during storms, 2) gather and document utility practices related to VM programs, and 3) identify new options for VM programs that could result in less system damage during storms and overall greater resiliency.

EPRI worked with participating utilities on six VM research activities, which are summarized in this report: 1) an industry survey, 2) a literature review, 3) a series of interviews with VM program managers and subject matter experts, 4) a study of the force of impact on distribution equipment from tree failures, 5) a damage prediction modeling study, and 6) a compilation of practices gathered from the program interviews in a Microsoft One Note repository to help facilitate comparative investigation of the VM research results. The full reports of these activities are attached as appendices. The report provides the results of this effort and recommends gathering of specific types of data in the future to prioritize VM resiliency improvements.

Keywords
Distribution grid resiliency
DGR
Enhanced tree trimming
Hazard tree removal
Vegetation management

Executive Summary

EPRI undertook a three-year Distribution Grid Resiliency (DGR) research project to study six tasks of most importance to utilities to enhance distribution resiliency. This report describes the results of the vegetation management (VM) DGR task.

Background and Objectives

Tree-related outages are one of the most prevalent, if not the leading cause of interruptions and damage affecting the distribution system during major storms. As the impact of outages has become more severe in recent years, the focus on VM has heightened. While developing and implementing an effective VM approach is important to utilities, a challenge utilities face is choosing which VM programs to implement to ensure that they are making the most informed investment decisions.

The objectives of the VM task were to 1) better understand the mechanisms of vegetation-caused damage to distribution infrastructure during storms, 2) gather and document utility practices related to VM programs, and 3) determine if there are new options for VM programs that could result in less system damage during storms and overall greater resiliency.

To address this challenge, EPRI conducted a number of research activities for this task and summarized them in this report. The studies include an industry survey, a literature review, a series of more in-depth interviews with VM program managers and subject matter experts, a study of the force of impact on distribution equipment from tree failures, and a damage prediction modeling study. EPRI also compiled practices gathered from the program interviews in a Microsoft One Note repository to help facilitate comparative investigation of the VM research results.

Results

In the industry scanning efforts, studies, and compilation of data in the repository, the DGR project team found that there are no new techniques, practices, technologies, or equipment regarding VM practices that the industry needs to adopt. The current VM practices used are in fact the industry's leading practices. Overall, the industry takes advantage of increasing opportunities for information sharing concerning VM techniques and best practices across the industry.

Another observation is that the same VM techniques used for reliability are also used for resiliency. In some cases, VM for resiliency means expending more resources, but using the same techniques. Research revealed that most utilities' approach to VM to maintain day-to-day reliability differs from their approach to major storm resiliency only in degree. The recommended VM options therefore, are the same two main VM practices that many utilities are already using: enhanced tree trimming (ETT), and hazard tree removal.

Quantifying the costs and benefits of VM options is problematic due 1) inherent variability in VM itself, and 2) limitations in data collected by utilities. Regarding inherent variability, VM costs and benefits vary considerably from utility to utility due to variation in tree exposure, tree types, tree growth rates, tree density, trimming specifications and contracting approaches, and the presence of vines. Regarding data limitations, data gathered by utilities and presented to EPRI poses some limitations when used to evaluate the costs and benefits of resiliency options. Most of these limitations are due to the fact that the data is incomplete in some way – it does not provide all of the information needed to evaluate option costs and benefits.

The incomplete nature of this utility data is understandable. Most of the data involves activities during outages – during the restoration period. During this period, utilities are immersed in restoring service as quickly and safely as possible to as many customers as possible. During this busy time, when utility personnel and resources are strained to their limits, the additional burden of gathering data on these outages is difficult. Even with the best of intentions, data gathering during outages must be relegated to second priority, behind the restoration itself.

Gathering outage data after restoration is complete is possible, but complex, and requires dedicated resources to accomplish. Assembling data from various sources after the fact does not guarantee that all needed data can be gathered. Some of the data needed simply may not have been recorded in any form and cannot be inferred from the information that exists following restoration of services.

In order to prioritize VM resiliency improvements, more detailed information needs to be collected about the individual outages that occur. This data can be grouped into the categories of basic, operational, construction, and vegetation information. EPRI recommends collection of quantitative data that enables determination of the costs and benefits of specific VM practices. This report details the types of data needed.

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Section 1: Introduction

This section provides an overview of the Distribution Grid Resiliency (DGR) project, describes the motivation for and scope of the Vegetation Management (VM) task, and outlines the organization of this report.

Overview of the Distribution Grid Resiliency Project

When hurricanes, ice storms, and other significant weather events occur, the electric distribution system is vulnerable to damage and outages. The impacts and costs of these storms can be exorbitant, given the critical nature of electric power systems and their interdependency with other critical infrastructures, such as natural gas and oil, water supply systems, banking and finance, transportation, and others. The frequency and severity of recent storms has focused industry attention on the need to enhance the resiliency of the distribution system so that it will experience less damage during these events. Distribution resiliency improvements can include changes in design standards, construction practices, maintenance and inspection practices, and restoration practices. The appropriate set of activities to harden a distribution system is utility-specific. A significant challenge for utilities is to determine the optimal set of distribution improvements that are acceptable within their regulatory framework, address their particular system parameters and weather characteristics, improve reliability, enhance resiliency, and enable more rapid recovery during and after extreme events.

In response to this challenge, EPRI gathered input and feedback from utility experts on distribution resiliency around the country, and based on this direction, established a three-year research project on grid resiliency.

The overall goal of this research is to create actionable information that utilities can apply to enhance the resiliency of their distribution systems to major weather events. Resiliency can encompass the following forms:

- Damage prevention – Hardening of overhead lines to resist damage, undergrounding, and vegetation management.
- Easier repair – Maintenance, retrofits, or new designs to facilitate damage repair; limit pole damage and cascading failures.
- Isolation and reconfiguration – Isolation of damage to minimize the number of customers affected.
- Recovery – Improved technologies and processes to accelerate restoration.

- Community sustainability – Improved communications with customers and the community (for example, estimated restoration times); maintaining electric supply to critical infrastructure such as traffic signals, prisons, hospitals, and cell towers.

The project is organized around the following six DGR tasks (see Figure 1-1):

DGR Task 1 – Overhead Structure Resiliency: The objective of this task is to identify options for improving the resiliency of overhead distribution infrastructure via hardening, graceful degradation, and ease of repair. This task is described in a separate EPRI report [1].

DGR Task 2 – Vegetation Management: The objectives of this task are to better understand the mechanisms of vegetation-caused damage to distribution infrastructure during storms; gather and document utility practices related to vegetation management (VM) programs, specifically related to storm damage; and determine if there are new options for VM programs that could result in less system damage during major storms. This task is the subject of this report.

DGR Task 3 – Undergrounding: The purpose of this task is to compile representative cost data on the undergrounding of distribution infrastructure so that utilities may better assess this option for improving distribution grid resiliency in major storms, such as wind and ice storms. This task is described in a separate EPRI report [2].

DGR Task 4 – Modern Grid Technology: The goals of this task are to document the challenges and opportunities that key modern grid technologies present with respect to distribution grid resiliency; gather and document utility practices intended to manage these challenges, and identify and communicate opportunities that can be exploited for the benefit of the industry; and identify and scope specific proposals for EPRI research to overcome difficult-to-manage challenges, or further exploit high value opportunities. This task is described in a separate EPRI report [3].

DGR Task 5 – Storm Response Practices: The goal of this task is to leverage the collaboration that exists among utilities to identify, document, and share leading practices for major storm response. This task is described in a separate EPRI report [4].

DGR Task 6 – Prioritization of Options: In this task, EPRI aims to provide utility decision makers with guidance for prioritizing and selecting among the resiliency options identified in the other five distribution grid resiliency (DGR) project tasks. This task is described in a separate EPRI report [5].

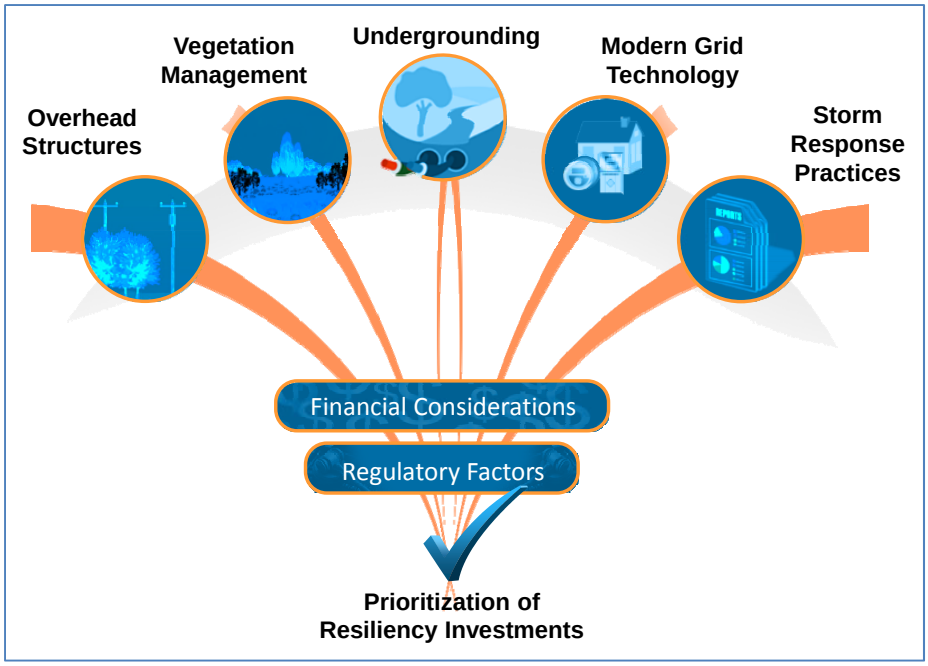

Figure 1-1
The six DGR tasks

The following table lists the titles and product identification (PID) numbers for the six DGR reports.

Table 1-1
DGR reports and publication numbers

Report	PID Number
Distribution Grid Resiliency: Overhead Structures	3002006780
Distribution Grid Resiliency: Vegetation Management	3002006781
Distribution Grid Resiliency: Undergrounding	3002006782
Distribution Grid Resiliency: Modern Grid Technology	3002006783
Distribution Grid Resiliency: Storm Response Practices	3002006784
Distribution Grid Resiliency: Prioritization of Options	3002006668

Motivation for the Vegetation Management Task

A survey of eight utilities found that approximately 80 percent of outages are due to tree during major events. Vegetation management consumes a large percentage of the maintenance costs for distribution systems in areas of the country with significant vegetation. These two facts present a high motivation for utilities to optimize their VM approaches.

The motivation of the VM research task is to help utility companies reduce the impact of vegetation-caused damage to the distribution grid during severe weather. The VM research task established these objectives:

- To better understand the mechanisms of vegetation-caused damage to distribution infrastructures during storms.
- To gather and document utility practices related to VM programs, specifically related to storm damage.
- To determine if there are new options for VM programs that could result in less system damage during major storms.
- To gather and document cost and benefit information for VM programs.

The VM research task aimed to evaluate the best practices of VM, as well as document and share current VM practices being utilized across the industry. The goal of this work is to provide a knowledge base of information about VM practices that utilities can use to identify and adapt industry-leading practices to their VM programs.

Scope of the Vegetation Management Task

The research conducted during this task initially focused on selected VM processes that were considered a priority during a series of pre-project (2012) industry workshops. Specifically, the research focused on the following areas:

- Evaluation of results from previous storms
- Characterization of tree program specifications and contract attributes
- Correlation between trim specifications and actual damage
- Identification of customer outreach programs that materially change tree exposure to smaller or more wind-resistant tree species
- Use of tree growth restrictors
- Identification of emerging trimming practices that help limit tree damage during major weather events

As the project evolved and industry scanning activities (literature review, utility interviews, and studies) revealed insights, the scope was expanded to include identification of the following:

- Industry trends that have led to wide adoption across the industry of best practices for VM
- Limitations in outage data gathering that complicate quantification of VM practices evaluation
- Data gathering needs to improve this quantification of VM practices evaluation
- Challenges in gathering this needed data

Organization of this Report

The following list provides a brief summary of the sections in this report.

1. Introduction – Provides an overview of the DGR project, a three-year research project on grid resiliency.
2. Industry Scanning Activities – Provides a summary of the industry scanning activities conducted for the VM task: a preliminary utility survey, a literature review, and more in-depth subject-matter-expert interviews.
3. Force of Impact from Tree Failures – Summarizes an investigation of the destructive potential of falling tree branches impacting overhead distribution lines.
4. Modeling Weather Damage Using VM, LiDAR, and Infrastructure Data – Summarizes an EPRI co-sponsored study that the University of Connecticut (UCONN) conducted on the use of VM, LiDAR, and infrastructure data to model weather damage on distribution systems.
5. Assessment of Industry VM Practices and Data Collection Needs – Provides a summary of the investigated options for this task, describes the broad adoption of industry VM best practices, identifies data limitations in quantitatively evaluating VM practices, identifies data collection needs to enable this quantification, and identifies challenges in gathering this needed data.
6. Conclusions and Recommendations – Provides a summary of the key findings from the three-year study and lists recommendations.
7. References.
8. Appendices – Appendix A is a list of acronyms used in this report. Appendices B through G contain the complete studies summarized in this report and additional information.

EPRI compiled practices gathered from the subject-matter-expert interviews in a Microsoft OneNote repository to help facilitate comparative investigation of the VM research results. The "EPRI Utility Vegetation Management Practices Repository" is available on a DVD entitled "EPRI Distribution Grid Resiliency Project; Year 1, Year 2, and Year 3 Deliverables," EPRI 3002007075.

Section 2: Industry Scan

Overview

The VM Task 2 task force conducted three industry-scanning activities:

- A preliminary survey of utilities on VM practices (conducted in 2013)
- A literature search of current VM practices (conducted in 2013)
- A more in-depth survey of utility VM practices (conducted in 2014)

The 2013 VM survey sought to characterize the state of VM programs in participating utilities through 24 survey questions on how programs were administered, with what resources, and how utilities were dealing with vegetation-specific issues. The survey was designed by EPRI with input from Davies Consulting LLC and from the utilities participating in EPRI's DGR project. This section summarizes the results of this survey, and Appendix B includes the full report on the preliminary survey [6].

The 2013 literature scanning activity reviews the ANSI and ISA standards that have been established for VM practices since 2006 and various VM management plans published by utility companies. This section summarizes the results of this survey, and Appendix C includes the full report on the literature review [7].

The third scanning activity was development of an interview guide and conduct of interviews with VM program managers to gather a more in-depth assessment of leading VM practices. This section summarizes the results of this survey, and Appendix D includes the full report on the in-depth interviews [8].

Summary of Vegetation Management Practices Survey (2013)

The VM practices survey addressed one of the primary objectives of the DGR research project, which is to gather and document utility practices related to VM programs, with a particular focus on options for improving system performance in major events.

For this objective, EPRI conducted an industry survey that covered five main areas of focus, or categories, as follows:

- **Governance, Funding and Regulatory Coordination** – This category covered questions about budget decision making, regulatory relations, and identifying the function within an organization that is responsible for VM implementation.
- **Program Planning and Measurement** – This category focused on pre-work planning and inspections prior to routine line clearing, and measuring the cost-effectiveness of results.
- **Program Attributes** – This category focused on the basis of program scheduling and planning, in particular related to controlling tree growth and removal.
- **Contracting Approach** – This category focused on how VM contractors are managed and paid and the maximum number of contract tree crews assigned to a VM field supervisor.
- **Use of Technology** – This category focused on determining the technologies that are used to help plan, schedule, or administer the VM program and how the technology is used.

The VM survey was conducted using Survey Monkey, a web-based survey application, between August and November of 2013. The survey was sent to the utility advisors for the DGR VM task force. Twenty-six utility companies responded to the survey.

Survey Findings

The VM survey categories showed the following predominant characteristics and practices among utility companies.

Governance, Funding and Regulatory Coordination

- The majority of utilities run VM programs from within Operations, with some using Operations supported by Asset Management or another corporate function.
- For the single driving factor determining VM budgets, finance, trim cycle and regulatory mandates were rated equally. However, examined in combination with other factors, trim cycle became a dominant theme.

Program Planning and Measurement

- Most of the utility companies patrolled and inspected feeders as part of the planning process. Ten companies also conducted additional species analysis as part of planning.
- Some companies attempt to quantify the benefit associated with the money spent on VM. However, one-half of the companies do not attempt to analyze their spending.

- One-half of the companies do not actively conduct customer satisfaction surveys. Most of the other one-half of companies incorporate VM-related customer satisfaction questions into their annual customer satisfaction surveys.
- Just over one-half of the companies conduct forensic post-storm analyses of tree failures following a major event.

Program Attributes

- The majority of companies trim to cycles that are between three and five years.
- The majority of companies place equal emphasis on trimming the backbone system and the lateral systems.
- Almost two-thirds of the companies do not trim the secondary, or only trim it when it runs below the primary.
- The majority of companies place clearance height at 10 feet.
- The majority of utilities have hazard tree programs in which such trees are removed.
- One-half of the companies use tree growth regulators to slow the growth of tree limbs.

Contracting Approach

- Most companies employ a contracting approach that uses a combination of fixed-price contracts for scheduled cycle trims and time and equipment for small circuits and reactive trimming.
- Over one-half of the companies allow their internal VM staff to supervise 16 or more contractor tree crews in the field.

Use of Technology

- Most utility companies use geographic information systems (GIS) in some way to plan or manage their VM programs.

Key Trends – Activities Receiving More Funding

The survey revealed that more than one-half of the companies are changing their VM options due to increased storm activity in recent years and recognition that trees are a major cause of outages. The VM options that are receiving increased funding and activity are the following:

- Implementing hazard tree programs
- Modifying (increasing) clearances in key areas
- Changing the basis by which they prioritize circuits and/or determine cycle for groups of circuits
- Getting their systems on cycle or onto a shorter cycle
- Using technology to perform analysis and track metrics for continuous improvement

Hazard Tree Programs

Hazard trees are those trees that pose a risk to utility equipment because they are close enough to come in contact with the system if they were to fall, and likely to fall because they are dead or in poor health, or if soil conditions are such that the tree could uproot. All but three of the utilities have hazard tree programs in which such trees are removed.

The majority of utilities define the territory in which they will identify hazard trees in a way that takes the height of the tree into consideration. Eleven companies considered any tree with a height greater than the tree's distance from the centerline of the feeder. Seven companies focused on a narrower zone, in which the tree is tall enough to touch the conductor if the tree were to fall.

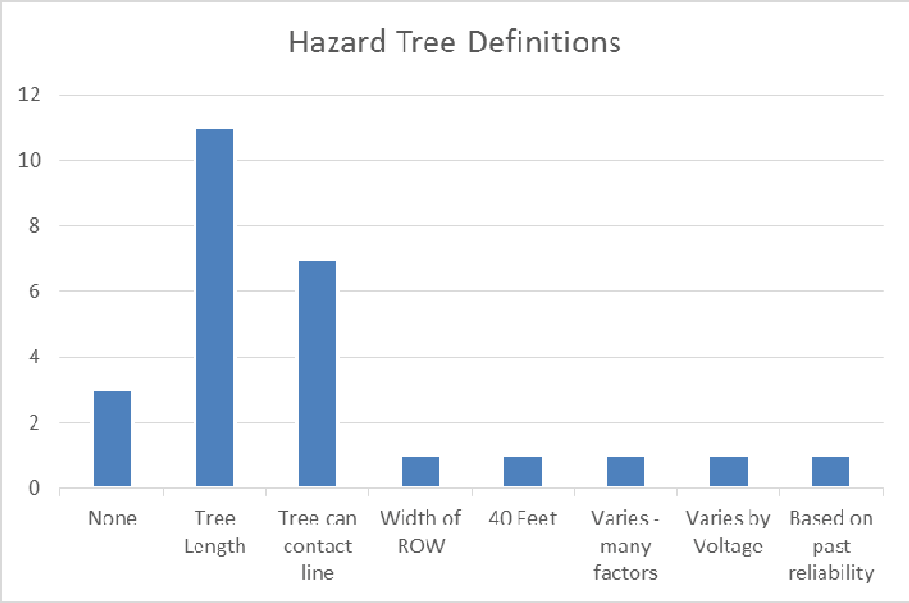

Figure 2-1
Criteria for identification of hazard trees

Related to hazard tree programs are efforts to analyze trees affected by infestations. Eleven companies do not perform any analysis relating to insect impact, although many of these companies are in areas not affected by infestations. Another 11 companies perform forensic analyses on fallen trees and branches when trees interrupt power in an area known or suspected to be infested. The remainder of the companies rely on locally conducted studies to determine which areas are vulnerable to insect damage. Only five utilities identified techniques for contending with the emerald ash borer beetle, but the tactic they all had in common was to remove and destroy affected trees.

Clearance Programs

Clearance is the distance above, below, and to the side of conductors that should be kept clear of any form of vegetation. Utilities strive to keep this zone clear by trimming several years' growth back from the conductors when branches are on the cusp of encroaching on the zone. Approximately one-third of companies define larger clearances for higher voltages. Two companies have declared different clearances for backbones versus laterals.

The majority of clearances are set at 10 feet, with values ranging from 5 to 20 feet. Some companies have declined to define a clearance, but focus instead on describing a process whereby the arborist cuts according to their expertise and judgment, removing an amount of wood appropriate for the species of tree, the voltage of the circuit, and time expected to elapse before the next trim.

One-half of the companies use tree growth regulators to slow the growth of tree limbs for VM.

Trim Cycle Programs

It is a fairly common practice to establish a trim cycle of 3 to 4 years and commit to making sure the entire system is trimmed in that timeframe. In some cases, a utility identifies different trim cycles for different parts of the system. Whether there is a single period for the entire system or a number of declared variants, this is known as trimming to a cycle. The overwhelming majority of companies trim to cycles that are 3 to 5 years in length.

Only one company, with very short clearances, reported a two-year cycle. Only three companies declared cycles greater than 5 years, although another four companies stated they were not on a cycle, meaning their budget was insufficient to proactively trim all circuits in the system on a schedule, and instead focused on reactive trimming.

A consideration entertained by some jurisdictions has been to accelerate the work around the backbone while focusing less effort on laterals. The underlying driver of this practice is the probability that backbone outages have the potential to have greater impact on reliability than those on the laterals. The survey found that many companies are reluctant to execute this approach as it poses significant operational challenges. Of the 26 participating companies, only one trims their laterals on a different schedule than their backbones.

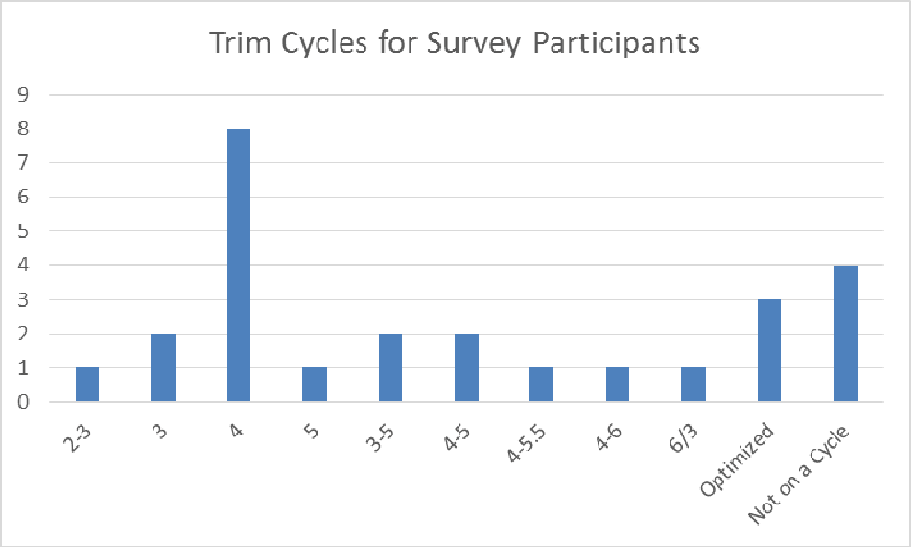

Figure 2-2
Survey participants' backbone trim cycles

Technology Programs

Only six companies are not using GIS in some way to plan or manage their VM programs. Of the twenty companies using GIS, one stands out in terms of the extent of its GIS utilization, where such information as tree species and numbers, work and payment tracking, weather data and more are factored into the decision making process. The majority of the companies use information systems for defining and tracking work.

Summary of Vegetation Management Literature Search (2013)

EPRI conducted a literature review of current practices specific to Integrated Vegetation Management (IVM) that support DGR in 2013. This review highlighted applicable standards, risk mitigation and leading VM practice concepts. The intent of this review was to provide DGR project participants with an understanding of IVM and its leading practice applications.

The specific objectives of this literature review were as follows:

- Identify IVM initiatives that can be utilized by other utilities.
- Identify principles of risk management that are incorporated into IVM.
- Identify asset management processes and modern technologies that are being utilized as part of IVM programs.
- Identify initiatives that are being used to address DGR that are incorporated into IVM programs.

There were several growing initiatives within the utility industry that included new options or different approaches to addressing vegetation management. They are grouped in the general categories of process enhancements, technology utilization, and tree growth regulators (herbicides).

Among the key trends evident in this review is the establishment of reliability indices and VM metrics that focus on understanding the system average interruption frequency index (SAIFI) impact of tree-related outages. Most utilities focused on targeting mainline distribution because of the potential SAIFI impact of those type of outages compared to lateral equipment.

Most VM programs have used cycle-based trimming for long enough periods that the adverse impact of outages caused by tree growth is minimal compared to that of falling trees, limbs and branches. Thus, most programs focus on tree trimming versus tree growth regulation. Similarly, maintaining standard minimum clearances does not seem to be generally acknowledged as being useful. Instead, targeted trimming for identified risks is more utilized.

Many utilities have hazard tree identification and removal strategies. These utilities have developed hazard tree programs to prioritize the mitigation of risk associated with these trees. The processes in these programs vary but are generally dovetailed into cycle-based trimming activities, at least from an identification methodology. Removal of hazard trees is prioritized by their likelihood of adversely impacting the reliability of service. Thus, mainline distribution is often the target.

Another area of consensus is public education. Most utilities provide VM education awareness. As part of this program, nearly all utilities provide some information regarding public safety during storms and highlight the risk of downed wires. Many utilities are now using arborists to interact with stakeholders and work with property owners to facilitate the VM education process.

Other major initiatives utilized within the industry are in the general categories of process, technology utilization, and tree growth regulation.

Process Enhancements (Standards Adoption)

As relates to process enhancements, several utilities have embraced the updated American National Standards Institute (ANSI) standards and International Society of Arboriculture (ISA) best management practices.

Prior to the 2012 publication of the ANSI and ISA standards and guidelines, there has been little guidance to the electric utility industry. There are no federal standards set forth by the Federal Energy Regulatory Commission (FERC) or the U.S. Department of Energy for distribution level voltages. The North American Electric Reliability Corporation (NERC) standards only apply to transmission level voltages. Thus, distribution voltage VM requirements are the jurisdiction of state regulatory agencies.

The National Electric Safety Code (NESC) provides general guidance for line maintenance and worker safety, acknowledges that vegetation may interfere with the safe operation of overhead conductors, and recommends that these situations be addressed according to the needs of the specific utility. The NESC is not prescriptive regarding the frequency or determination for vegetation management, nor does it establish clearance standards.

ANSI, established in 1991, established tree maintenance standards for improving public safety that have been used throughout the utility industry for the last 20 years. The ANSI standards address safety requirements for vegetation management and best practices for trimming and pruning operations.

In 2006, the ANSI standards were updated to include an IVM standard that incorporates asset management principles as they relate to risk management. This standard, referred to as A300, was revised again in 2012 to incorporate "consensus performance standards based on current research and sound practice for writing specifications to manage trees, shrubs and other woody plants." [9]

The IVM standard differs from previous vegetation management options in that it necessitates more sophisticated and comprehensive management oversight. As defined by ANSI in the A300 Standard (2012), IVM is "a system of managing plant communities in which compatible and incompatible vegetation is identified, action thresholds are considered, control methods are evaluated, and selected control(s) are implemented to achieve a specific objective." The reason for the tree risk assessment standard is "to assess structural integrity and other factors that affect the level of risk to people or property and to provide information for mitigating risk". [9]

ANSI A300, Part 7 offers a systematic way of planning and implementing an IVM program consisting of six steps:

- Set Objective
- Evaluate the site
- Define action thresholds
- Evaluate and select control methods
- Implement IVM
- Monitor treatment and quality assurance

The term "integration" as it relates to IVM is a recognition that each of the steps is integrated into the other and that the process is principled on continual improvement because each successive application necessarily builds upon the lessons learned from the previous application of the process.

The ISA organization also provides best management practices to guide arborists, and the people who employ them, toward the most appropriate arboricultural techniques. The ISA standard focuses solely on tree risk assessment and not the overarching goals and issues of tree risk management. Thus, it is geared toward guiding the arborist. The ISA standard is included in the ANSI A300 Part 9 standard and outlines the recommended process of tree risk assessment.

Risk Assessment

Tree risk assessment is the systematic process to identify, analyze, and evaluate tree risk. The manner in which this process is applied depends on the context. The parameters of the risk assessment may include objectives, applicable policies and legal requirements, and the methods used to carry out the risk assessment.

Generally, there are two approaches to undertaking risk assessment: quantitative and qualitative. There are advantages and limitations to each, depending on the objectives, requirements, resources, and the degree of uncertainty. Regardless of the approach, there are limitations inherent in the risk assessment process due to the nature of the unknowns that are inextricably tied into the process of managing trees (for example, weather, traffic issues, and rates of progression of decay).

Tree risk categorization is similar to the categorization of risk used as part of traditional asset management programs. It relies on developing a matrix that estimates the likelihood of the combined events of a tree failure occurring and the tree impacting a specific target against the consequence of the resulting event.

Once the risk is understood, mitigation efforts can be developed that address the likelihood of failure, the likelihood of impact, or the consequence of failure. Mitigation efforts may include a range of approaches, such as:

- Target management, which focuses on evaluating options for some action on the target to mitigate the risk
- Pruning
- Installing structural support systems
- Adding lightning protection to trees
- Modifying the site
- Using tree growth regulators

The immediacy and type of response to developing mitigation plans is guided by the severity of the risk associated with the situations.

Risk reporting is the documentation of the risk assessment information, conclusions, recommendations and mitigation efforts, which is necessary to help inform future decisions as well as ensure that communications with stakeholders are effective.

Technology Utilization

Many utility companies are investing in technology to improve their VM programs, especially due to the availability of software programs tailored for VM needs and objectives. The software features used appear to depend on a utility's specific VM goals and methods. Utility companies have also started focusing on making field crews more comfortable with technology.

Companies may have laptops (for example, Panasonic ToughBook CF-19) and printers mounted in vehicles for field use. The laptops are used to perform inspections, collect data, and obtain permissions. After utilizing these laptops in the field, the utility company recognized that the new system eliminated some problems relating to handwritten records that were difficult to read and helped to standardize the use of terms in reports. Since crew members used their own terms to categorize and describe the work and tasks performed, the drop-down menus with specific descriptions provided by the software ensured that all field records had consistent terminology.

Several utilities are using geographic information systems (GIS) and computer-based management tools as well.

Tree Growth Regulators

Significant research has provided utilities with another tool to address what is to many utilities the leading cause of outages during adverse weather events. Tree growth retardants reduce the need for constant pruning and consequently reduce the risks and costs associated with pruning. In one example, a utility experienced 200% improvement in required pruning and moved from a twice a year trim cycle to a once every two years trim cycle. Using tree growth regulators has improved the city of Glendora, CA efforts to manage trees in historically difficult areas, such as parking lots and road medians.

Summary of Vegetation Management Practices Interviews

As part of the DGR study, EPRI collaborated with DGR study participants in 2014 to identify current and emerging VM practices. This research, initiated to expand upon the information collected in the 2013 survey, was accomplished through a series of in-depth telephone interviews with subject matter experts at over 20 utilities across North America.

A comprehensive interview guide was developed to help identify VM activities, attributes, and processes implemented (or considered) to mitigate distribution system damage caused by vegetation during major storm events; as well as to understand the metrics used to determine the value VM provides for a utility.

This section provides insights from these interviews. The interviews focused on nine key areas related to VM practices:

- VM organization
- Roles and responsibilities of the VM organization
- VM program budget
- VM program scope
- Line clearance specifications
- Metrics and tree damage data
- Program management
- Contractor and contract management
- Use of technology in VM programs

Key Trends – Factors Influencing Trimming Practices

A theme that resonated throughout the investigation was that many utilities are moving toward standardization in their VM practices. VM programs are migrating toward a more risk-based approach as promoted by the ANSI and ISA standards.

Although ANSI clearing standards are being applied across the board for utilities, trimming specifications were found to vary depending on a number of factors.

- Tree SAIFI – System average interruption frequency index
- Tree SAIDI – System average interruption duration index
- Reliability – How a system performs on a day-to-day basis
- Grid-based –The distribution infrastructure
- Circuit-based – Circuit type (backbone or lateral)
- Fixed cycle – The fixed period of time used to perform routine tree maintenance

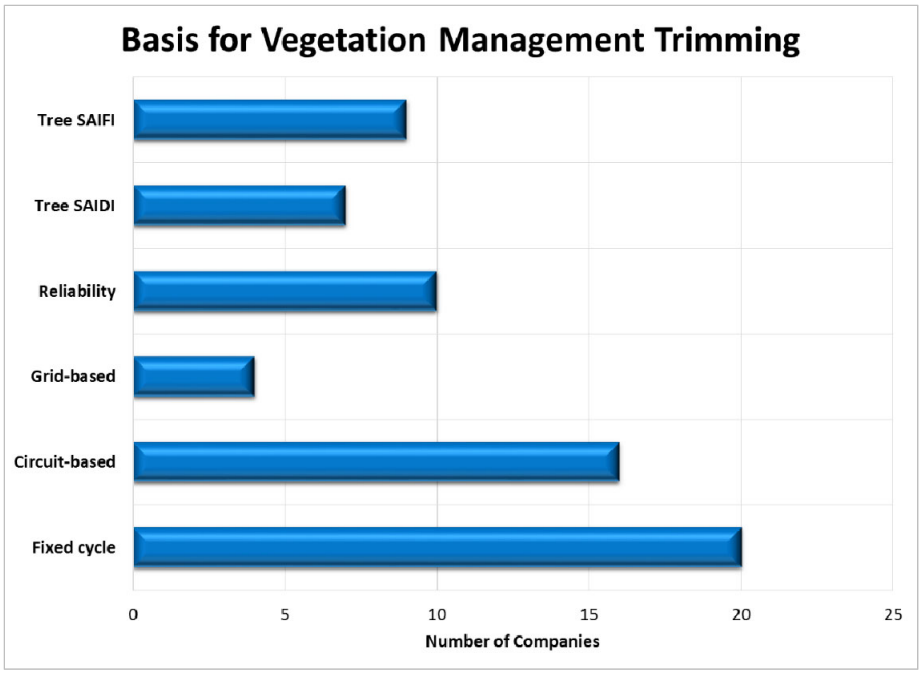

Figure 2-3
Tree trimming basis practices

Key Trends – Asset Management Approach

The asset management-centered VM programs generally relied on specific metrics that were geared to determine the value of previous and on-going investment; specifically the SAIFI, the SAIDI and the customer average interruption duration index (CAIDI). Of those companies using metrics, tree SAIFI was the most commonly used.

Companies that used integrated asset management feeder-specific data that captured the underlying root causes used this information to make decisions regarding VM investments. Those companies that tracked one or more of these indices were able to best describe the value of each of the aspects of their respective programs. Interestingly, tracking these indices and associating the holistic decision-making process with asset management objectives helped justify certain traditional VM programs. The actual data has provided additional information that has compelled companies to modify aspects of their programs (for example, determining the maintenance trimming cycle or the investment in hazard tree programs).

A leading practice used by several companies (to differing degrees) involved identifying customers who were impacted by outages more frequently than the norm. For instance, one company noted a program that employed an approach that targeted customers who had experienced four or more outages, of which two

or more were tree related. As a result of this program, the same company developed tree CAIDI and analysis tools to identify the outlier customers who were experiencing significantly more outages than the system average. This information was used to inform the utilization of tree patrol resources.

Metrics Used to Guide Resiliency Investment

Another theme that emerged from the interviews was the use of predominantly reliability-driven metrics to justify VM investment decisions. These resiliency investment justification metrics are the following:

- Tree SAIFI
- Tree SAIDI
- Tree CAIDI
- Number of customers affected
- Type of customers affected
- Customers experiencing multiple outages
- Cost per customer interruption
- Likelihood and consequence of VM outage
- Critical infrastructure feeder priority
- Trim cycle
- Cost

The overall trend is a more focused analysis of data. Figure 2-4 shows the degree in which various metrics affect VM program managers' decisions.

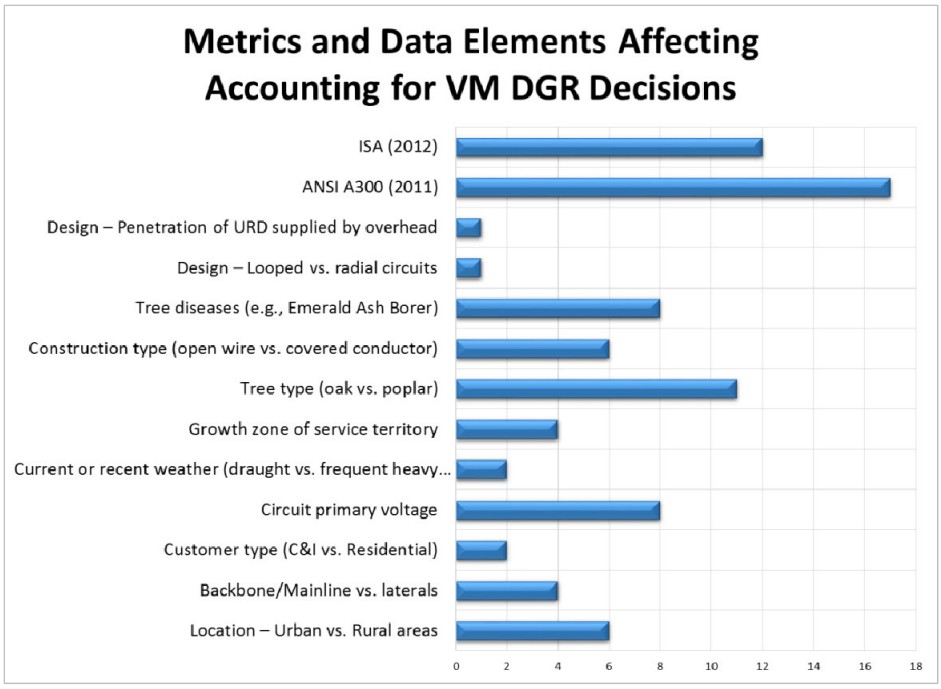

Figure 2-4
Basis of VM DGR decisions

Hazard Tree Programs

While hazard tree programs are not new, the interviews showed that the attention, processes, and analysis applied to hazard tree programs has evolved.

Several companies are incorporating the guidelines set forth in ANSI 300 Part 9 for evaluating the risk associated with hazard trees, such as the likelihood and impact of the failure of the identified hazard tree. There are leading practice efforts for determining the probability aspect, which is incorporated into the overall risk analysis.

When assessing a population of at risk trees, companies are prioritizing areas and trees based upon the empirical strength of the species of tree and whether the tree is in a blighted or epidemic area. Other proactive efforts include:

- Hazard tree by hazard tree inspections
- Determination of whether the number of potentially impacted customers is larger than 500 customers
- Prioritization of hazard tree investments based on the prioritization of feeders, the critical infrastructure, and number and type of customer
- Use of GIS handheld technology to rapidly determine the exact location and thus the potential system impact of identified hazard trees
- Use of sonic scans for off right-of-way (ROW) trees to establish the health of the tree.

Technology Utilization

Highlights in the technology utilization area include:

- GIS technology
- Weather-informed VM programs
- Smartphone and similar mobile platform devices

Most companies are using GIS technology for various utility purposes and have established a VM-specific layer in their GIS platform to enhance its ability to manage vegetation. A wide array of information can be captured in GIS applications, such as:

- Locations of poles
- Property owner information
- Risk analysis data
- Trim dates
- Setback information
- Individual trees for removal
- Areas for mowing and herbicide application
- Property boundaries
- Archeological areas
- Tree species
- Customer issues
- Dead tree locations
- Vine locations
- Refusals for tree removals
- Actual tree removals

The evaluation of weather information is another example of where a risk-based approach is being incorporated into the development of VM options. Specifically, analyzing weather information specific to certain areas, such as the magnitude and direction of the prevailing wind, and the amount of lightning due to elevation, is included when determining the options that are employed.

Some utilities are beginning to use mobile network devices such as smartphones and tablets to help establish and improve grid resiliency and storm response. This technology:

- Provides real-time two-way data flow regarding VM information
- Enables capturing relevant vegetation-related data during storm patrols
- Can link directly to the control center's outage management system (OMS) via GIS coordinates to provide photographs of damage and information regarding various tree and system conditions.
- Enables the electronic execution of repair work by linking with the OMS and work management system.

See Figure 2-5 for details on applied technologies.

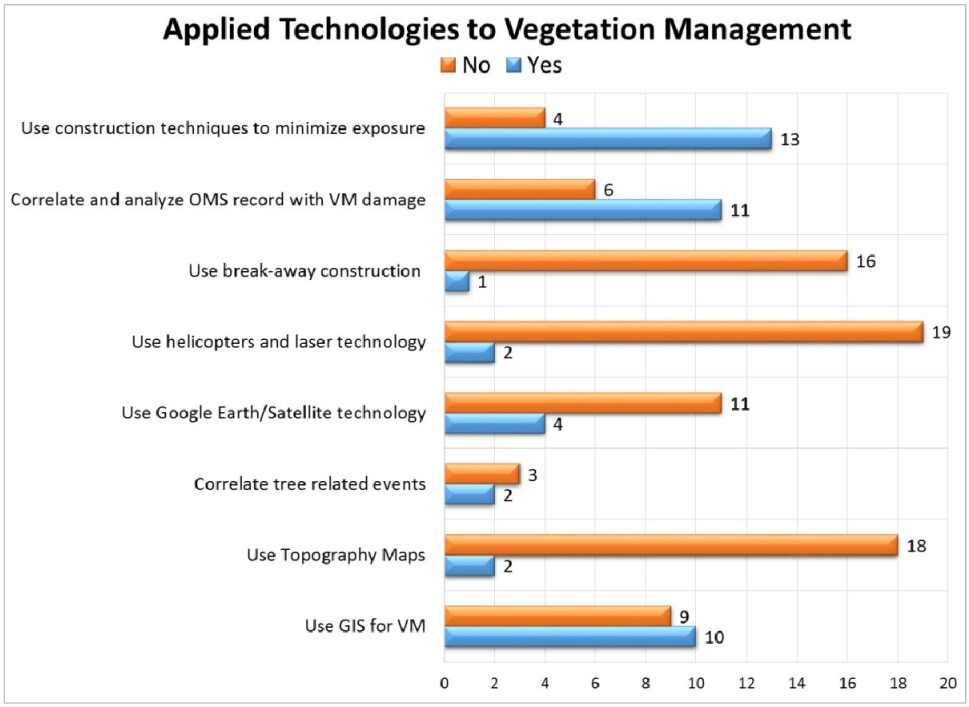

Figure 2-5
Utilities use of technology in VM

Outcomes of Industry Scan Activities

The literature review revealed that a significant number of utilities are addressing VM in traditional and similar ways. These traditional methods and philosophies include:

- Trimming practices focused on eliminating opportunities for vegetation to adversely impact utility infrastructure
- Targeted cycle trimming with average cycle periods where critical facilities (based on condition surveys) are trimmed more often and often include mainline or high impact feeders
- Reliability-centered programs based on feeder inspections or hot spot inspections as realized through reliability performance

The most notable VM program enhancements include the use of risk-based asset management principles and best management practices as set forth in the most recent ANSI/ISA guidelines. The ISA tree risk assessment guidelines, outlined in the ANSI A300 Part 9 standard, helps to ensure that the investments made in managing vegetation are efficient and effective. As the adoption and use of these guidelines become more widespread, further improvements in VM strategies inevitably will be realized and costs could be more efficiently managed.

The leading practices for improving distribution grid resiliency – increased line clearances, enhanced/blue-sky trimming of circuit backbones, and implementation and expansion of hazard tree programs – are not new VM practices. Although resiliency considerations may have increased the funding level, fundamentally these practices are elements of long-standing, reliability-driven VM programs and benefit stakeholders whether the driver is traditional day-to-day system performance or resiliency during a major storm.

Section 3: Force of Impact from Tree Failures

As part of the DGR project, EPRI conducted an investigation of the destructive potential of falling tree branches impacting overhead distribution lines [10]. This section summarizes this study, and Appendix E contains the complete study.

Motivation for this Study

While the destructive potential of the structural failure of trees is generally well understood, less consideration has been given to assessing the damage potential of impact on overhead utility lines. In recent years, however, the impact of falling tree branches has become a higher concern. A gathering of some 200 arborists at the Tree Risk Assessment Symposium (Morton Arboretum, September 2012) identified the failure of branches as a leading cause of damage and a significant concern shared by utility, commercial, and municipal arborists.

The two modes of failure associated with tree-initiated interruptions on the energy delivery system are electrical and mechanical failure. The electrical mode of failure occurs when tree or parts of trees provide a short circuit fault pathway between areas of unequal electrical potential. The mechanical mode of failure is caused by structural failure of the tree or parts of trees (branches) causing physical damage to energy delivery infrastructure. Mechanical damage results as a tree fails, taking down conductors, cross arms, and poles as it falls. Mechanical damage can be extensive in major storm events.

The objective of this research was to identify and quantify metrics that would be useful in describing the destructive potential of falling trees branches. The intent was to provide distribution engineers with a tangible basis for the following:

- Assess the durability of overhead distribution system infrastructure exposed to tree and branch failures
- Characterize the line strikes in a quantifiable manner, to be useful in infrastructure resiliency and survivability studies

The decision was made to focus on branch failures in this investigation, as the frequency of incidences of damage to overhead power systems due to branches is higher than that due to whole tree failures under most weather conditions. Very large branches and whole trees were outside the scope of this study, as this investigation was intended to identify the risk of line strikes that could be survivable through changes to energy delivery infrastructure.

Background

High winds, ice, and accumulations of heavy snow can overload trees to the point of structural failure. Broken branches falling onto the overhead distribution lines have the potential to damage lines, conductors, and supporting poles leading to interruptions and extended outages as repairs are made to the system.

An assessment of risk associated with tree failures requires consideration of both the likelihood that a branch failure will occur resulting in a line strike, and the magnitude of impact on the line. Utility VM programs focus on the first consideration and are intended to reduce the likelihood of tree failures and line strikes. The second part of the risk equation is less well understood: the potential for structural damage when a line strike occurs.

Literature Review

A literature review was conducted to locate data on the mass of trees, tree sections, and branches. Due to the limited nature of this body of work, the review was expanded to include works by the authors and others who have not been published in the public domain. The literature revealed a research study that correlated the masses for branches very closely with the branch diameter measured at the base [11]. The study participants applied their own analysis of branch diameter and mass to sample branches and concurred that diameter was a relatively good surrogate for mass.

The study participants also reviewed engineering studies regarding the performance of overhead lines following an impact. One such investigation [12] used simulation modeling to assess impacts and to determine the ability of overhead lines to withstand falling tree limbs. The forces generated by medium-to-large limbs falling from 15 feet above a power line were shown to be sufficient to break various components including conductors, cross arms, and poles. The engineering analysis determined that relatively light masses (21-26 lbs) dropped from a height of 15 feet (< 5 m) would exceed 100% of the system's designed mechanical load capacity in 200-foot spans of overhead conductor (#6 CU-336 AAC).

Study Approach

The study approach was to replicate a series of branch drop tests. Branch specimens were limited to two tree species to build a meaningful sample set within the time constraints of the testing. Branch specimens were fully foliated at the time of harvest. As many as six replications were completed for each specimen: three in full leaf, followed by three with foliage removed.

The fieldwork for this study occurred during a week-long scientific endeavor as part of the International Society of Arboriculture's Tree Biomechanics Week in August 2013. The event was intended to provide researchers actively working in the area of tree biomechanics with the opportunity to come together, generate questions, exchange experimental design ideas, and coordinate scientific efforts on a common site.

This project focused on characterizing and quantifying the amount of energy available at the point of impact on a target due to the structural failure of medium-sized tree branches, generally defined as less than 8 in. (20 cm) in diameter at the point of attachment. Important factors considered in making this assessment included the mass and position of the failed branch relative to the target, the velocity at which it was traveling when it struck the target, and rates of acceleration and deceleration.

Line strikes were simulated by dropping branches from a fixed height onto a rigid target. The researchers recorded data that described the branch, its velocity, and the acceleration of both the branch and target. Eighteen branch specimens in full leaf from two different tree species were dropped on a fixed target. As many as six replications were completed with each specimen, and a subset of the replications was conducted with branches that had been stripped of leaves. Branch velocity was determined by interpretation of high speed video. Target acceleration and branch deceleration due to impact were recorded directly. The researchers used the data and the mass of the branch to calculate the potential energy, kinetic energy, and momentum associated with falling branches as well as the force of impact on the target.

A rigid section of well casing was used as the target for branch impacts, which provided a worst-case study. The force of impact on an overhead electric distribution line would be expected to be lower than those observed due to the dynamic nature of a span of conductor power line suspended between poles.



Figure 3-1
A defoliated branch in free all above the target

The researchers used data-logging accelerometers (Model X16-2, Gulf Coast Data Concepts) to record impact data on both the branch and target. Accelerometers were attached to the branch and to the target (pipe) in order to measure the peak force that occurred during the impact. A high speed (300 fps) video camera was used to record each branch drop.

Once instrumentation was prepared, a nylon lifting strap was attached to the branch at the center of gravity. A crane was used to lift the specimen to a height of 23 feet (7 m) above the target. The 23-foot drop height was intended to approximate a branch falling into a span of distribution line.

The study process consisted of lifting and dropping each branch three times. The foliage was then removed and three more drop tests were completed, for a total of six replications. In some cases, the branch specimen was broken during the drops, reducing the number of replications. A total of 86 branch drops were completed with 18 branches.

Key Findings

The study captured three types of data that are useful in characterizing the destructive potential of a falling branch:

- The mass of the branch, determined by direct measurement using a scale
- The velocity of the falling branch, determined by analysis of high speed (300 fps) video interpretation
- The change in acceleration at impact, determined by direct observation by accelerometers on the target and branch

The study found that the mass of the branch affected the potential and kinetic energy, the momentum transfer, and the force of impact. The researchers calculated the kinetic energy of a branch in free fall immediately prior to striking a target. Some of the energy represented in the branch is lost to aerodynamic drag as the branch falls toward the target. The effect of aerodynamic drag can also be seen in a comparison of the kinetic energy associated with branches in full leaf as opposed to leafless, as they would be during the dormant season. Obviously, this seasonal effect would not be relevant for conifers.

Branches that were dropped in the leafless condition reached higher velocities at impact than those in full leaf, though the difference in velocity was not substantial. These replications suggest that impact velocities are limited by the relatively short fall distances between most branches in the upper crowns of trees and adjacent overhead lines. Since the branches were still accelerating prior to impact, branch failures on very tall trees and trees up slope of the line have the potential to result in considerably higher kinetic energy available at impact with an overhead line.

The data allowed the peak force, impact time (duration), and displacement (deflection) to be measured. During an impact, the transfer of energy from one object to another is the peak force. The peak force depends on both the amount of energy transferred and the time over which the energy is transferred. Because the time of impact is very short in these tests, when the branch hits the pipe, the peak accelerations are high.

If the time of impact is longer, as would be the case when a branch hits a power line, the peak acceleration and peak forces are less as the energy transfer process is expended over a longer period of time.

Force is also dependent on the target characteristics and the response due to impact by a branch. The response of an overhead distribution line is much more dynamic than a rigid pipe, and depends on a number of factors such as:

- Conductor type
- Span length and tension
- Flexibility of conductor attachment points, cross arms, and poles
- Guying and other pole attachments

The rigid target used in this investigation simplified the analysis and presents a worst-case scenario. The force of impact on a span of overhead conductor would be less than the force observed on the rigid target system, and the flexibility of the overhead line would absorb some of the impact.

The tests completed in this project took place in August while trees were in full leaf. Accumulations of wet snow or ice can add significantly to the total mass of a falling branch, thereby increasing destructive potential. In prior studies [13], the weight of accumulated snow was calculated by comparing snow-covered and unloaded branch weights. The weight of accumulated snow averaged 165% of branch weight, and ranged from 100% to nearly 300%.

Key Outcomes

The project was successful in providing quantitative evidence of the destructive potential of line strikes by branches. The metrics quantified included potential energy, kinetic energy, momentum, and resulting force of impact associated with falling branches.

This information can be applied to study the structural load-bearing capacity and behavior of overhead electric distribution lines, as follows:

1. Existing designs can be evaluated to determine those least likely to survive a branch impact strike of the magnitude characterized in this study. It may be possible to develop a means of ranking the relative robustness of in-service line types, leading to refinement in the industry's approach to risk-based condition assessment work. An assessment of vegetative conditions associated with in-service plant of the most fragile designs could then be made in an effort to identify and mitigate elevated likelihood of branch failures.
2. The findings of this investigation can be used in an engineering investigation of potential improvement in overhead line design. It may be possible to reduce the risk of branch strikes by developing more robust designs for use in system improvement upgrades and new construction projects.

In addition, findings from this investigation may also support the development of branch strike consequence rankings based on branch diameter and line type. Utility arborists applying risk assessment standards (ANSI A300 Part 9) and best management practices (ISA Tree Risk Assessment) follow a basic rating method that considers both the probability and consequence of failure. To do so will require engineering analysis that will translate worst-case strikes on a rigid target to the dynamic response of a line strike.

A similar study involving an entire tree could be undertaken to establish a quantitative basis for the destructive energy and resulting force experienced by a target struck by a tree. There are some important differences including mass, the manner in which trees topple, and their position relative to lines. However, the test methodology, instrumentation, and analytic methods developed in this investigation of branch strikes can be adapted to a study of whole tree failures.

Other tree species can also be examined with regard to their most likely failure mechanisms and the tests replicated under those circumstances.

Section 4: Modeling Weather Damage Using VM, LiDAR and Infrastructure Data

As part of the VM Task in the DGR project, EPRI co-sponsored a study that the University of Connecticut (UCONN) conducted on the use of VM, Light Detection And Ranging (LiDAR), and infrastructure data to model weather damage on distribution systems [14]. This section summarizes the results of this study. The complete study is included in Appendix F of this report.

Motivation for this Study

Because of its high ratio of woodlands to urban areas, Connecticut has experienced prolonged power outages due to the interaction of trees and overhead lines during major storms. Hurricane Sandy (2012) was especially damaging for Connecticut, when at its peak, over 500,000 customers lost power.

Electric utility companies are tasked with managing tree stands surrounding overhead lines to maintain acceptable reliability for customers. VM is a multi-faceted program that consists of managing trees and other flora by trimming above, below, and on the side of overhead lines.

Many models have been created to predict storm damages for distribution networks. Examples of variables used in the damage models include: wind gust, sustained wind, soil moisture, attributes of the electric infrastructure, and land cover. Given that land cover has generally been used to represent the trees around the overhead lines, this study sought to show that incorporating additional tree-related data around the overhead lines could improve the accuracy of damage prediction models.

In particular, this study evaluated how different model-forcing complexities related to trees can improve damage prediction models, including the use of a hazardous tree dataset based on LiDAR data as an alternative to land cover data. As airborne LiDAR data becomes more widely available for New England, land cover data can be replaced with more accurate tree-covered land data and thus improve existing damage prediction models and help facilitate VM impact assessment studies.

Background

Researchers in the Departments of Environmental Engineering, Natural Resources and the Environment, and Mathematics at UCONN, in collaboration with Connecticut Light and Power (CL&P) and the EPRI DGR project team, investigated the use of VM (that is, tree trimming) and LiDAR-derived hazardous tree information (HazPix) for predicting damage to the eastern division of the CL&P service territory during Hurricane Sandy.

The study, conducted in 2014, focused on how different model-forcing complexities related to trees can improve damage prediction models. Specifically, the researchers evaluated the benefit of a new LiDAR-derived hazardous tree pixel dataset they created as an alternative to land cover data.

The study also examined how the inclusion of detailed data about overhead power lines (that is, bare or covered conductors; backbone or lateral circuits) can improve the model error metrics. Given the temporal and spatial constraints of the data, the study focused exclusively on damages that occurred during Hurricane Sandy in eastern Connecticut.

The purpose of the study was to examine how VM and LiDAR data can be used to develop a more accurate damage prediction model that would help in the evaluation of VM options.

Distribution Infrastructure

The overhead distribution network has many attributes that contribute to whether or not damage occurs, including different conductor types; pole size, age and material; cross-arm size, material and configuration; and operating voltage. This study focused on attributes directly related to the conductors, which were generalized into two categories: bare or covered conductors. The reasoning behind the reduced classification was that different conductor types suffer from different types of damage (that is, incidental touching of trees for bare conductors, destruction of conductors for bare and covered conductors), occurring with varying frequency.

In addition to conductor type, the distribution network can also be divided into two circuit categories: backbone and lateral circuits. For the UCONN study, a backbone circuit is the portion of the distribution circuit beginning at the substation and ending at transitions to single or multi-phase circuitry protected by single-phase devices; a lateral circuit (or side tap) is a single or multi-phase portion of a distribution circuit that is supplied by the backbone feeder and protected by single-phase devices.

Prior studies [15] showed that backbone circuits perform better than lateral circuits during storms because they have been better maintained. This knowledge led the researchers to segregate overhead lines by circuit type (backbone or lateral) in addition to conductor type (bare or covered).

LiDAR-Derived Tree Height Information

Airborne LiDAR data has been used for more than a decade to model the heights of forest canopies. Canopy Height Models (CHM) are digital representations of a forest canopy and can make it possible to identify trees that are within striking distance of power lines. The identification of these trees provides a direct physical basis for damage prediction models.

Identifying tree crowns is an ongoing challenge in the field of remote sensing, with deciduous trees being particularly difficult to map without very high resolution LiDAR data. The researchers created a dataset of hazardous tree pixels (HazPix) as a proxy for hazard trees. The hazardous tree pixels were defined as 1-m pixels in a CHM that are tall enough and close enough to contact a power line in the event of a whole or partial tree failure. Multiple hazardous tree pixels can correspond to a single tree. However, intuitively there should be a high correlation between the number of hazardous tree pixels and number of hazard trees in a given area.

Study Area

The study area is eastern Connecticut due to the availability of LiDAR data over this region (see Figure 4-1). A spatial grid resolution of 0.5 km was used to aggregate the data, resulting in 9,000 0.5-km grid cells covering the study area. The gridded approach allowed the explanatory variables to be represented as the average conditions in each grid cell. All explanatory data with the exception of the weather simulation data was processed at the 0.5-km grid resolution. Weather simulation data was processed at a 2-km grid resolution.

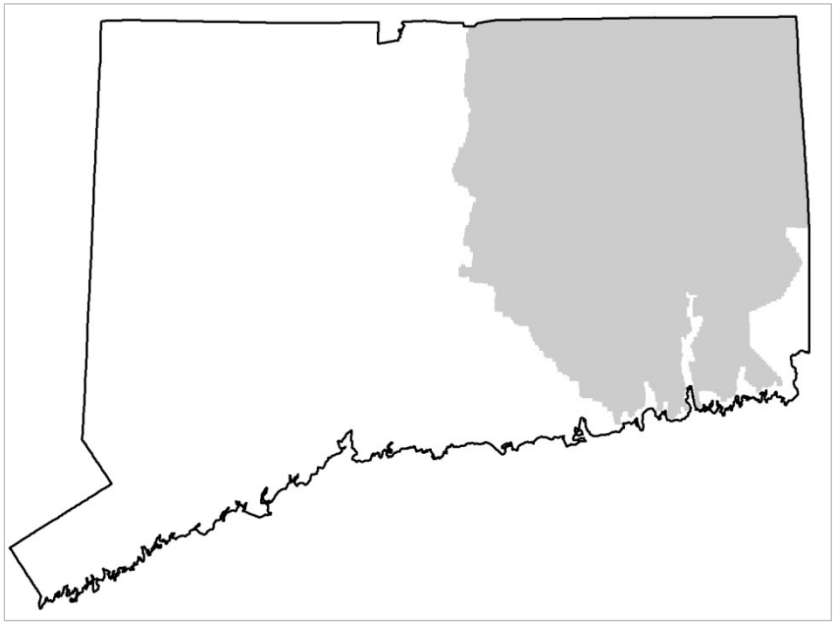

Figure 4-1
Distribution of the 4600 km2 LiDAR data in eastern CT over the study area

Study Approach

The study selected a number of parameters in developing the data to use in the damage prediction models, as follows:

- Binary response variables
- Weather simulation and verification
- Storm hardening
- Land cover
- VM variables

Damages to the overhead lines are known as trouble spots; trouble spots are geographic locations that require a line crew to restore power. A trouble spot therefore is independent of the number of customers affected by an outage. Of the 9000 0.5-km grid cells in the model's spatial domain, 1320 had one trouble spot, 440 had more than one trouble spot, and no grid cell had more than eight trouble spots. This led the researchers to choose a binary response model that produced a balanced sampling approach. An indicator of "1" was assigned to a trouble spot (BinaryTS) if damage occurred in the grid cell; otherwise, a "0" was assigned.

Weather event simulations were created using the Advanced Research dynamics core of the Weather Research and Forecasting Model (WRF) version 3.4.1. Each event simulation was dynamically downscaled from analyzed fields provided by the Global Forecast System (GFS) produced by the National Center for Environmental Prediction (NCEP). In order to minimize initial condition (IC) and boundary condition (BC) uncertainty, the events were modeled as hindcast. Hindcasting is a way of testing a mathematical model by estimating inputs from past events to see how well the output matches the known results. The GFS analyses were used to derive both the model's IC and BC updates.

Storm hardening of the distribution network refers to using more resilient infrastructure and practices to improve system reliability. In order to fully evaluate the characteristics of the distribution network within the context of storm hardening, a full and reduced dataset of infrastructure was prepared for analysis. The study aimed to determine if allowing for storm hardening practices (which focus on the backbone) would provide any better information for the model. The reduced dataset included only the sum of isolating devices per grid cell (that is, fuses, switches, transformers, and reclosers). The full model included additional information on circuit type (backbone or lateral), conductor type (bare or covered) and the sum of isolating devices per grid cell.

To calculate the land cover around power lines, the study used the 2006 land cover data over eastern Connecticut, but at the 0.5-km grid resolution. A 60-m buffer was created around the lines to capture the surrounding land cover around power lines. Points were placed uniformly every 30 m along each side of the buffer, and were spatially joined to the land cover layer. The percentage of points in each land cover category was calculated for each 0.5-km grid cell. The percentages of deciduous and coniferous forest were combined into a single variable called

"PercentForest" (the sum of the deciduous and coniferous percentages). All other land cover variables were excluded. Using the processed land cover data, it was determined that tree species in eastern Connecticut are five times more likely to be deciduous than coniferous.

The Enhanced Tree Trimming (ETT) specification during 2009-2012 varied for backbone and lateral circuits. For the conductor, The ETT clearance zone for lateral circuits is 8 feet to the side, 20 feet overhead, and cut brush flat to the ground; for backbone circuits, the clearance zone from the conductor is clear overhead and cut brush flat to the ground. Comparatively, the Standard Maintenance Trimming (SMT) specification during 2009-2012 was less aggressive. SMT clearance for lateral circuits must provide a minimum of 20 feet of overhead clearance within reach of a 55-foot lift unit; for backbone circuits, trimming must clear to previous overhead clearances within reach of a 70-foot lift unit. In all cases, if greater than one-third of the tree was removed, the entire tree should be removed (when appropriate).

Instead of measuring VM as "years since last trim" per circuit (as many electric utilities do), the study presented the average conditions within a grid cell by conductor type (bare or covered) and circuit type (backbone or lateral). The study accounted for VM efforts by summing the length of treatment by wire type in each grid cell and normalizing by line length. A linear decay function was applied to the SMT to express the diminishing benefit of such treatments as time passes (for example, for a 4-year trimming cycle, a 25% decay was applied for each passing year). A cumulative function was applied to ETT because the benefit of such trimming activities is thought to be longer lasting and more effective than SMT.

In addition, the hazardous tree pixel (HazPix) dataset was created as previously mentioned. Hazardous tree pixels consisted of grid cells with heights taller than the minimum height required to strike the power lines in the event of a whole or partial tree failure. Assuming the power line height (Hline) was 10 meters, the calculated distance (d) of a buffer around the power lines was 15 meters. The buffer reflects the uncertainty of the power line locations. Based on the above methodology, hazardous tree pixels were extracted throughout the study area (see Figure 4-2) and hazard pixel counts were summarized at the 0.5-km damage model grid resolution. The counts were then normalized by total overhead line length (resulting in HazPix/km) for use in the models.

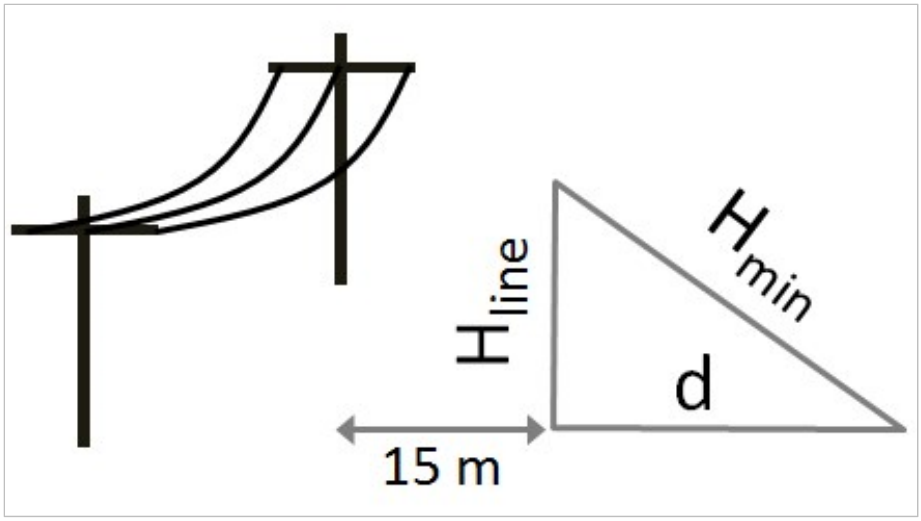

Figure 4-2
Calculation of the minimum hazard pixel height for a given location

Methodology

The study used the open source statistical software program R to complete all modeling and analyses. The R predictor model randomForest is known in the literature for predicting hurricane damages and outages. The predictions from all of the decision trees are referred to as the "forest," which is the average of the forest predictions used as the final prediction. Random forests are relatively easy to interpret compared to other machine-learning models and tend to have robust performance.

To ensure that predictors did not add unnecessary complexity to the model structure, five model-forcing complexities were used to investigate the added value of incorporating: (a) vegetation management, (b) the LiDAR-derived hazardous tree pixel dataset and (c) detailed infrastructure in the damage prediction model. The following is a description of the five models used for comparison:

- Model 1 (the baseline model) consisted of a full set of weather variables and land cover, and a reduced subset of infrastructure variables.
- Model 2 was built to show the improvement of including detailed infrastructure data with the land cover data.
- Model 3 was built to show the improvement of Model 2 with additional VM data.
- Model 4 included the data from Model 2 with the HazPix data.
- Model 5 included all of the detailed infrastructure, VM, and HazPix data, but no land cover data.

To compare the benefit of HazPix and land cover data, Models 1, 2 and 3 used land cover data to represent the local tree conditions and Models 4 and 5 used the HazPix data as an alternative to land cover.

The study chose to down-sample the data using the balanced random forest (BRF) algorithm repeated 10,000 times; this is also known as repeated balanced sampling (RBS). This resulted in a distribution of the error metrics for each model. The RBS algorithm allows for a distribution of the model error metrics to be created from the 10,000 iterations, which provides a better view of how the model will perform with different training and validation data.

The R package SDMTools was used to describe the model performance more completely. The researchers applied seven metrics for model comparison: area under the curve (AUC), false omission rate (FOR), true positive rate (TPR), true negative rate (TNR), proportion correct (PC), Cohen's kappa (K) and bias score (BIAS). The metrics were chosen to highlight the skill of the model predicting true positives (TPR), true negatives (TNR), true negative omissions (FOR), overall accuracy (AUC, PC), spatial accuracy (K), and tendency of the model to overestimate or underestimate events (BIAS).

The error metrics are briefly described as follows:

- The AUC metric is an accuracy metric that shows the model discrimination (the ability to correctly identify true negatives and positives); an AUC of 1 represents a perfect prediction, and an AUC of 0.5 or less represents a test that is no better than chance.
- The FOR metric indicates the chance of having the condition among those that test negative; a FOR of 1 indicates that all predictions for negatives were false, a FOR of 0 indicates that there were no false negative.
- The TPR metric, also known as sensitivity, is how many times TP was correctly predicted given a positive reading; a TPR of 1 indicates a model is perfect at predicting true positives, and a TPR of 0 indicates a model that is incapable of predicting true positives.
- The TNR metric, also known as specificity, is a measure of how many times negatives are actually predicted; a TNR of 1 indicates a model is perfect at predicting where damage won't happen, and a TNR of 0 indicates a model cannot predict where damage doesn't happen.
- The PC metric is simply a measure of how many observations are correctly identified; a PC of 1 indicates a perfect predictor, a PC of 0 indicates a predictor that can't identify where damage does (or doesn't) happen.
- Cohen's kappa statistic (K, also known as Heidke Skill Score in meteorology) is a measure of how many times a prediction is guessed by chance. A K of 1 indicates perfect spatial accuracy, whereas a K of 0 indicates no spatial accuracy.

Key Findings

The researchers evaluated the error metrics of five model-forcing complexities related to storm hardening and system resiliency, and investigated the improvement of each complexity in a hurricane damage prediction model. As more variables related to the distribution network infrastructure and local tree height data (HazPix) were added to the model, there were improvements in the model error metrics.

A comparison of Model 1 and Model 2 showed that the model with more detailed infrastructure data performed better than the model with less detailed data. A comparison of Model 2 and Model 3 shows that if tree height data is not available, the next best model was one that included VM data and detailed infrastructure data. If tree height data is available, the tree height data in combination with the detailed infrastructure data would likely provide the best error metrics. The combination of the VM, HazPix, and detailed infrastructure data may not improve prediction accuracy better than the tree height model due to over-fitting.

Of all the variables investigated, HazPix was the best representation of trees around the power lines; and the model that included HazPix (Model 4) was the best classifier for predicting damages. The model rankings show that added data may improve damage predictions during hurricanes, and that the detailed infrastructure with HazPix data may be best to improve damage predictions. When analyzed with respect to the actual range of values for each error metric, the results for Model 4 (HazPix model) indicated a "fair" classifier. Though moderate in terms of percent improvement, the study showed that adding data about tree conditions can improve damage predictions if such data is available. Table 4-1 shows the results of the error metric calculations.

Table 4-1
Relative improvement in the error metrics compared to baseline model (Model 1)

Model	AUC	FOR	TPR	TNR	PC	K
Model 1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Model 2	132.5%	211.5%	211.5%	-25.9%	132.5%	132.5%
Model 3	150.2%	267.7%	267.7%	-31.3%	150.2%	150.2%
Model 4	**463.2%**	553.7%	553.7%	**0.4%**	**463.2%**	**463.2%**
Model 5	273.9%	**563.5%**	**563.5%**	-39.2%	273.9%	273.9%

The added value of HazPix is a function of the overhead line location accuracy in the GIS data. The study found that that the actual location of overhead lines could vary with a median horizontal accuracy of 11.8 m from the location specified in the shapefile. Correction schemes exist that can be applied. For example, utility poles can be differentiated from other features by their height and small cross-section. Pole heights are consistently between 10.5-12.0 m and tree trimming typically ensures that other features of comparable height are not

adjacent to the poles. Thus, utility poles may be detected as a cluster of LiDAR returns having: 1) a maximum height of 10-12 m, 2) a horizontal footprint less than 2 m across, and 3) located within 15 m of a reported pole location. In order to be detected, poles will likely need to include a cross-arm and not be sheltered by tree cover. Accurate locations for these poles are the most critical. Poles lacking a cross-arm tend to be on lateral circuits, which have less impact on overall power outages when compared to backbone lines.

Key Outcomes

The results of this data modeling study showed the benefit of using attributes of the overhead lines (percentage of bare or covered wire and percentage of backbone or lateral circuit) with hazardous tree (HazPix) data. Random forest regression was used to predict a binary response variable denoting whether or not any damage occurred in a 0.5-km grid cell.

Five model-forcing complexities were evaluated by selecting the model with the most improved error metrics. Although all model-forcing complexities improved, the damage prediction relative to a baseline model, the model forced with HazPix data was the most accurate model for predicting hurricane damages.

The damage prediction model count for trouble spots proved to be quite accurate. The actual number of trouble spots recorded during Hurricane Sandy was 8688; using data from the model, 8615 trouble spots were calculated. Preliminary analysis indicated enhanced tree trimming (ETT) provides 35% reduction in trouble spots. However, more detailed damage data is needed for the damage prediction model to differentiate VM options.

A sensitivity analysis using the HazPix data showed a moderate increase in the HazPix numbers could increase hurricane-induced damages by more than 20%. As LiDAR data becomes more widely available for New England, HazPix data can be incorporated to improve existing damage prediction models and facilitate VM impact assessment studies.

Recent LiDAR data is available for northwestern Connecticut where more trees are coniferous and the population is sparser. A future study could compare the performance of Model 4 over eastern CT, northwestern CT, or both regions combined.

Section 5: Assessment of Industry VM Practices and Data Collection Needs

This section provides utility decision makers with an evaluation of the research and data compiled by the VM task force. The following areas are discussed:

- The investigated options for this task
- The broad adoption of industry VM best practices
- The current data limitations in quantitatively evaluating VM practices
- The data collection needs to enable this quantification
- The challenges in gathering this needed data

Introduction

In addition to the industry scanning activities described in Section 2 of this report, EPRI compiled practices gathered from the subject-matter-expert interviews in a Microsoft One Note repository to help facilitate comparative investigation of the VM research results. The repository places like practices employed by multiple companies alongside one another for easier reference. EPRI also provided other helpful information, such as survey results, references, and practice comparisons and analysis. The Practices Repository is not intended to be a "living database" updated by utilities, or by EPRI, as practices change. Rather, the repository contains "snap shots" of noteworthy practices identified at the time the immersions were conducted. The "EPRI Utility Vegetation Management Practices Repository" is available on a DVD entitled "EPRI Distribution Grid Resiliency Project; Year 1, Year 2, and Year 3 Deliverables," EPRI 3002007075. [1]

Summary of VM Options

In the industry scanning efforts, studies, and compilation of data in the Repository, the DGR project team found that there are no new techniques, practices, technologies, or equipment regarding VM practices that the industry needs to adopt. The current VM practices used are in fact the industry's leading

[1] Microsoft OneNote 2013 or newer is needed to open and navigate the Practices Repository.

practices. Utilities today are active in the International Society of Arboriculture (ISA), which conducts annual conferences that provide education about VM practices. Similarly, most utilities are following the American National Standards Institute (ANSI) standards. A growing number of arborist-trained and certified professionals have assumed VM program manager roles in the industry. Overall, the industry takes advantage of increasing opportunities for information sharing concerning VM techniques and best practices across the industry.

Another observation is that the same VM techniques used for reliability are also used for resiliency. In some cases, VM for resiliency means expending more resources, but using the same techniques. Research revealed that most utilities' approach to VM to maintain day-to-day reliability differs from their approach to major storm resiliency only in degree.

The recommended VM options therefore, are the same two main VM practices that many utilities are already using:

- Enhanced tree trimming (ETT)
- Hazard tree removal

These two options are further discussed below.

Enhanced Tree Trimming

The ETT specification differs from standard maintenance trimming (SMT) in its broader specification of trimming, primarily with respect to vertical clearance above the primary conductors For example, a utility may specify removal of tree limbs to provide for 15 feet of clearance above the conductors for SMT. However for ETT, effectively all tree limbs above the primaries are removed. Also referred to as "blue sky" or "reach of bucket" clearance, ETT is more costly than SMT; however it provides a higher level of confidence for mitigating future tree-caused interruptions. Some utilities limit ETT to circuit backbones, while others will apply ETT to both backbones and laterals.

Hazard Tree Removal

Hazard tree removal programs focus outside of the trim corridor to identify weak, decaying, or dead trees with the potential to fall across the distribution line in storm conditions. Hazard trees are prioritized according to their likelihood of adversely impacting the reliability of service. Thus, mainline distribution is often the target. As noted in Section 2, activities involving hazard tree programs have increased in recent years, and the processes and analysis applied to hazard tree programs has evolved.

Many utilities follow the guidelines set forth in ANSI 300 Part 9 for evaluating the risk associated with hazard trees, such as the likelihood and impact of the failure of the identified hazard tree. Leading practice efforts for determining the probability aspect are incorporated into the overall risk analysis.

When assessing a population of at-risk trees, utilities are prioritizing areas and trees based upon the empirical strength of the species of tree and whether the tree is in a blighted or epidemic area. Similarly, leading practice efforts regarding determination of the impact of a failed hazard tree are incorporated into the overall risk analysis. These proactive efforts include:

- Hazard tree inspections in which the number of potentially impacted customers is larger than a predetermined number of customers (for example, 500 customers)
- Prioritization of hazard tree investments based upon the prioritization of feeders, the critical infrastructure, and number and type of customer
- Use of GIS handheld technology to rapidly determine the exact location and thus the potential system impact of identified hazard trees
- Use of sonic scans for off right-of-way (ROW) trees to establish the health of the tree

VM Costs and Benefits and Data Collection Challenges

Quantifying the costs and benefits of VM options is problematic due to the following:

- Inherent variability in VM itself
- Limitations in data collected by utilities

Regarding inherent variability, VM costs and benefits vary considerably from utility to utility due to variation in the following factors in the service territory:

- Tree exposure
- Tree types
- Tree growth rates
- Tree density
- Trimming specifications and contracting approaches
- The presence of vines

Anecdotal evidence suggests that the presence of vines alone can double the cost and effort required for VM.

Data gathered by utilities and presented to EPRI poses some limitations when used to evaluate the costs and benefits of resiliency options. Most of these limitations are due to the fact that the data is incomplete in some way – it does not provide all of the information needed to evaluate option costs and benefits.

The incomplete nature of this utility data is understandable. Most of the data involves activities during outages – during the restoration period. During this period, utilities are immersed in restoring service as quickly and safely as possible to as many customers as possible. This is one of the utility's primary reliability charges – to minimize outage durations once they occur. This responsibility to

maintain reliability is at the core of the utility's obligation to serve. Large restoration efforts during major weather events are monumental endeavors for utilities, with multiple sets of personnel working around the clock, seven days per week, in utility operation centers and in the field.

During this busy time (during outages), when utility personnel and resources are strained to their limits, the additional burden of gathering data on these outages is difficult. Even with the best of intentions, data gathering during outages must be relegated to second priority, behind the restoration itself.

Gathering outage data after restoration is complete is possible, but complex, and requires dedicated resources to accomplish. Assembling data from various sources after the fact does not guarantee that all data needed can be gathered. Some of the data needed simply may not have been recorded in any form and cannot be inferred from the information that exists following restoration of service.

Specific Data Limitations

The project team performed a preliminary screening analysis of the data to determine which data sets offered the most promise for usefulness in analysis of various resiliency options. Based on this screening, EPRI then performed detailed analyses of the most promising data sets from four utilities. In general, these data sets reflect the following types of data limitations:

- **The data covers a short period of time.** This limitation can skew the results because of the limited sample size. Data gathered over a five-year period, for example, is much more likely to include a broader range of storm types, storm severity, damage types, damage severity, and so on, than two years of data.
- **There are inconsistencies in the types of data gathered across utilities**, making aggregation of data across utilities difficult. Different utilities define various data fields differently, and gather and record the data in different ways, precluding an "apples to apples" comparison. These differences are often sufficiently substantial to make comparisons meaningless.
- **There are inconsistencies within a utility as to definitions of data fields**. For example, within a given utility, the definition of a clearance zone for vegetation management may vary over time, or across different types of data forms.
- **There are inconsistencies within a utility as to how data is gathered**. For example, some data fields (for example, equipment damaged, details about tree-related outages, pole types affected, restoration actions implemented, and so on) are inconsistently completed by field crews within the same utility. Again, this is likely due to the time constraints imposed on repair crews, as they face a large number of needed restorations.
- **Needed data is not collected**. For example, the length of time needed to repair equipment damaged in an outage is needed in order to compare repair times across types of circuits, locations, and hardened and unhardened equipment. To determine the length of time needed to complete a repair of a given type, the time that a crew arrived at the outage location to address the

repair and the time that the repair was completed is needed. However, in some cases, data on only the time of the start of the outage and time of the completion of the repair is available. In this case, the "time to repair" would include the time that the outage sits in a queue waiting to be addressed, while other repair orders are handled.

- **There exists a wide variability in the types of data related to vegetation** due to the variable nature of vegetation itself (climate, region, soil, species, density, maturity, and so on).

In order to assess the costs and benefits of VM practices with adequate data, an outcome of this research task is to examine and define the type of data that is needed, based on what is currently lacking. EPRI recommends collection of quantitative data that enables determination of the costs and benefits of specific VM practices. The following sections list the data fields needed in outage records to evaluate the benefits and cost-effectiveness of VM options.

Recommended Data Sets for Comparative Option Assessment

Most utilities use a system of record for tracking outages on their power systems. This system of record typically contains basic information including time of interruption, time of restoration, clearing device location, the number of customers affected, and a cause for the interruption. These records are used to calculate reliability indices such as SAIDI, SAIFI, and CAIDI. The indices are used to measure a utility's performance and can help drive reliability improvements.

In order to further prioritize resiliency improvements, more detailed information needs to be collected about the individual outages that occur. This data can be grouped into four categories of information:

- **Basic information** consists of 12 data fields that are needed to perform rudimentary reliability calculations and form the basis for making better informed decisions to improve resiliency.
- **Operational information** for each outage consists of seven data fields that provide insight into the operational efficiencies of restoration and indicates how a utility handles service interruptions.
- **Construction information** for each outage consists of nine data fields that provide insight into construction standards of affected areas and can identify equipment failure trends and areas for construction improvement.
- **Vegetation information** for each outage consists of eight data fields that provide insight into the effectiveness of VM programs and ways to better plan VM resources to increase resiliency.

Table 5-1 provides a listing of all data fields by category. Appendix G contains definitions of each of these data fields.

Methodologies to Analyze Costs and Benefits

EPRI does not propose a specific methodology for capturing and analyzing data for costs and benefits, leaving that process for each utility to determine. Utilities can model a data analysis program based on their resources, priorities, and service territory attributes. Because VM is typically the most expensive maintenance program for utilities, capturing the additional data noted in this report would enhance cost and benefit analysis, and support decision making, to better utilize available resources.

Table 5-1
Data that utilities need to gather to better prioritize resiliency options

Basic Information	Unique Identifier	Construction Information	Fault/Damage Location (Pole #/GPS)
	Date/Time of Interruption		Component Damaged/Failed
	Date/Time of Restoration		Pole Break Location
	Duration		Pole Construction Type
	State/Region/Division		Number of Phases at Fault Location
	# of Customers Interrupted		Conductor Size/Type
	Fault Clearing Device Location (Pole #/GPS)		Age of Pole/Equipment
	Fault Clearing Device Type (GPS)		Identify Mainline/Lateral/Secondary
	Interruption Cause		# Circuits at Fault Location
	Detailed Cause Information	Vegetation Information	Inside/Outside Clearance Zone Identified
	Weather at Time of Interruption		Side Distance Tree/Limb Came From
	Storm Identifier		Vegetation Failure Mode
Operational Information	Size/Rating of Clearing Device		
	# of Phases Interrupted		Direction Tree/Limb Fell From
	Dispatch Date/Time		Diameter
	Crew Arrival Date/Time		Compromised Tree/Limb
	Voltage Class of Interrupted Area		Species
	Restoration Action		
	Switching Performed with Cross Reference		

Section 6: Conclusions and Recommendations

The DGR project team concluded that the current leading VM practices (enhanced tree trimming and hazard tree removal), while not new to the industry, are being implemented with an increased rigor and degree of activity across the industry.

One of the drivers motivating this increased activity is the publication and adoption of revised industry standards and guidelines over the study period. Most utilities have embraced the ANSI standard and ISA guidelines. Tree trimming practices to prevent rapid regrowth have become more sophisticated as the result of the ANSI standards. The ISA guidelines, along with the related ANSI A300 Part 9 standard, outlines the recommended process of tree risk assessment, which supports hazard and risk tree programs.

While the VM research task did not identify new techniques regarding VM practices, the VM research did uncover a number of significant trends in the use of technology aids, as follows:

- Geographic information systems (GIS) have been customized with VM-specific capabilities. The data is used for recording locations of poles, trim dates, trees identified for removal, areas for mowing and herbicide application, risk analysis data, property boundaries, archeological areas, tree species, customer issues, dead tree locations, and vine locations.
- GIS is also used in conjunction with other technologies such as outage management systems (OMS), pictometry, and Light Detection And Ranging (LiDAR) systems.
- LiDAR data is used for identifying the height of tree canopies and creating digital images of geographic areas.
- Sonic scanning of right-of-way (ROW) trees to help determine the health of the tree.
- Statistical software programs are used for data analysis and damage prediction modeling.
- Weather simulation systems are used for correlation modeling and forecasting (for example, Weather Research and Forecasting Model).

- Asset management software is used to analyze root causes, which can be used to make VM investment decisions. For example, targeting customers with frequent tree-related outages in order to inform the use of tree patrol resources.
- Mobile computing devices are used for real-time fieldwork communications and management.

As the overall goal of the DGR research project was to create actionable information that utilities can apply to increase the resiliency of their distribution systems to major weather events, the DGR team determined that more complete data sets are needed to identify resiliency improvement opportunities. EPRI recommends more detailed and complete information be collected for individual outages as outlined in Section 5.

While traditional methods to manage vegetation management remain the mainstay of utility efforts throughout the industry, changes in standards, technology, and other initiatives such as the use of metrics, risk assessment, and asset management approaches will continue to drive improvements that will alter the landscape for utility VM programs.

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Appendix A: List of Acronyms

ANSI	American National Standards Institute
AUC	area under the curve
BRF	balanced random forest
BC	boundary condition
CHM	canopy height models
CAIDI	customer average interruption duration index
DGR	distribution grid resiliency
ETT	enhanced tree trimming
FOR	false omission rate
GIS	geographic information system
GFS	Global Forecast System
HazPix	hazardous tree pixels
IC	initial condition
IVM	integrated vegetation management
ISA	International Society of Arboriculture
LiDAR	Light Detection And Ranging
NCEP	National Center for Environmental Prediction
NESC	National Electric Safety Code
NERC	North American Electric Reliability Corporation
OMS	outage management system

PC	proportion correct
ROW	right of way
RBS	repeated balanced sampling
SMT	standard maintenance trimming
SAIFI	system average interruption frequency index
SAIDI	system average interruption duration index
TNR	true negative rate
TPR	true positive rate
UCONN	University of Connecticut
VM	vegetation management
WRF	Weather Research and Forecasting Model

Appendix B: Industry Scan Report: VM Practices Survey (2013)

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EPRI Distribution Grid Resiliency:

Vegetation Management

Summary of 2013 Vegetation Management Practices Survey

December, 2013

EPRI Project Manager

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Appendix B

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Appendix B

ABSTRACT

Vegetation management continues to be a significant challenge to providing safe and reliable and resilient service in overhead electric distribution systems throughout the US. The EPRI Vegetation Management (VM) Practices Survey seeks to describe the current state of VM programs amongst participants in the US and Canada.

Due to the increased frequency and severity of recent major storms Distribution grid resiliency has become a critical issue surrounding society and modern life, due in large part to cultural dependency on electricity. The environment within which utility companies reside and operate in, continually challenge electric distribution systems throughout the United States especially in the area of vegetation and the management of its impact on system resiliency. Indeed, vegetation interference is one of the main contributors to outages on overhead distribution systems. Today, even short outages have a significant impact upon society's ability to function safely and efficiently. It is with this backdrop that EPRI has undertaken a review of significant efforts being used throughout the United States, seeking to identify opportunities that can be leveraged and replicated to help overcome the challenges posed by vegetation interference.

In support of the EPRI Distribution Grid Resiliency project, this document identifies common practices amongst the participating utilities and highlights interesting or unique approaches which might bear further investigation.

Keywords

Distribution
Distribution Grid Resiliency
Practices
Reliability
Vegetation Management

Appendix B

EXECUTIVE SUMMARY

In support of the objective to gather and document utility practices related to Distribution vegetation management (VM) programs, with a particular focus on strategies for improving system performance in major events, EPRI conducted a web survey of utility practices across a number of thematic areas:

- Governance, Funding and Regulatory Coordination
- Program Planning and Measurement
- Program Attributes
- Contracting Strategy
- Use of Technology

EPRI released the survey on August 27, 2013, and participant responses were collected through November 7, 2013. With many variables in play, the survey revealed a considerable diversity in approach across the various participants, however as a general rule, significant blocs of companies had similar approaches on a topic by topic basis.

While the linkage between respondent names and their specific answers has been stripped for this high-level analysis, certain companies have stood out for their approach to contract management, use of technology, and treatments to prevent the spread of harmful insects. EPRI will follow up with these organizations through interviews to learn more about these approaches and determine if they could indeed stand up as leading practices. EPRI will document and include the results of the interviews (in Chapter 5) in an updated version of the *Literature Review of Vegetation Management Concepts, Methods and Management in Support of Distribution Grid Resiliency* report.

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Appendix B

1 INTRODUCTION

The purpose of this report is to provide a background on the current practices employed by utility survey participants to manage vegetation. It is generally understood that throughout the majority of the US, tree related outages, whether falling limbs or entire trees, are the largest contributor to the overall damage realized by the electric system during adverse weather events.

As a result of the significant impact created by these power outages it is important that utilities develop vegetation management programs that appropriately address the risks associated with the results of tree related outages. Although trees are not generally owned by utilities, an effective vegetation management program is integral to meeting the regulatory obligation of the utility to provide safe and reliable power. Each utility has its unique challenges based upon, among other things, geography, regulatory environment, budget constraints, environmental sensitivities and weather.

Throughout the last decade, the impact of outages has become more severe as society has become more dependent upon electricity. Thus, the focus on electric grid resiliency has heightened the focus upon vegetation management because of its overall impact during adverse weather events. It is critical in grid resiliency strategy development that utility companies develop and implement an integrated vegetation management strategy and selection process to manage the constrained budget with competing priorities to ensure that the utility is achieving its strategic goals and objectives through informed investment decisions.

Overview of Vegetation Management Task

Within the vegetation management (VM) task of its research into Distribution Grid Resiliency (DGR), EPRI will focus on identifying, documenting and sharing VM practices being utilized across the industry. The results of this research will provide a knowledge base of information about VM practices that utilities can use to identify and adapt industry leading practices to their VM program.

The specific objectives of this research activity are to:

- Gather and document utility practices related to VM programs, with a particular focus on strategies for improving system performance in major events.
- Determine and document the mechanisms of vegetation-caused damage to distribution infrastructure during storms, particularly major or “super” storms
- Gather and document cost – benefit information for vegetation management programs
- Identify lessons learned from major storm events
- Determine if there are new options for VM programs that may lead to reduced damage during storms.

Survey Purpose

The survey directly addresses the first objective outlined above and seeks to identify opportunities to follow up with specific participants to gain insight into the remaining objectives.

2 SURVEY OVERVIEW

Survey Methodology

The Vegetation Management Survey sought to characterize the state of Vegetation Management programs in participating utilities through a poll addressing how programs were administered, with what resources, and how utilities were dealing with vegetation-specific issues. The survey was designed by EPRI with input from Davies Consulting LLC and from the utilities participating in EPRI's DGR initiative. Using Survey Monkey, a web-based survey program, the questions were distributed to the utility advisors for the DGR Task 2 (VM) task force.

The first and largest round of responses arrived between August 27 and September 4. EPRI followed up with participants, driving additional waves of responses throughout October and into early November. In total, twenty-six operating companies responded to the survey.

Table 1 - Survey Participants

AEP - Appalachian Power	Central Hudson Gas & Electric Corporation
AEP – Indiana & Michigan	Commonwealth Edison
AEP – Kentucky Power	Consolidated Edison Company of NY
AEP – Ohio	FirstEnergy
AEP – Public Service of Oklahoma	Hydro One
AEP – Southwestern Electric Power	Long Island Power Authority
AEP – Texas	Memphis Light, Gas and Water Division
Alliant Energy	National Grid
Ameren	Orange and Rockland Utilities
Arizona Public Service Company	Pennsylvania Power and Light
Baltimore Gas & Electric	Southern Company – Alabama Power
BC Hydro	Southern Company – Georgia Power
CenterPoint Energy Houston Electric	Xcel Energy

Question Themes

The survey traversed a number of thematic areas ranging from governance to funding, regulatory relations, program execution, support systems and complementary efforts. The questions asked per each area were:

- **Governance, Funding and Regulatory Relations:**
  a. Where is Vegetation Management positioned within the organization?
  b. How is the budget determined for the VM program?
  c. Can the budget be exceeded and if so where does the additional funding come from?
  d. Does your company capitalize any portion of its VM program other than new construction?
  e. How is the investment necessary for VM proposed to the regulators?
- **Program Planning and Measurement:**
  a. Does the planning process allow for pre-work planning and/or inspection of circuits prior to routine line clearing?
  b. Are tree species and growth rates taken into account in the planning and scheduling of the VM program and if so, how?
  c. How do you measure the cost-effectiveness and results of the VM program?
  d. Does your company survey its customers for feedback on the VM program?
  e. Does your VM program conduct post-storm patrols for any vegetation-related issues following the restoration of service after a major storm?
  f. Have you implemented or do you plan to implement VM program changes in order to improve system resiliency to tree-caused damage in major storms

- **Program Attributes:**
  a. What is the basis for planning and scheduling the VM program – cycle, optimization, other?
  b. Does your vegetation management program include provisions for trimming secondary conductors?
  c. Does the VM program include a formal mid-cycle patrol?
  d. What are your minimum tree clearances above, below and to the side of roadside / backlot / yard / right of way circuits of varying voltages?
  e. Does your utility have a Hazard Tree program, and if so how is it defined?
  f. Do you employ Tree Growth Regulators?
  g. Do you evaluate insect impact contributing to tree disease and mortality rates in specific areas?
  h. Have you found a successful treatment for the Emerald Ash Borer?
  i. Who owns the poles upon which the electric distribution equipment is placed, and are rental fees and/or taxes paid to the owner of the property on which poles and equipment are placed?
  j. Does your company hold property owners responsible for hazard trees that have caused damage to distribution facilities after the property owner prevented you from removing the tree?
- **Contracting Strategy:**
  a. How are VM contractors managed and paid, and do the contracts include provisions for performance-based incentives and/or penalties?
  b. What is the maximum number of contract tree crews you assign to a VM field supervisor?
- **Use of Technology:**
  a. What technology do you use to help plan / schedule / administer the VM program and how is the technology used?

Appendix B

3 SURVEY SUMMARY AND FINDINGS

This chapter provides an assessment of the survey responses and insights gained from the analysis of the responses. In order to provide coherent analysis, the questions addressed in this section have been sequenced to align with the Theme Areas outlined in Section 2 of this document.

Governance, Funding and Regulatory

This thematic area focuses on how the VM organization is positioned within the company, how funding decisions are made and how the VM organization and/or company interacts with the regulator.

The overwhelming majority of utilities run VM programs from within Operations, with some using Operations supported by Asset Management or another corporate function.

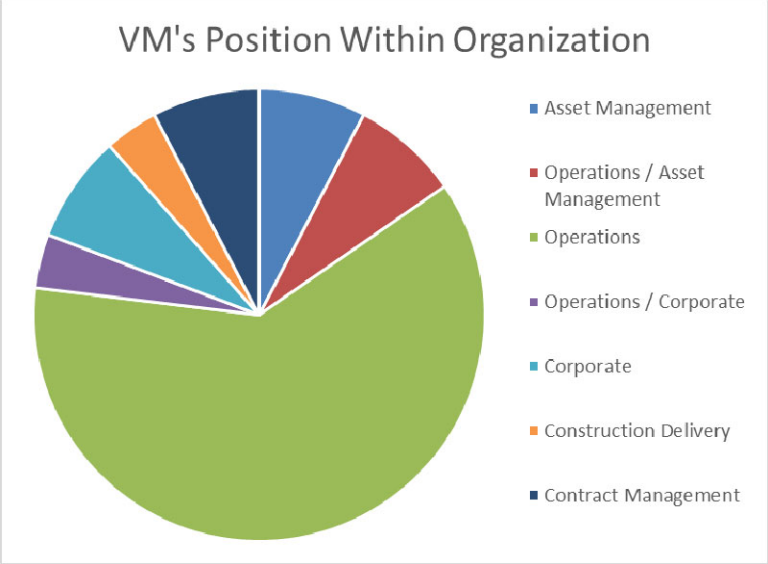

Figure 1 - Vegetation Management's Position in the Utility

Of the utilities citing a single driving factor for determining VM Budgets, Finance, Trim Cycle and Regulatory Mandates were given equal billing. When examining the various combinations of factors, Trim Cycle becomes the dominant theme, involved in 12 of 26 responses, followed by Regulatory Mandates, involved in 10 of 26 responses, and Reliability Goals, involved in 9 of 26 responses.

Table 2 - Source of Funding Decisions for VM

	Asset Management	Operations / Asset Management	Operations	Operations / Corporate	Corporate	Construction Delivery	Contract Management
Finance / ROE			4		1		1
Regulatory Driven			5			1	
Trim Cycle / Plan	1	1	3		1		
Reliability Goals			1				1
Trim Cycle / Plan, Regulatory	1	1					
Trim Cycle / Plan, Reliability Goals, Regulatory			1	1			
Trim Cycle / Plan, Reliability Goals			1				
Finance / ROE, Trim Cycle / Plan			1				

Three utilities declared there was no flexibility when it came to adjusting budgets, while twenty-two had the flexibility to draw funds from other corporate O&M or other programs to pay for additional work. Only one utility had a mechanism to go back to the ratepayer for additional funding.

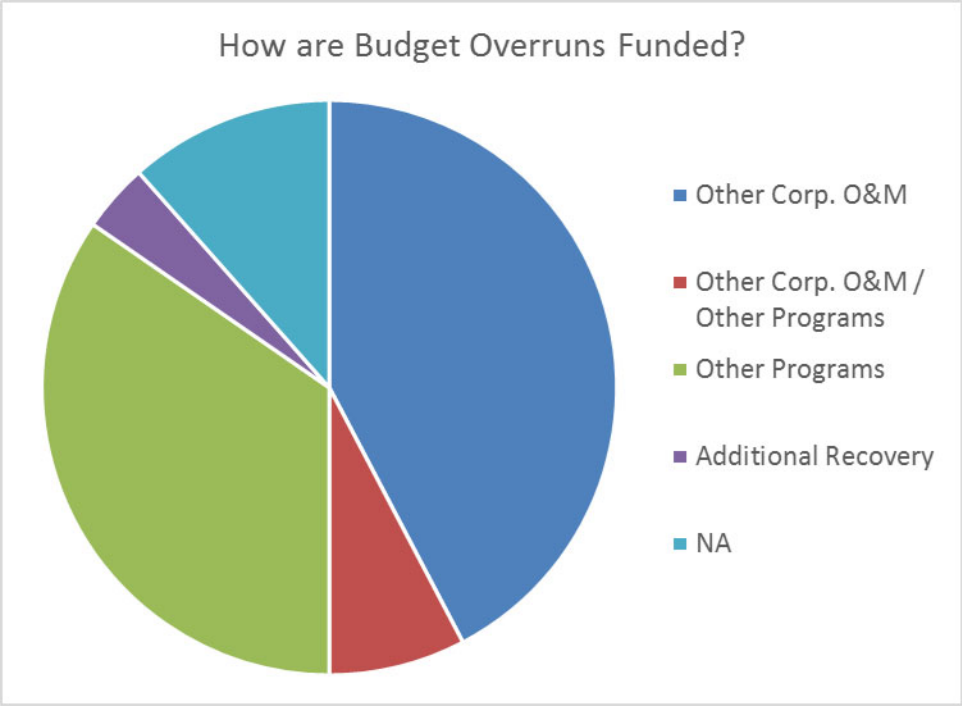

Figure 2 - Funding for Budget Overruns

Very few organizations had mechanisms for capitalizing VM work. The applicable mechanisms were:

- Capitalizing a portion of major storm work
- Increasing clearances
- The first ever application of an herbicide on a feeder
- Trimming in the immediate vicinity of new capital installations

The majority of utilities surveyed took some steps to socialize their VM programs and budget spends in advance of the rate case, whether through periodic meetings or detailed discussions. Only seven wait until the Rate Case to present their program, and three wait for regulator-driven meetings.

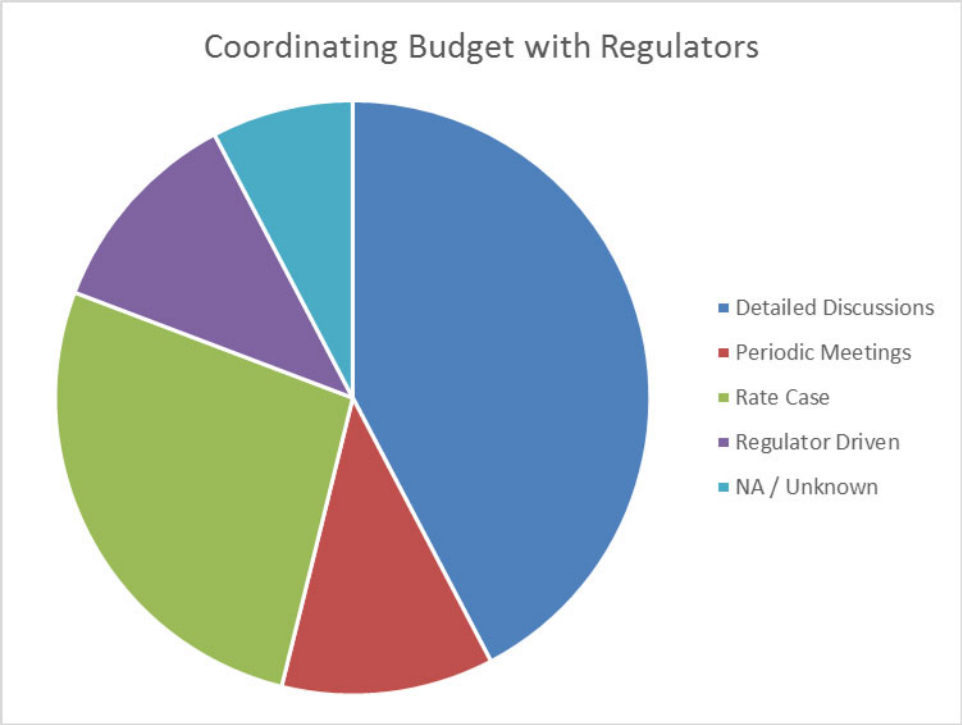

Figure 3 - How Budget is Communicated / Coordinated with Regulators

Program Planning and Measurement

This thematic area focuses on factors incorporated into the planning process and how measures are applied to the VM program.

Twenty-two of the twenty-six companies patrol and inspect feeders as part of the planning process. Of those, half include internal employees in the inspection team, while the other half carries out the inspections exclusively with third party companies or tree contractors. Only ten companies conduct additional species analysis as part of the planning process. Of these, most use line patrols to gather the data, but three look to external studies for species information.

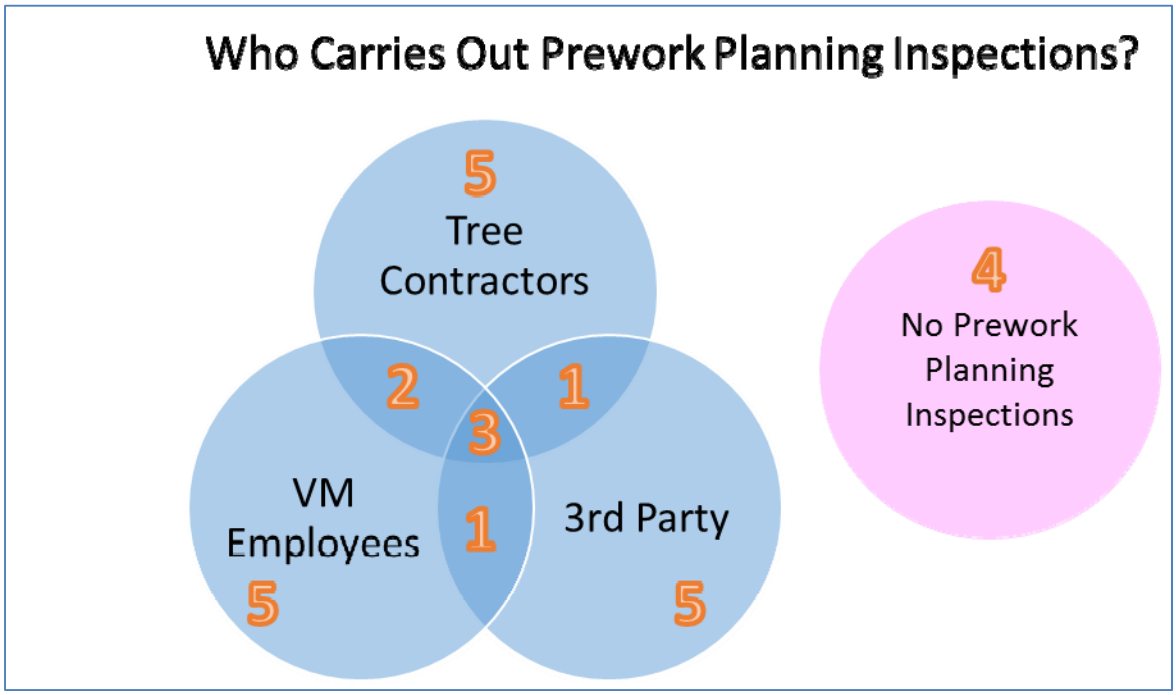

Figure 4 - Prework Planning Inspections

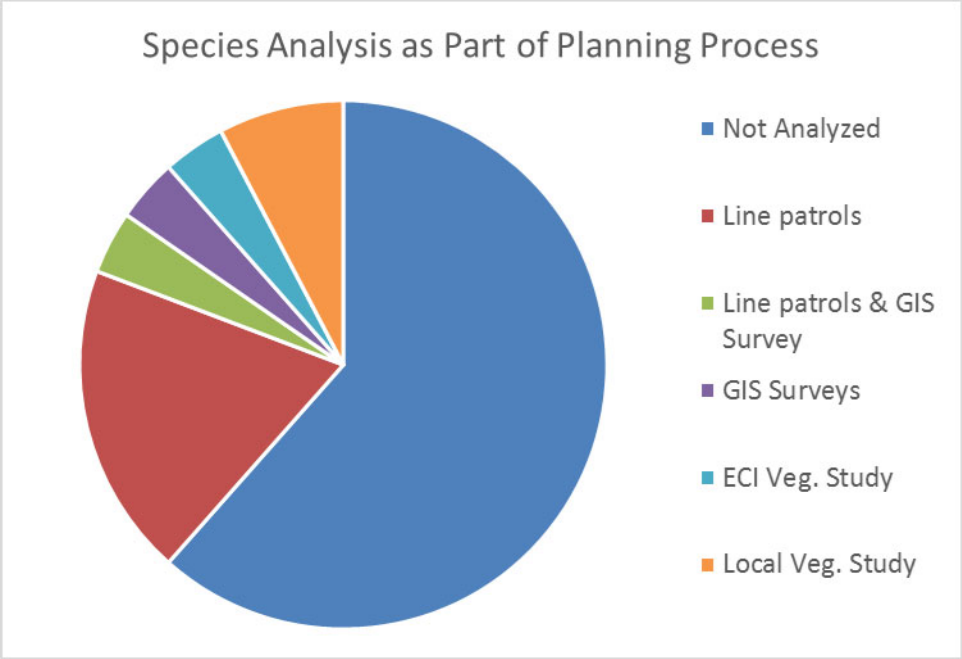

Figure 5 - Methods of Species Analysis

Three companies are using a dollar per customer served metric to evaluate the appropriateness of their VM spending levels. Ten others are striving to quantify the reliability benefit associated with the money spent on VM. The other half do not attempt to analyze their spending.

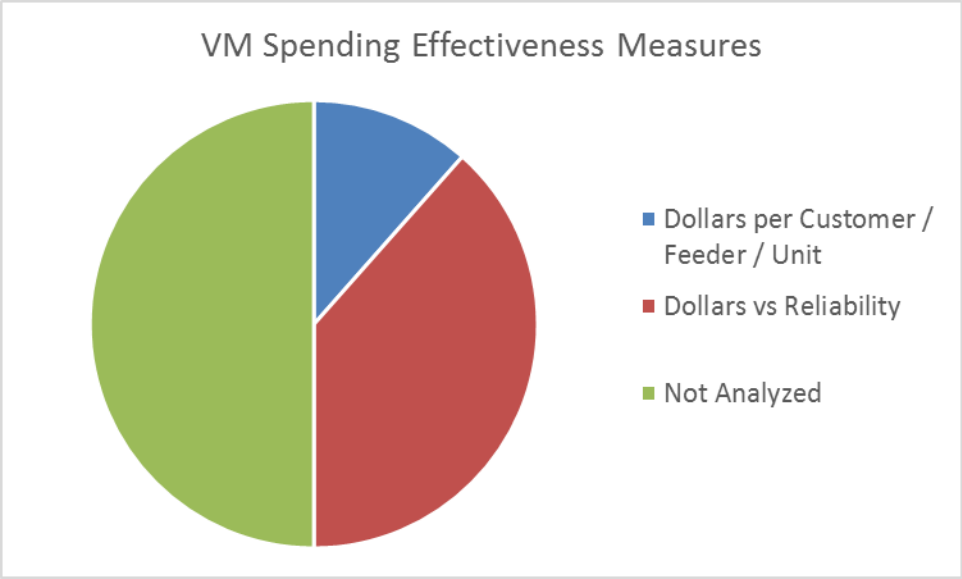

Figure 6 - Measures of VM Spending Effectiveness

Half of the companies surveyed do not actively conduct customer satisfaction surveys. Of these, one does send out door hangers or letters, and one reviews customer complaints, putting them slightly ahead of the companies which do not gather any data. Most of the other half of companies incorporate VM-related customer satisfaction questions into their annual customer

satisfaction survey. One contracts a third party to conduct phone surveys, while another surveys statistical samples on completed feeders each year.

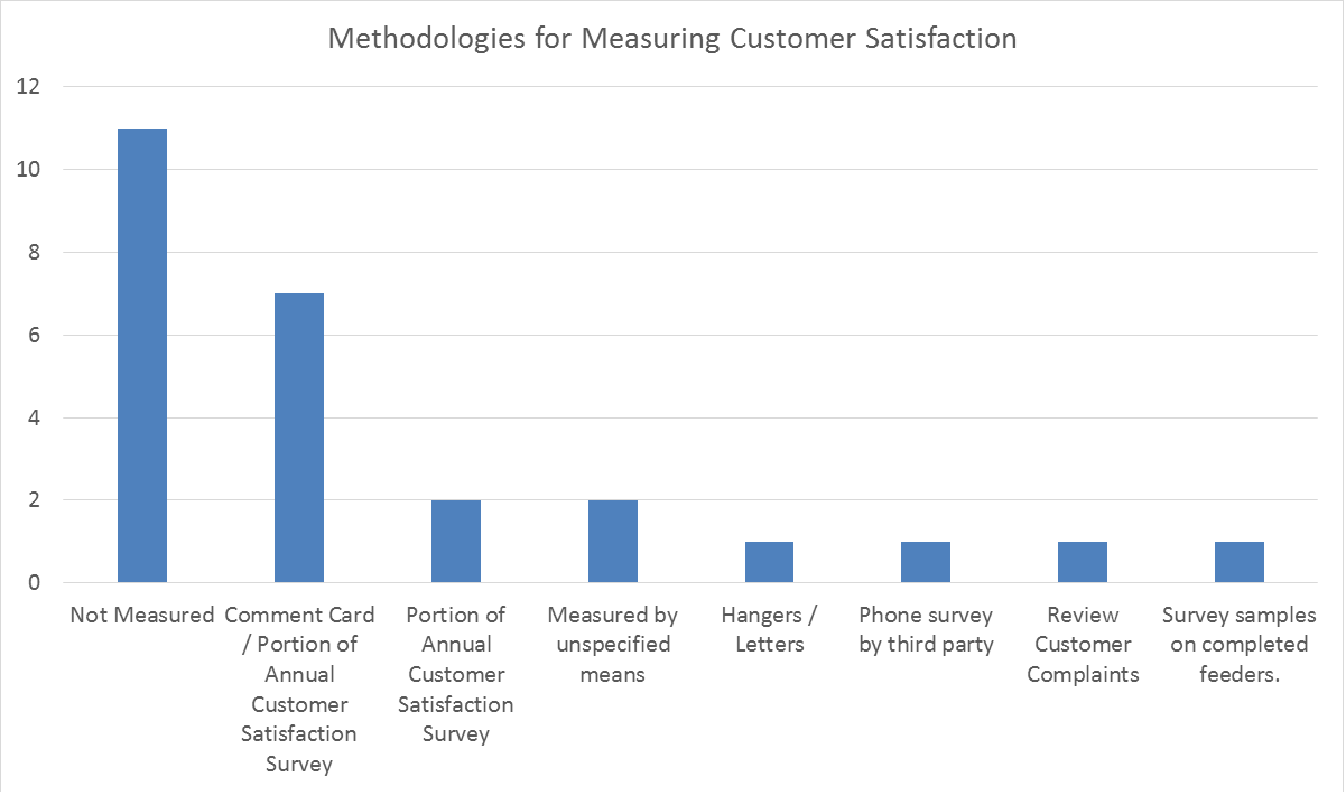

Figure 7 - Customer Satisfaction Measurement

Just over half (fourteen) of the companies do forensic post-storm analyses of tree failures following a major event. As a result of increased storm activity in recent years coupled with the recognition that trees are a major cause of outages in a major weather event, many companies are altering their approach to vegetation management. The eighteen companies changing up on VM are employing some combination of the following strategies:

- Increasing funding to either get their systems on cycle or onto a shorter cycle
- Modifying (increasing) clearances in key areas
- Changing the basis by which they prioritize circuits and/or determine cycle for groups of circuits
- Implementing Hazard Tree Programs
- Other forms of Analysis and Continuous Improvement

Table 3 - Methods to Adjust VM in light of Increased Storm Activity

Adjusting VM for Increased Storm Activity	Conducts Post-Storm Analysis	
VM Program Adjustments to Improve Resiliency	No	Yes
Modified Clearances in key areas		1
Modified Clearances		3
Modified Clearances & Reduced Cycle		2
Modified Clearances & Reduced Cycle & Changed Basis for Prioritization	1	1
Changed basis for prioritization	2	
Continuous analysis and improvement		1
Hazard tree as function of WPF program		1
Planned Chages Pending regulatory approval		1
Implemented proactive trimming & hazard tree		1
Seeking funding to get on cycle	4	
None	5	3

Program Attributes

This theme explores the activities undertaken and measures implemented to manage vegetation in the vicinity of conductors.

It is a fairly common practice to establish a period of three to four years and commit to making sure the entire system gets trimmed in that timeframe. In some cases, a utility will identify different periods, for different parts of the system. Whether there is a single period for the entire system or a number of declared variants, this is known as trimming to a cycle. The overwhelming majority of companies trim to cycles which are between three and five years. Only one company, with very short clearances reported a two year cycle. Only three companies declared cycles greater than five years, although another four stated they were not on a cycle, meaning their budget was insufficient to proactively trim all circuits in the system on a schedule, and instead focused on reactive trimming.

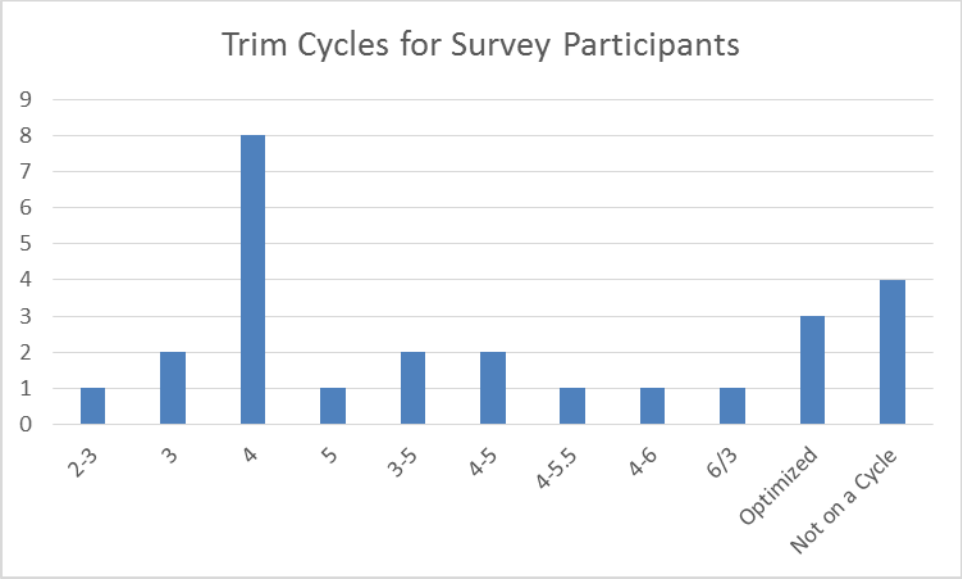

Figure 8 - Participants' Backbone Trim Cycles

Over the past decade, some jurisdictions have entertained the notion of accelerating the work on the backbone while focusing less effort on laterals. The underlying driver of this practice is the probability that backbone outages have the potential to have greater impact on reliability than those on the laterals, so greater SAIFI and SAIDI gains can be realized per dollar invested. While this works in theory, many companies are reluctant to execute such a strategy as it poses significant operational challenges. Of the twenty-six participating companies, only one trims their laterals on a different schedule than their backbones.

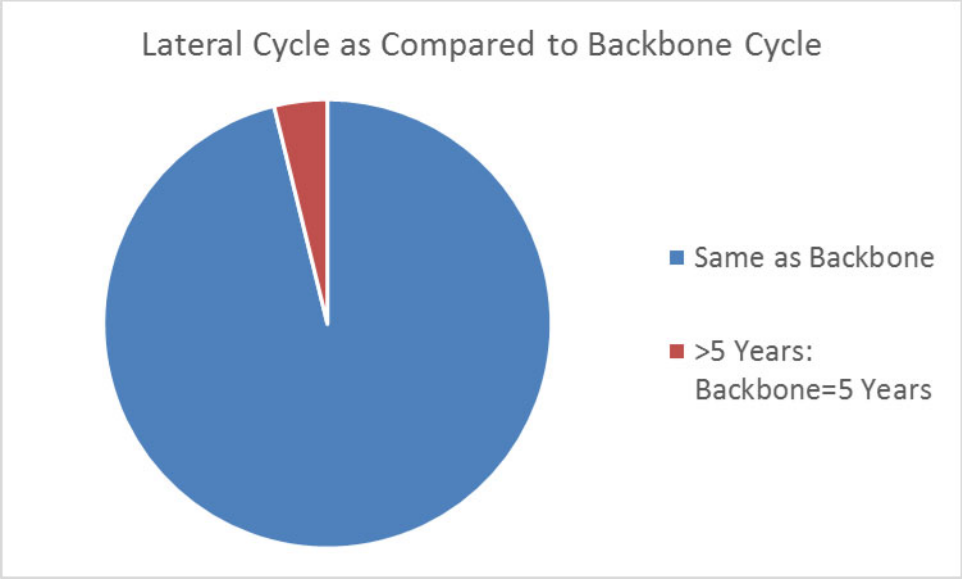

Figure 9 - Differences between Lateral Cycle and Backbone Cycle

Almost two third of the companies surveyed do not trim the secondary, or only trim it when runs below the primary.

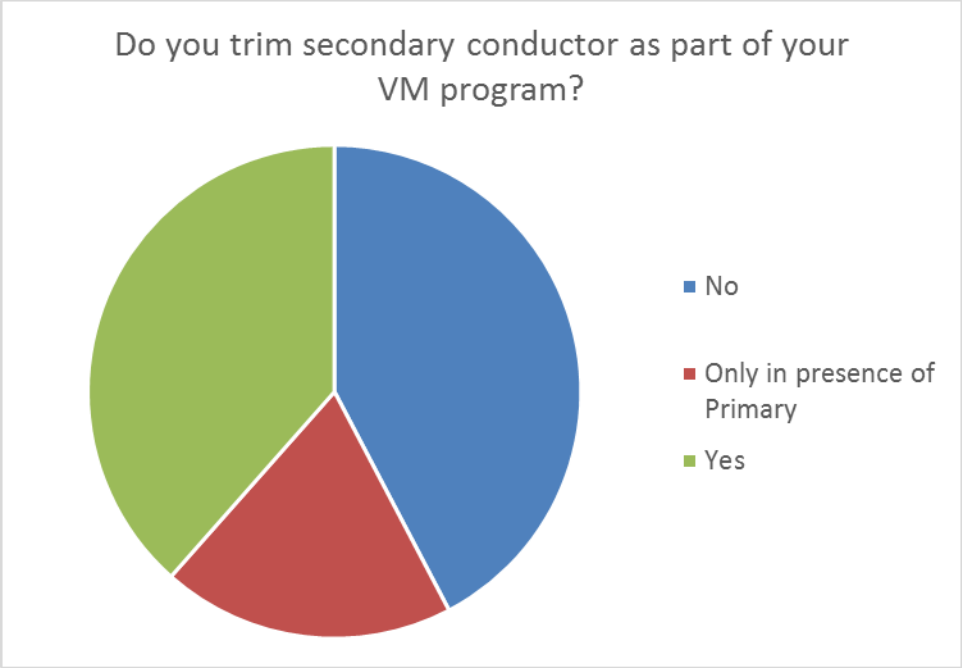

Figure 10 - Secondary Trimming

Only seven companies run a formal mid-cycle program.

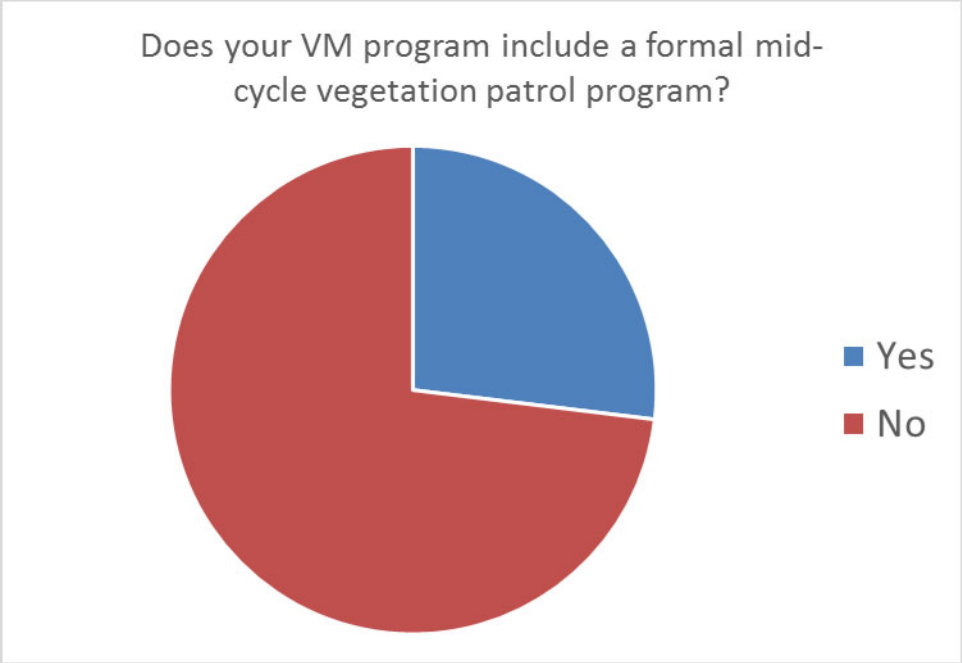

Figure 11 - Midcycle Patrols

Clearance is the distance above / below and to the side of conductors that should be kept clear of any form of vegetation. Utilities strive to keep this zone clear by trimming several years' growth back from the conductors when branches are on the cusp of encroaching on the zone. One generally expects that companies will define larger clearances for higher voltages. This holds true for approximately 1/3 of the companies. Two companies have declared different clearances for backbones vs. laterals.

The majority of clearances are set at 10 feet, with values ranging from 5 to 20 feet. Some companies have declined to define a clearance, but focus instead on describing a process whereby the arborist cuts according to their expertise and judgment, removing an amount of wood appropriate for the species of tree, the voltage of the circuit and time that is expected to elapse before the next trim.

For the most part, the companies' clearances are unaffected by whether the circuit is Roadside, Backlot, on the Right of Way or in a property owner's yard. There are three exceptions:

- For one company, the clearance on backlot is significantly less than it is for the other three categories.
- Two companies define smaller clearances for yard trees than they do for the other three feeder location categories

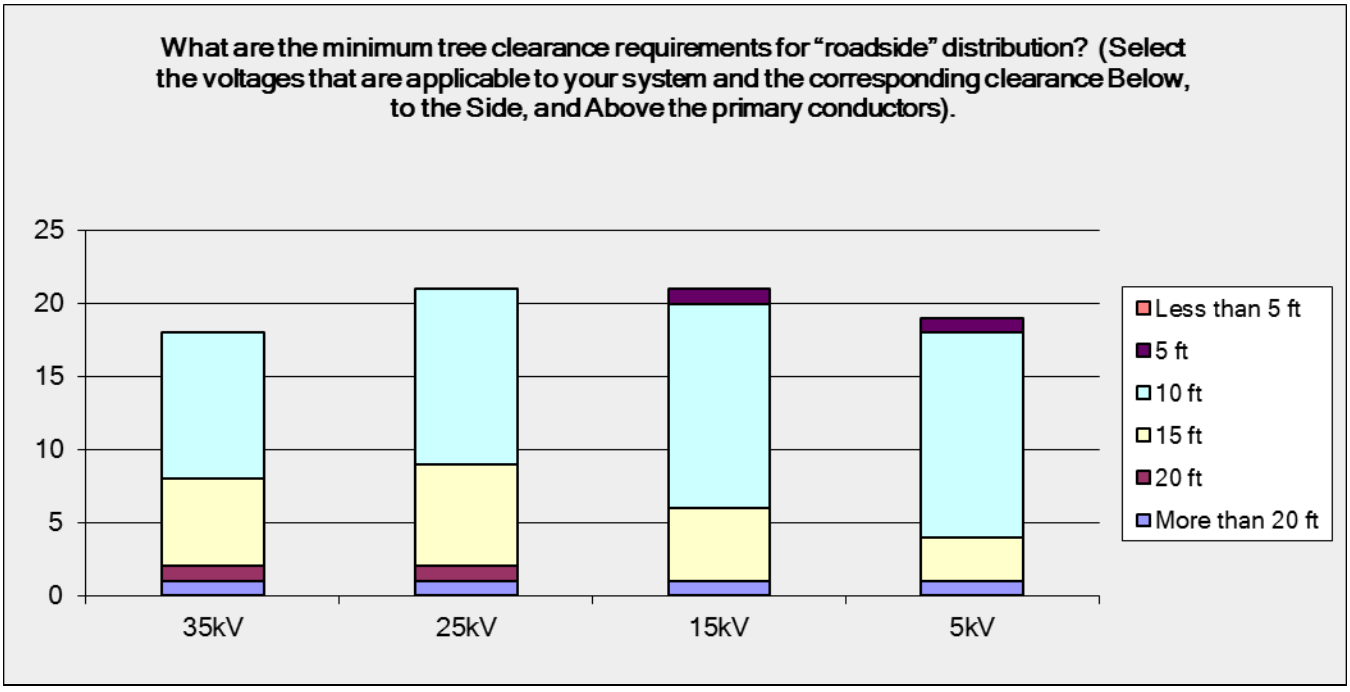

Figure 12 - Backbone Clearances

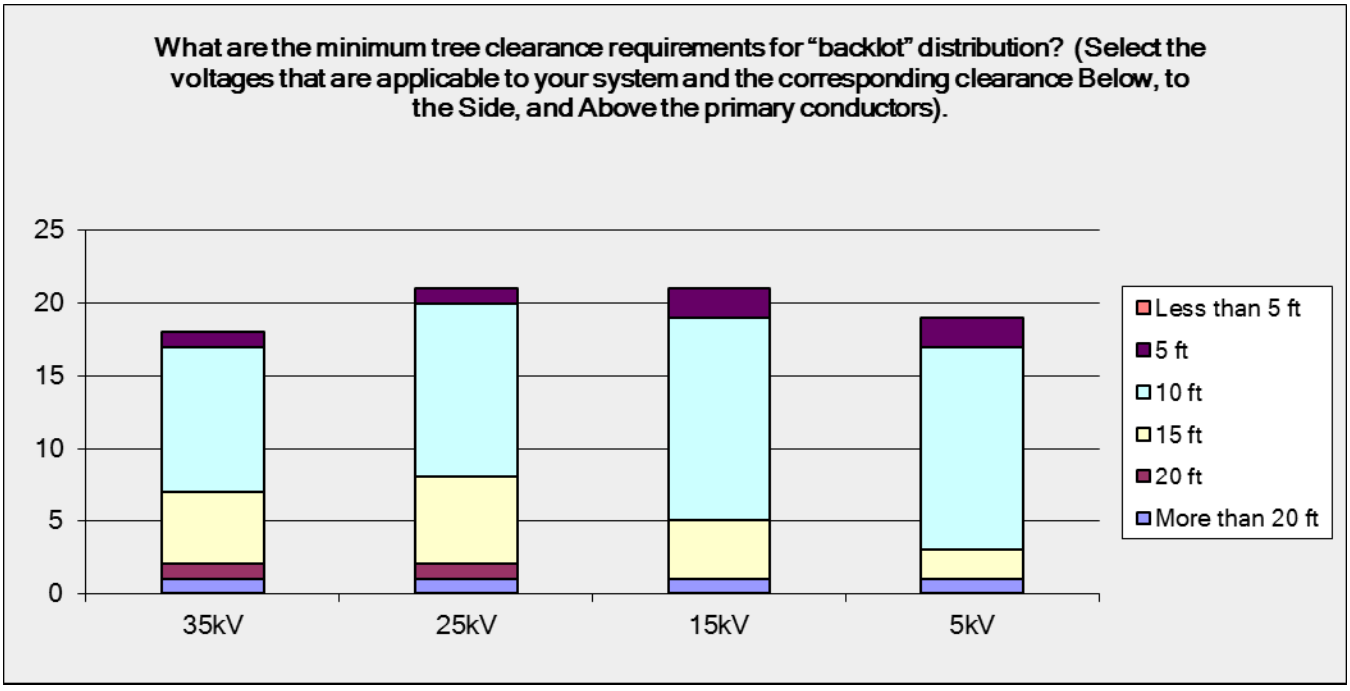

Figure 13 - Lateral Clearances

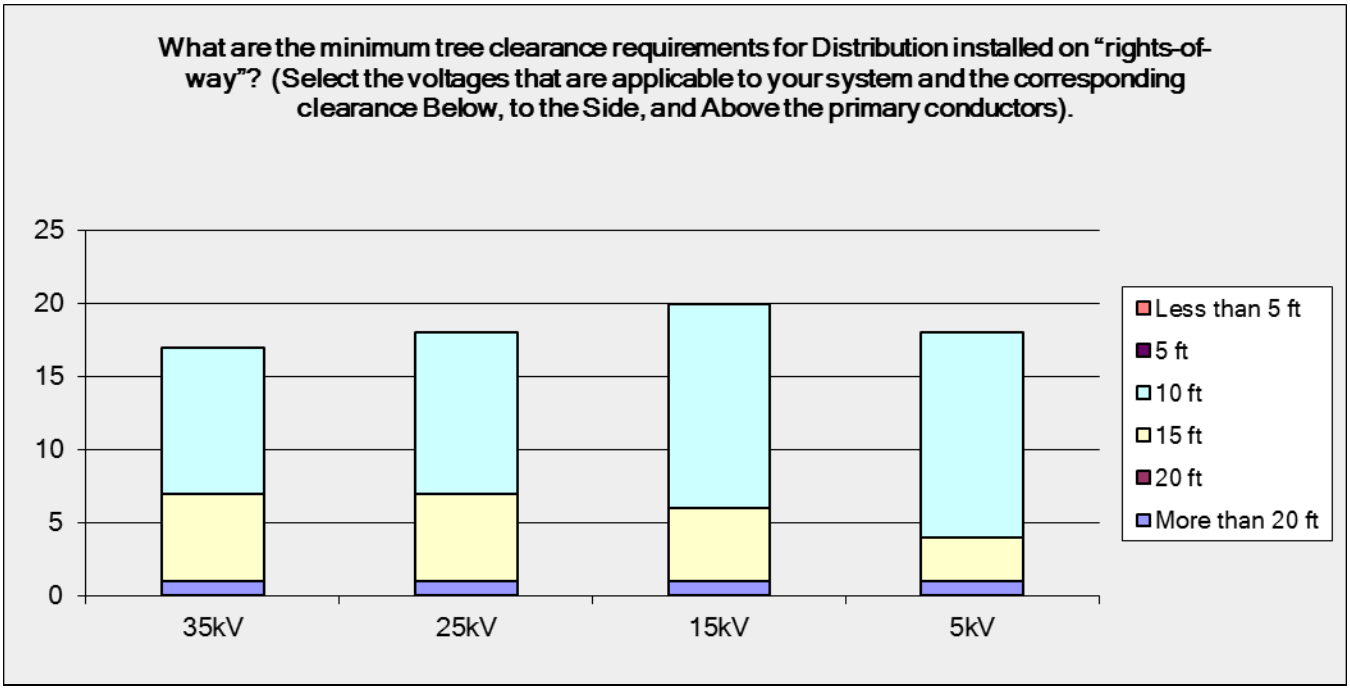

Figure 14 - Right of Way Clearances

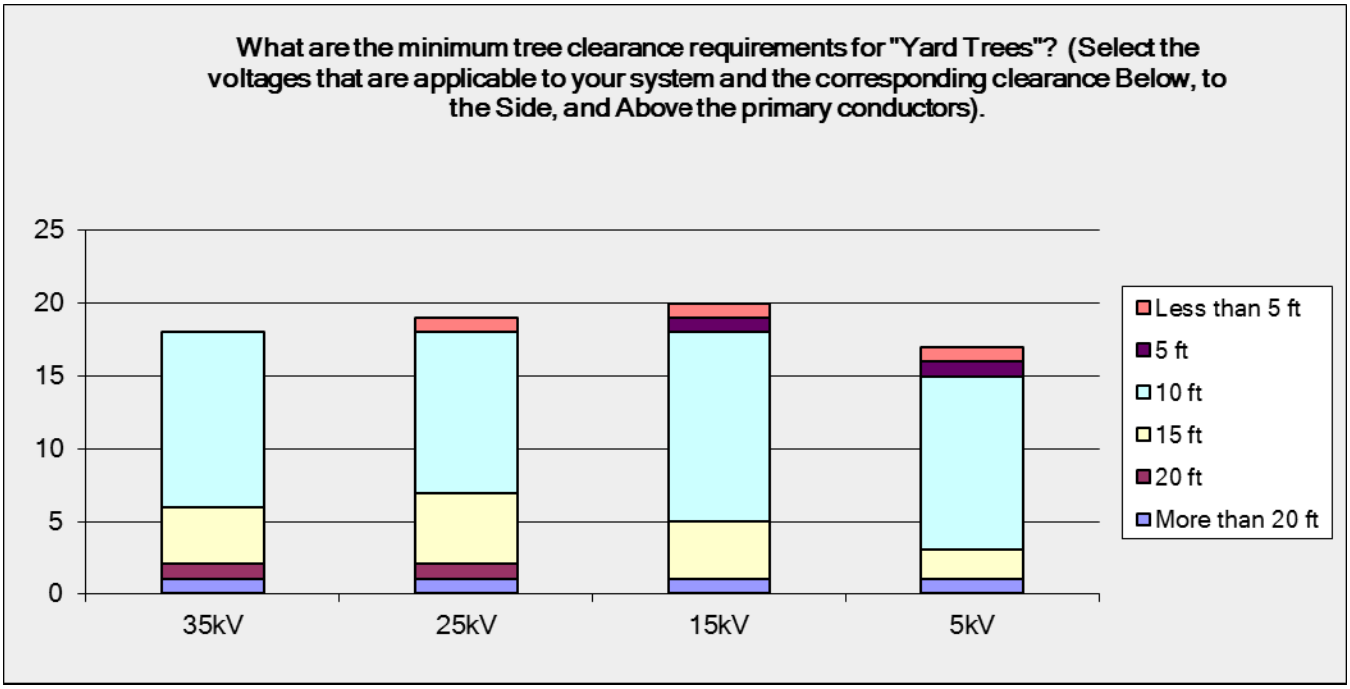

Figure 15 - Yard Tree Clearances

Hazard trees are those trees which pose a risk to utility equipment because they are close enough to come in contact with the system if they were to fall, and likely to fall because they are dead or in poor health, or if soil conditions are such that the tree could uproot. All but three of the utilities have hazard tree programs in which such trees are removed. The majority define the

territory in which they will identify hazard trees in a way which takes the height of the tree in consideration.

- Eleven consider any danger tree whose height is greater than the tree's distance from the centerline of the feeder.
- Seven focus on a narrower zone, in which the tree is tall enough to touch the conductor if the tree were to topple.

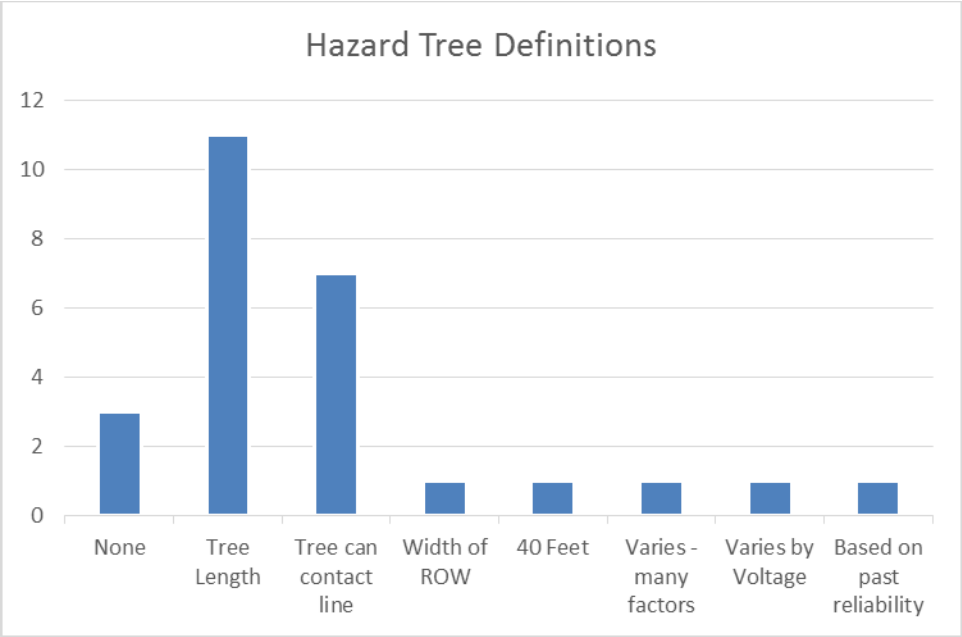

Figure 16 - Definitions of Hazard Tree Programs

Half of the companies use Tree Growth regulators to slow the growth of tree limbs as part of their VM strategy.

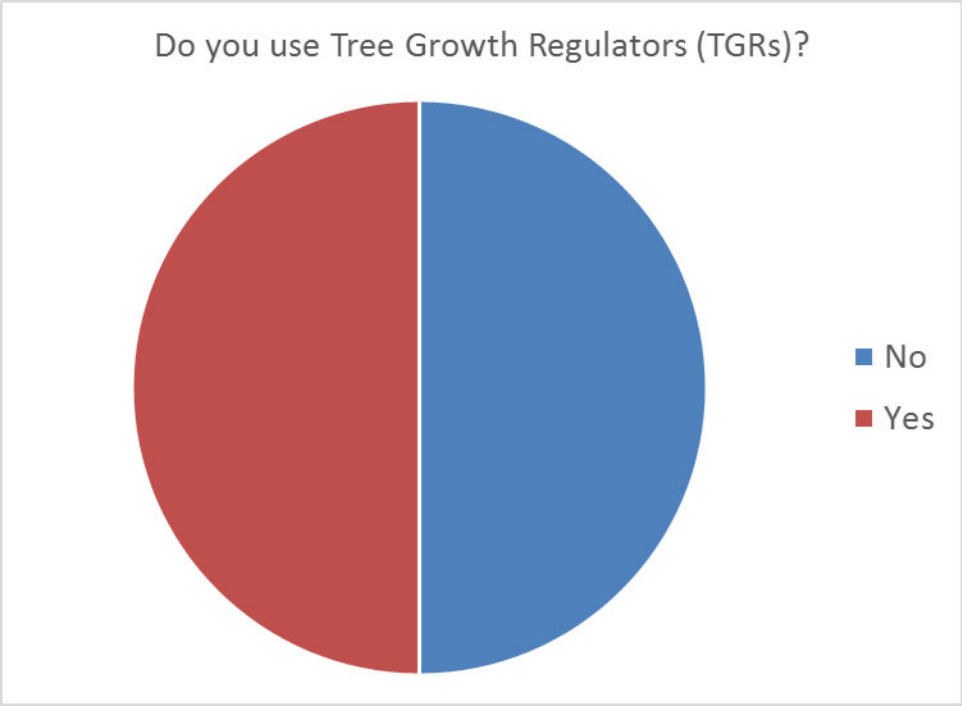

Figure 17 - Use of Tree Growth Regulators

Eleven companies do not perform any analysis relating to insect impact, although it must be noted that many of these are in areas not affected by infestations. Another eleven perform forensic analyses on fallen trees and branches when trees interrupt power in an area known or suspected to be infested. The remainder rely on locally conducted studies to determine which areas are vulnerable to insect damage.

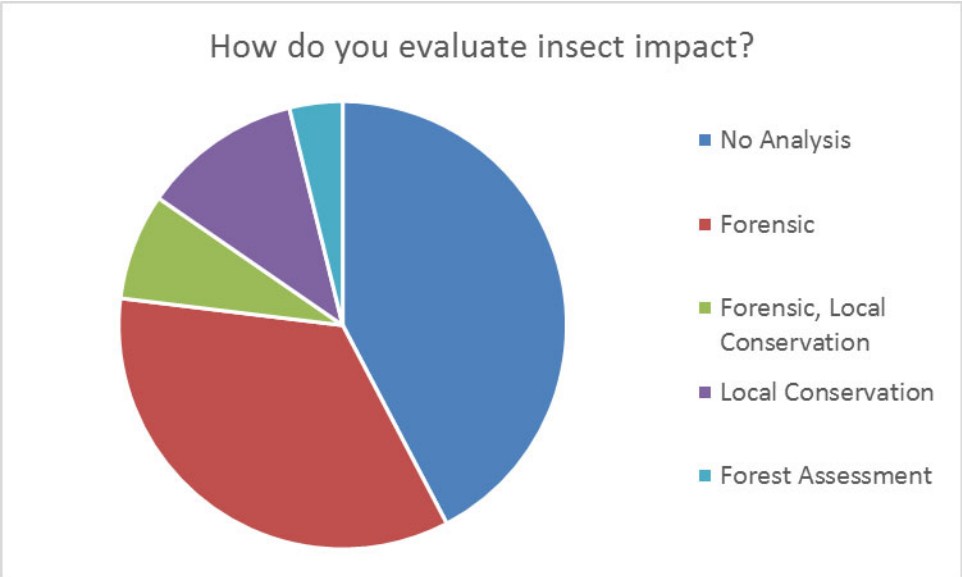

Figure 18 - Evaluating Insect Impact

Only five utilities identified techniques for contending with the Emerald Ash Borer Beetle, but the tactic they all had in common was to remove and destroy affected trees. One company did identify a Bayer product, Imidadoprin, which was effective in preventing the spread of emerald ash borers.

On the matter of pole ownership, only four utilities claimed exclusive ownership and access to their own poles. Five described themselves as sharing with only one other utility in some circumstances, and the remaining seventeen share with one or more utilities in areas within their territory. As a general rule, these pole-sharing situations are governed by joint use agreements, and while the electric utility is usually the pole owner, this is not always the case.

Contracting Strategy

This theme area explored the methods for compensating and monitoring VM contractors.

Common contract payment mechanisms for vegetation management include Time and Equipment (T&E), Unit-based pricing (e.g. price per mile, per tree, per volume of wood cut, etc.) and fixed price quotes for individual feeders. While two companies operate purely on units-based contracts and five work strictly with time and material contracts, most are using some combination of the various methods. Typically, this translates to fixed-price contracts for scheduled cycle trims and T&E for very small circuits and/or reactive trimming.

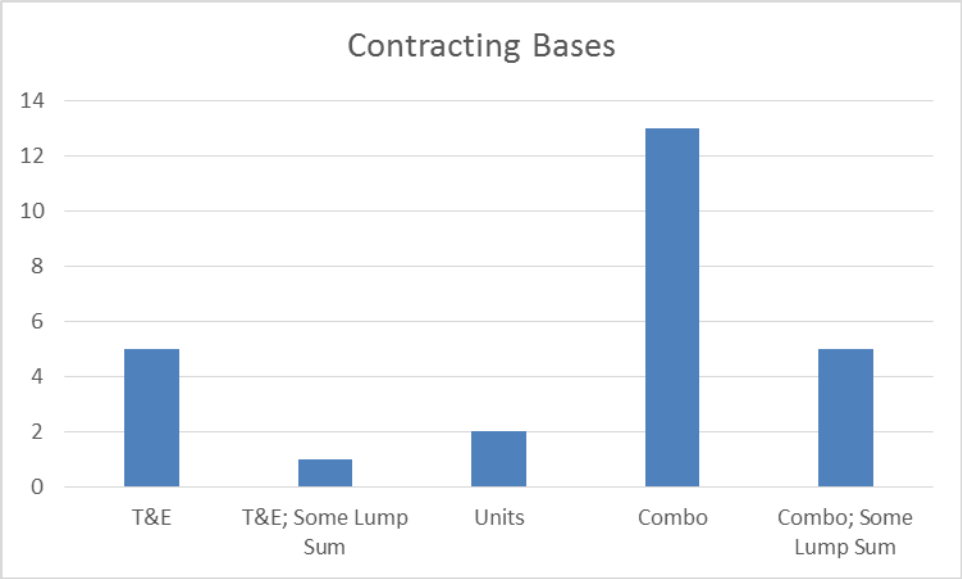

Figure 19 - Contract Bases

Just over half of the companies institute performance penalties and/or incentives associated with the trimming work. Another two have developed evaluation systems which influence contractors' opportunity to win future contracts. The remaining companies no performance incentives in place.

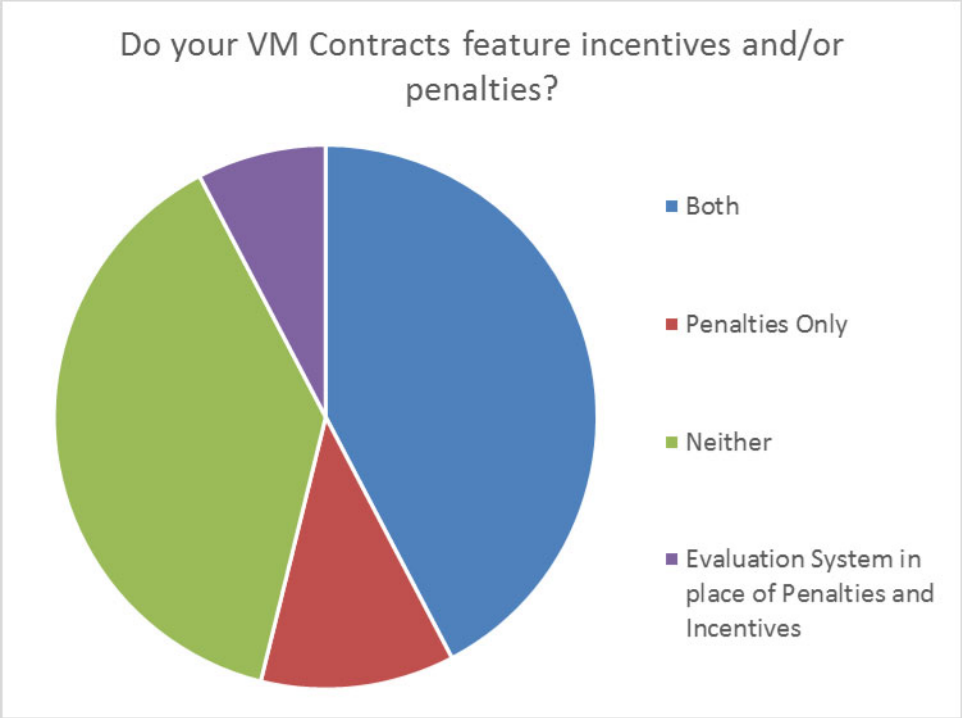

Figure 20 - Contract Incentives and Penalties

Just over half of the companies allow their internal VM staff to supervise sixteen or more contractor tree crews in the field. Four companies relegate crew management to the contractors themselves, one company works exclusively with internal resources and the remaining seven companies use supervisory ratios of one internal resource to 4-15 crews.

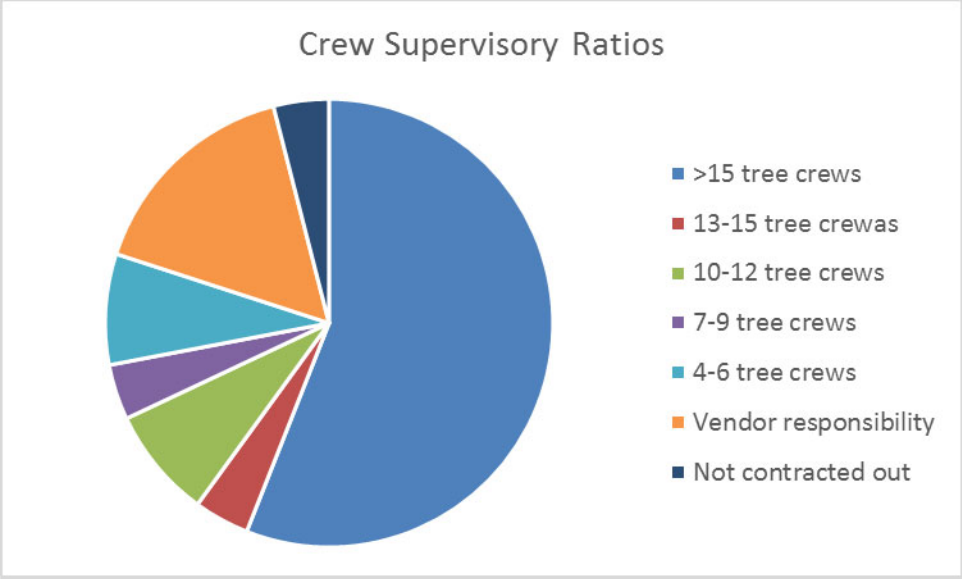

Figure 21 - Supervisory Ratios

Use of Technology

Only six companies are not using GIS in some way to plan or manage their VM programs. Of the twenty using GIS, one stands out in terms of the extent of its GIS utilization, where such information as tree species and numbers, work and payment tracking, weather data and more are factored into the decision making process.

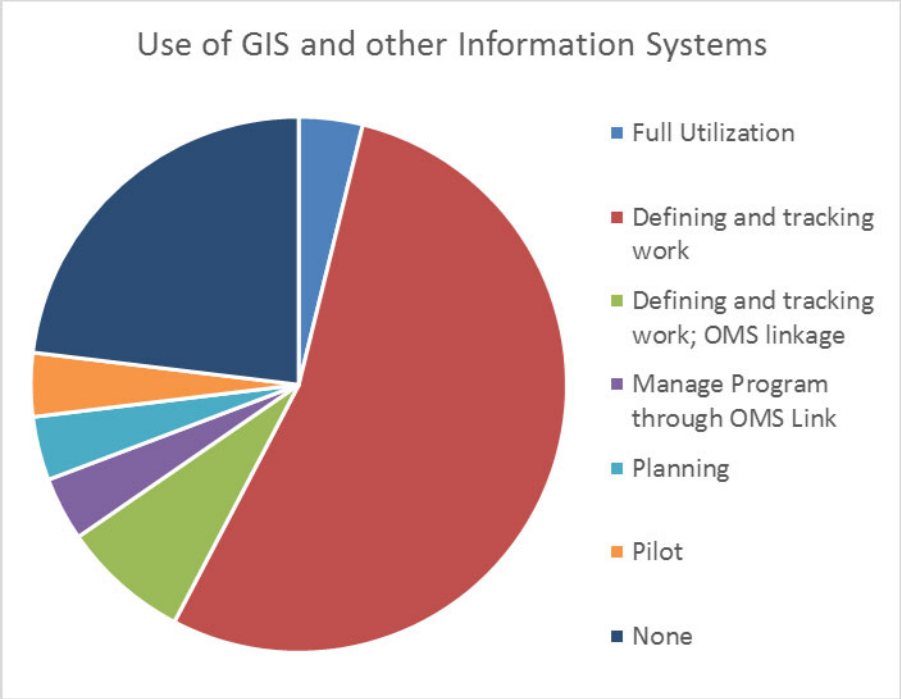

Figure 22 - Use of Information Systems

Appendix B

4 RAW RESPONSE TALLIES

The following tables and charts are drawn directly from the survey website, and rearranged into the theme areas. Please note that in many cases, it was possible to select more than one option for a given question, so the sum of the 'Response Count' may exceed the number of participants who answered the question.

Governance, Funding and Regulatory

Table 4 - Question 2 Responses

Where is your Vegetation Management group placed within your organization?		
Answer Options	**Response Percent**	**Response Count**
Corporate responsibility - other than asset management	11.5%	3
Operational responsibility - overhead distribution	46.2%	12
Operational responsibility - overhead transmission	3.8%	1
Operational responsibility - across transmission and distribution	23.1%	6
Asset management	15.4%	4
Other (please explain)	23.1%	6
answered question		26
skipped question		0

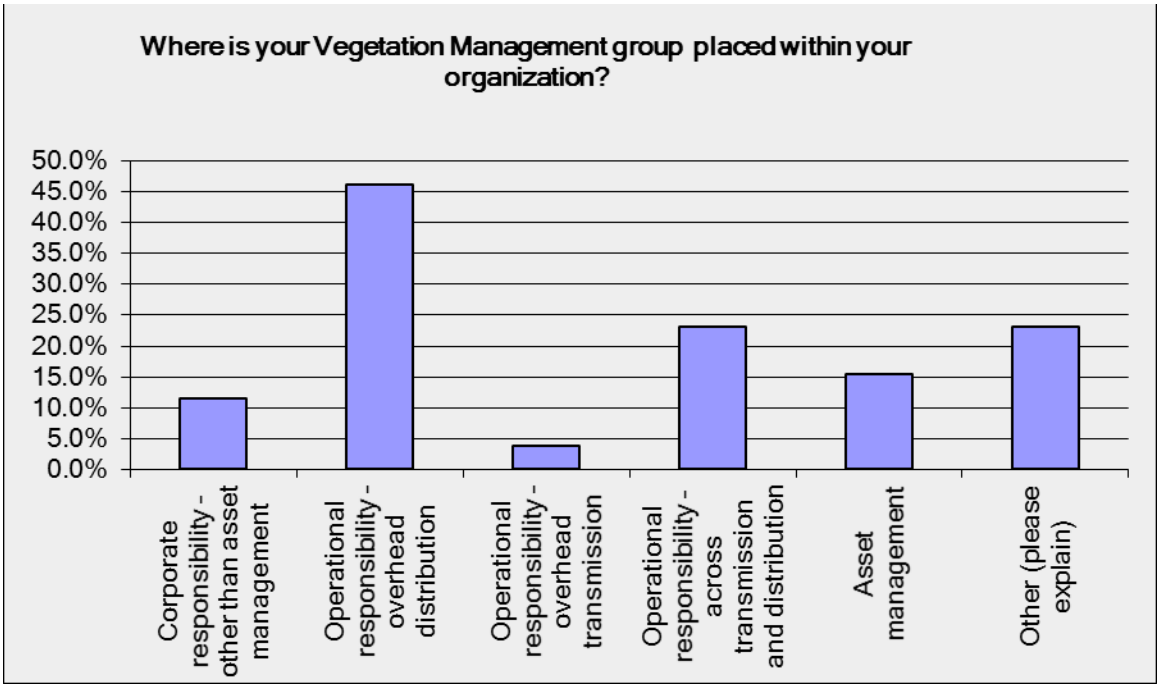

Figure 23 - Question 2 Responses

Free-Text Responses:

1.	Construction Delivery
2.	Asset Management is responsible for the funding and planning of vegetation maintenance with consultation of the operations group. Operations collect inventory based on the vegetation cycle with priorities defined by Asset Management. Both groups work very closely together in the planning, preparation and execution of the program.
3.	split by State
4.	Project and Contract Management
5.	Operational Responsibility-Overhead Distribution Corporate Oversight-Overhead Distribution Corporate Responsibility-Overhead Transmission
6.	Contract Management

Table 5 - Question 3 Responses

How is the budget determined for the VM program?		
Answer Options	**Response Percent**	**Response Count**
Finance determines allocation based upon impact to ROE	26.9%	7
Budget determined by actual necessary work as set forth by a circuit trim cycle or plan	42.3%	11
Operations determines budget based upon impact on SAIFI / SAIDI / CAIDI and meeting corporate / regulatory reliability goals	19.2%	5
Regulator allocated funding is determining factor	38.5%	10
Other (please explain)	15.4%	4
answered question		26
skipped question		0

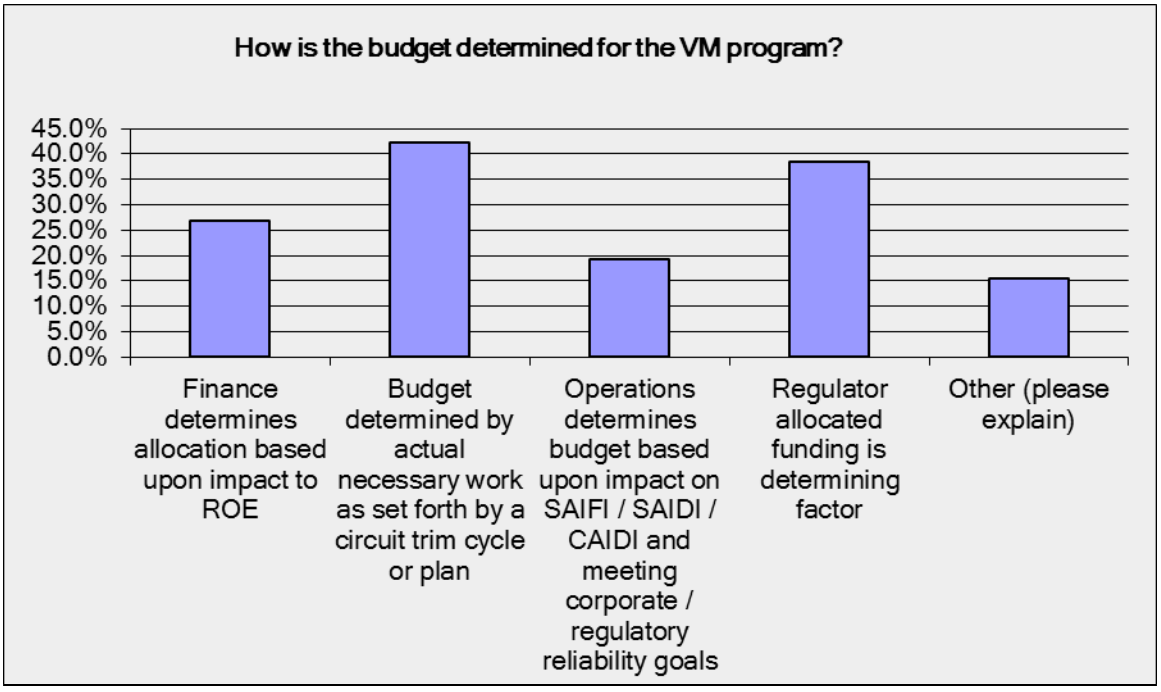

Figure 24 - Question 3 Responses

Free-Text Responses:

1. Operations and Vegetation Management develop the budget based on routine cycle requirements and SAIFI/SAIDI/CAIDI reliability needs.
2. Agreed commitment with the regulator.
3. Operating company heavily influenced by 2008 Vegetation Regulatory Rule; second operating company by Regulator mandated trim cycles
4. Influenced by many other things, e.g. earnings, politics, reliability results, desired cycle status, etc.

Table 6 - Question 7 Responses

If the budget is exceeded where does the additional funding come from?		
Answer Options	**Response Percent**	**Response Count**
Other corporate O&M funding	50.0%	13
Cutting other programs to acquire the funds	42.3%	11
We are permitted to seek additional recovery from customers via a regulatory filing	3.8%	1
There is already a provision in the rate case for recovery of additional funding	3.8%	1
Other (please explain)	15.4%	4
answered question		26
skipped question		0

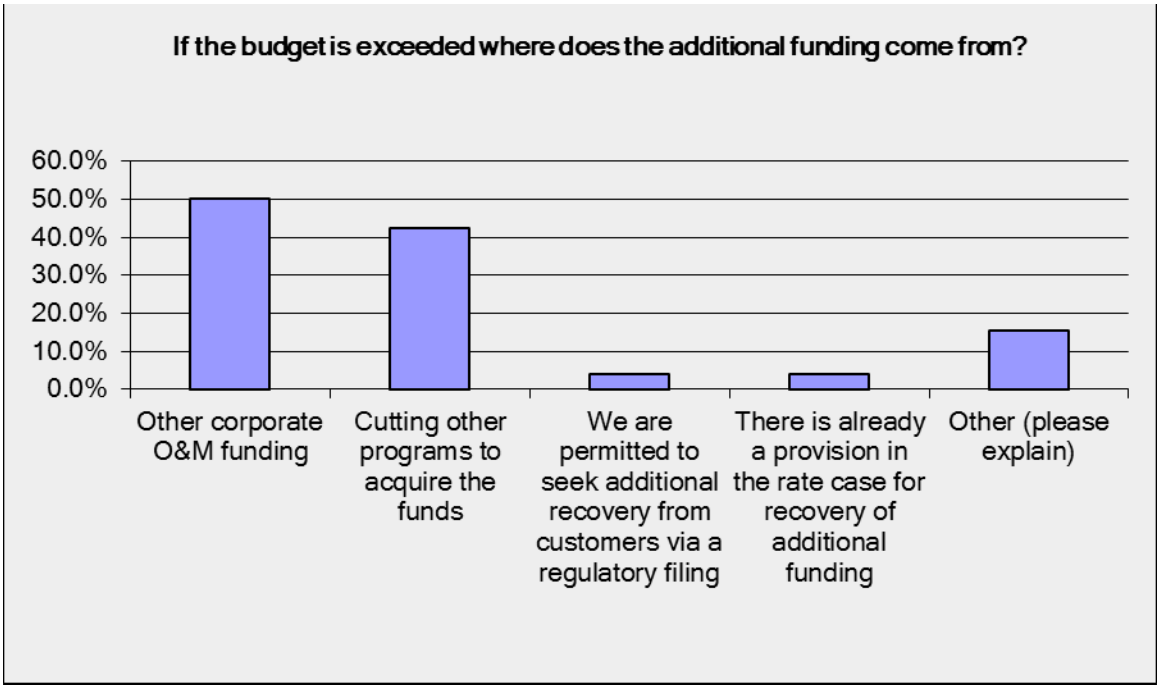

Figure 25 - Question 7 Responses

Free-Text Responses

1. Work plan is adjusted to meet budget target
2. Budget is not to be exceeded.
3. expected to stay within budget
4. We may need to cut scope

Table 7 - Question 29 Responses

Does your company capitalize some portion of its vegetation management program? (Note: other than for new construction).		
Answer Options	**Response Percent**	**Response Count**
Yes (please describe in text box below)	38.5%	10
No	61.5%	16
answered question		26
skipped question		0

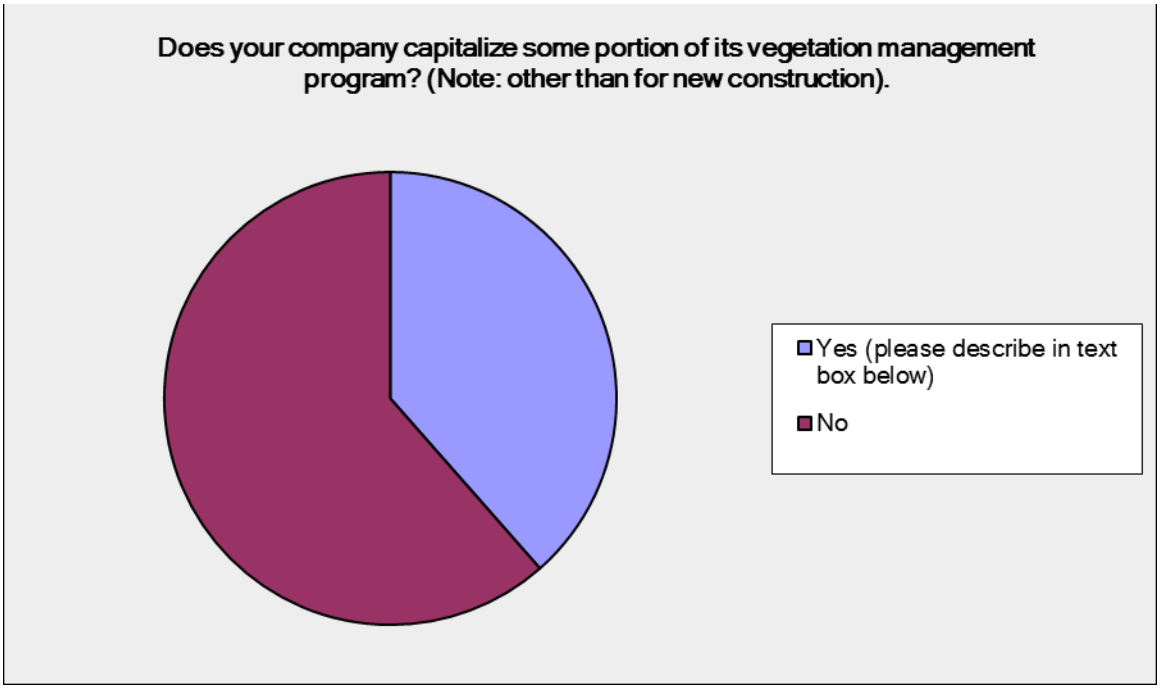

Figure 26 - Question 29 Responses

Free-Text Responses

1.	1) Initial application of herbicide 2) Widening of rights-of-way beyond originally cleared width
2.	a portion of major storm work is capitalized
3.	increasing the horizontal and vertical corridors
4.	Anytime we install a capital unit we trim the vegetation one span either direction

Table 8 - Question 6 Responses

How is the investment necessary for VM proposed to the regulators?		
Answer Options	**Response Percent**	**Response Count**
Included in rate cases by responsible witness	48.0%	12
Through periodic meetings with the regulator	16.0%	4
Investment is developed to meet the regulations set forth by regulator	20.0%	5
Through detailed discussion with regulator regarding the impact of vegetation on system reliability and potentially included in rate case submittals	44.0%	11
Other (please explain)	12.0%	3
answered question		25
skipped question		1

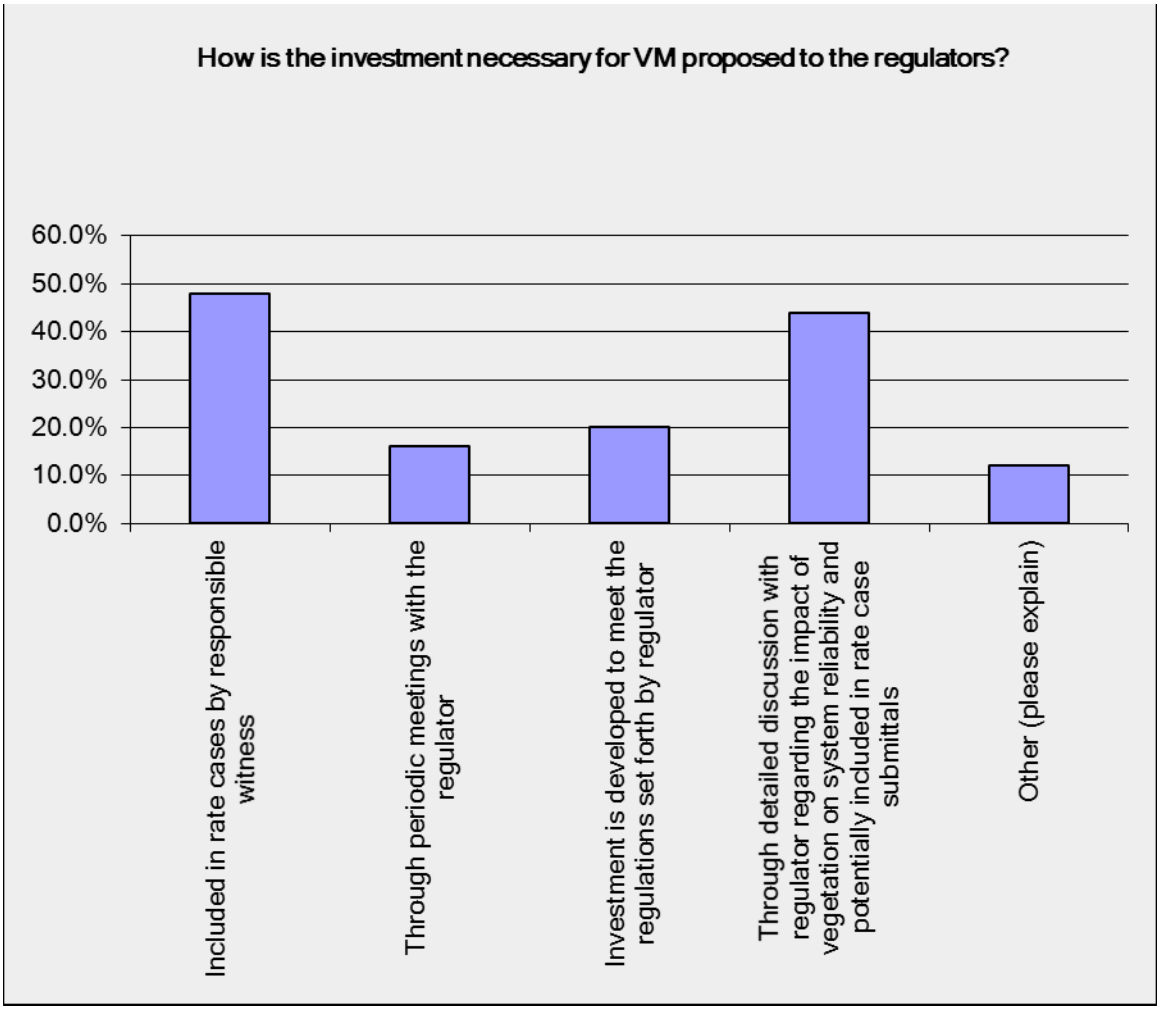

Figure 27 - Question 6 Responses

Free-Text Responses

1.	Not applicable at this time.
2.	unable to verify
3.	In one state, there is a mandate of maintaining 95% on 5 year cycle. This influences corporate decisions on budget forecasting.

Program Planning and Measurement

Table 9 - Question 31 Responses

Does your company conduct pre-work planning / pre-inspection on circuits prior to routine line clearing?		
Answer Options	**Response Percent**	**Response Count**
Yes, using company VM employees	42.3%	11
Yes, using third-party employees (e.g., ECI, etc.)	38.5%	10
Yes, using tree contractor employees	42.3%	11
No	15.4%	4
Other (please explain)		1
answered question		26
skipped question		0

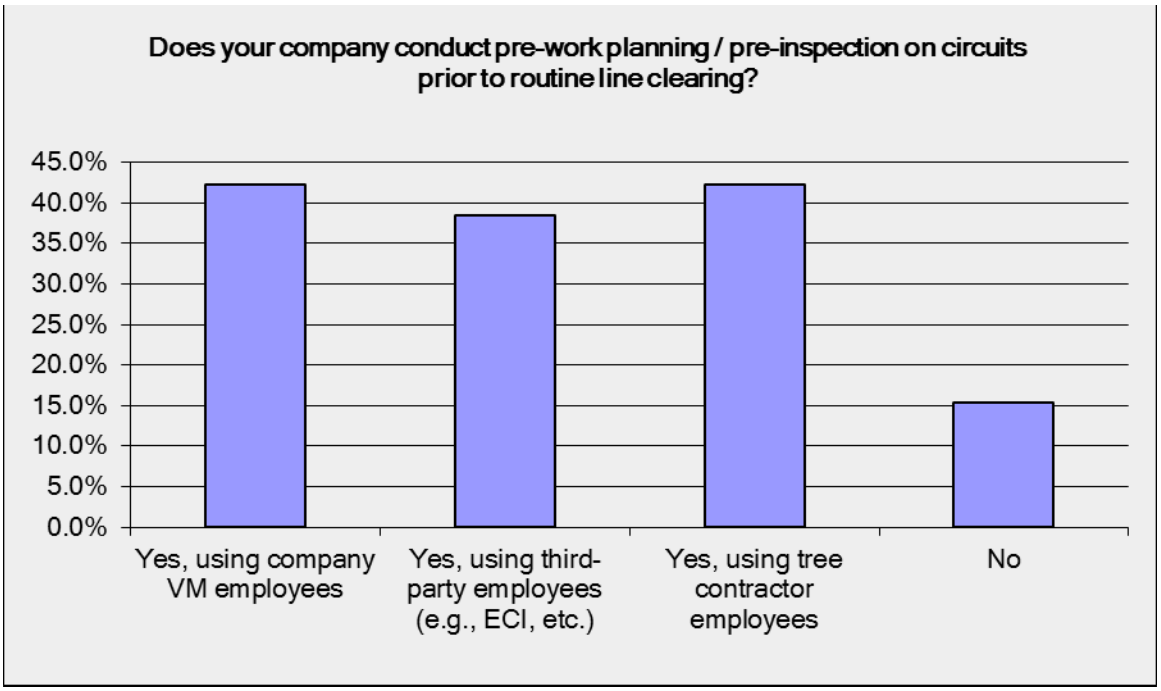

Figure 28 - Question 31 Responses

Free-Text Responses

1. Currently conducting pre-work planning by contract arborist on a limited basis

Table 10 - Question 9 Responses

Do you conduct analysis on the types of trees within a given area, if so how?		
Answer Options	**Response Percent**	**Response Count**
Aerial photography	0.0%	0
GIS surveys undertaken as part of VM program when doing work on a circuit	8.0%	2
Satellite mapping technology	0.0%	0
Line patrols	24.0%	6
We do not conduct analysis of tree types	60.0%	15
Other (please explain)	12.0%	3
answered question		25
skipped question		1

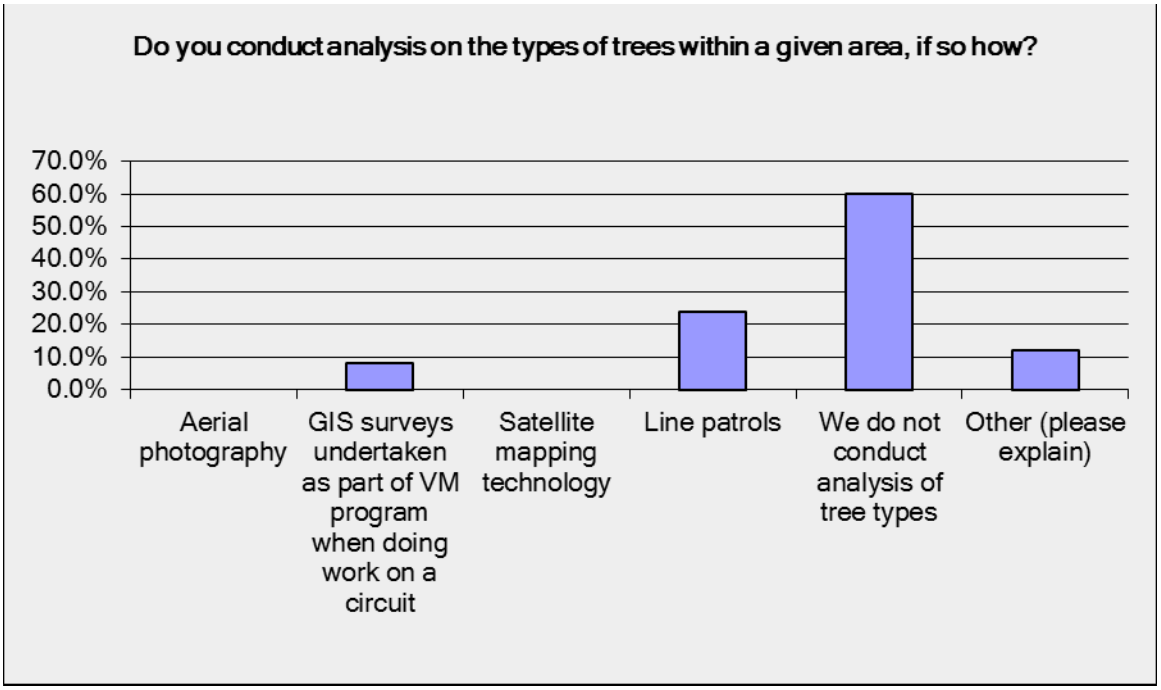

Figure 29 - Question 9 Responses

Free-Text Responses

1.	Westchester Region study "Condition Assessment of the Forests of Westchester County, New York was completed in 2008 by John Goodfellow. New York City Region tree analysis City of New York Parks and Recreation Department
2.	ECI vegetation study
3.	We are having an Urban Forest Assessment completed

Table 11 - Question 8 Responses

How do you analyze the value of the VM investment to customers?		
Answer Options	**Response Percent**	**Response Count**
Dollar per customers served	12.5%	3
Dollar per customers whose circuits were managed	4.2%	1
Dollar per avoided outage calculated	25.0%	6
Dollar per avoided outage minutes reduced	16.7%	4
Other (please explain)	58.3%	14
answered question		24
skipped question		2

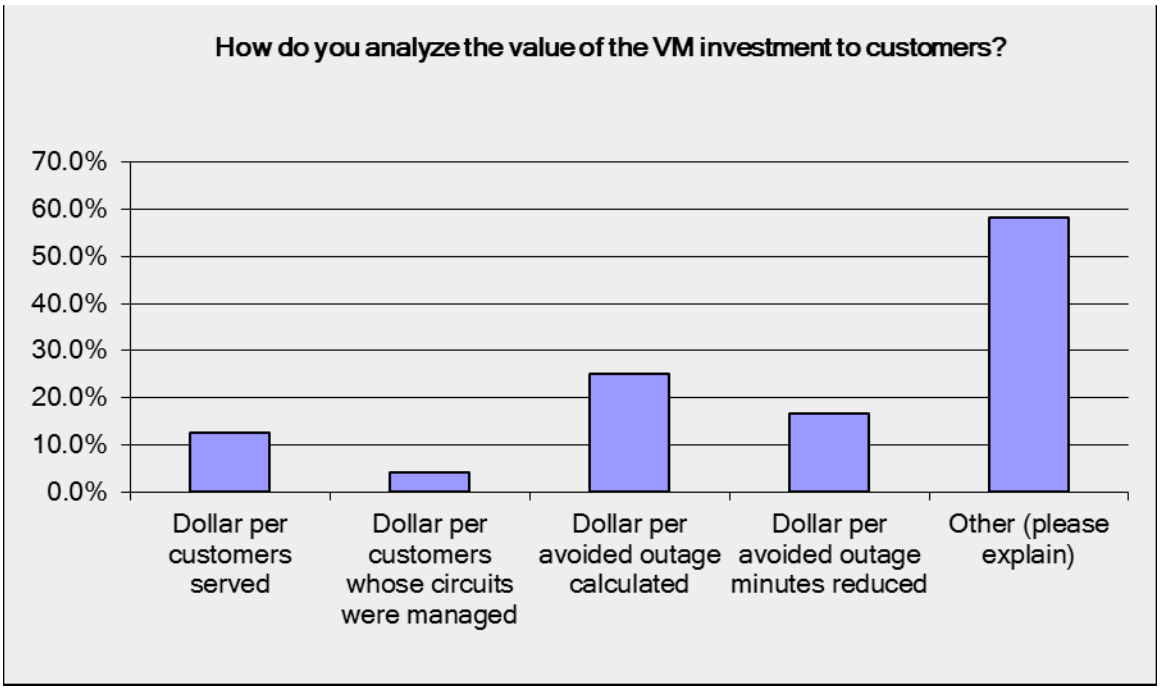

Figure 30 - Question 8 Responses

Free-Text Response

1. Estimate impact on reliability during business planning
2. N/A
3. No measure specific to VM.
4. Not Analyzed
5. Although the above are considerations the main driver is reliability.
6. unable to verify
7. Do not currently measure in these terms, although on occasion have used Dollars per Customer Served in other benchmarking studies.

8. Based on reliability numbers

Table 12 - Question 30 Responses

Does your company survey its customers for feedback on its vegetation management program?		
Answer Options	**Response Percent**	**Response Count**
Yes (please describe in text box below)	57.7%	15
No	42.3%	11
answered question		26
skipped question		0

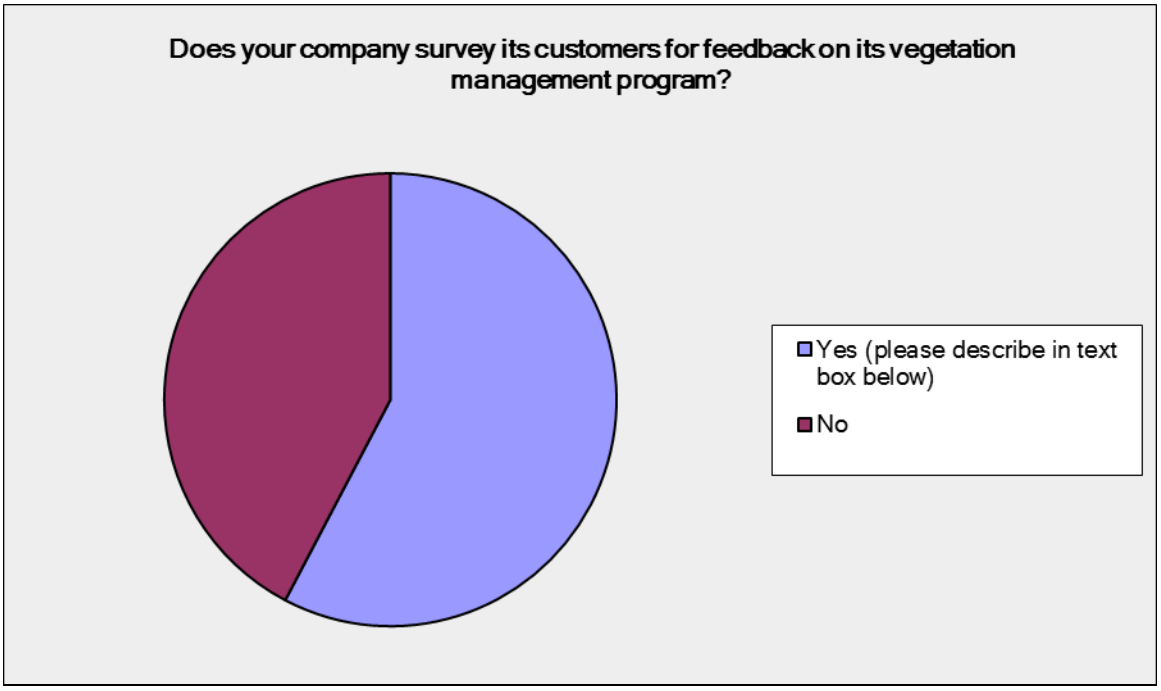

Figure 31 - Question 30 Responses

Free-Text Responses

1.	Conduct a sample survey on completed feeders.
2.	Vegetation Management does review customer complaints regarding pruning and removals.
3.	Regulations require annual general surveys be conducted starting in 2013. Vegetation management is included in these surveys.
4.	General customer satisfaction survey
5.	1) Customer comment card left w/ homeowners 2) Portion of annual cust. sat. survey addresses vegetation mgmt.
6.	We have done it in the past. Phone calls door hangers and letters
7.	Perform a formal post maintenance trim phone survey by an

outside company.

8. Did in the past and very little benefit was derived from results.

Table 13 - Question 25 Responses

Does your VM program perform post-storm patrols for any vegetations issues (as described above), following restoration of service after a major storm?		
Answer Options	**Response Percent**	**Response Count**
Yes	53.8%	14
No	46.2%	12
answered question		26
skipped question		0

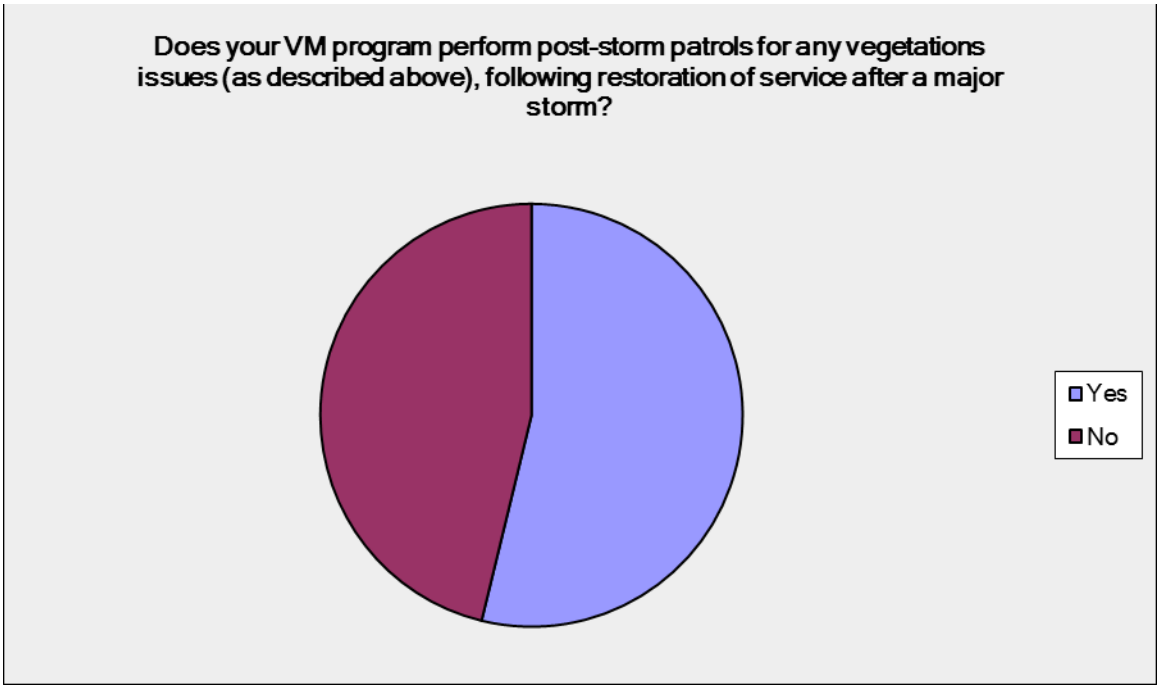

Figure 32 - Question 25 Responses

Adjustments to VM Plans for Resiliency:

- Change basis for prioritization
- Continuous analysis and improvement
- Hazard tree as function of a Worst Performing Feeder Program
- Implemented proactive trimming & hazard tree
- Modified Clearances
- Modified Clearances & Accelerated Cycle
- Seek funding to catch up to Cycle

Free-Text Responses

1.	Post storm activities are funded by other funding; not under Vegetation Management funding.
2.	We perform circuit sweeps on those circuits hardest hit. We also follow-up on all trouble calls related to tree issues.

Program Attributes

Table 14 - Question 4 Responses

If your vegetation management is on a trim cycle, please select the cycle for circuit "backbone" (not laterals off the main line from the substation).		
Answer Options	**Response Percent**	**Response Count**
Not on a trim cycle	15.4%	4
2 Year trim cycle	0.0%	0
3 Year trim cycle	11.5%	3
4 Year trim cycle	38.5%	10
5 Year trim cycle	11.5%	3
Greater than 5 Years	0.0%	0
Optimized	15.4%	4
answered question		26
skipped question		0

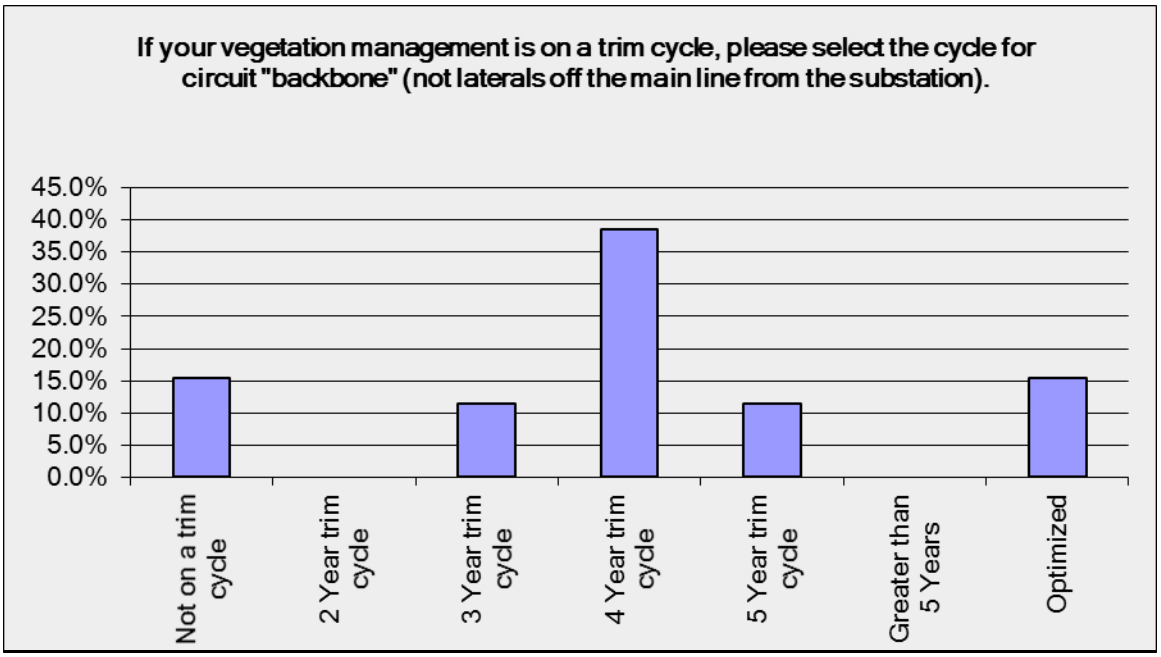

Figure 33 - Question 4 Responses

Free-Text Responses

1.	35kV - 3 year 12kV - 5 year
2.	Operating company 1 - 5.5 year cycle Operating company 2 - 5 year cycle Operating company 3 - 4 year cycle
3.	4 Years is an average. 3 to 5 years are the regular cycles based on growth rates.
4.	System average is 3.5 years
5.	Suburban trim cycle is a 3 year direct cycle Urban trim cycle is a 2 year direct cycle for 27KV and 33KV, 3 year direct cycle for 4KV and 13KV
6.	For one operating unit have urban 4 year cycles and rural 6 year cycle base on customer density per mile
7.	Different for each OpCo and sometimes within regions of each OpCo. * One OpCo has one region on 3 year, one on 4 year, and another on 5 year. This is due predominantly on precipitation and irrigation causing increased growth. * Another OpCo targets everything for 5 years with a mid-cycle inspection on multiphase. * Some jurisdictions are targeting four years. * Another OpCo targeting four years. * Yet another OpCo is targeting five years. * We anticipate in the future with technology enhancements of tying together reliability of maintenance maps, tree densities, customer counts, customer types, etc, to be able to customize cycles on a per map basis.
8.	7 Operating Companies on 4yr backbone schedule 3 Operating Companies on a 5yr backbone schedule
9.	Cycles vary by feeder location/easement/and vegetation growth patterns. We currently do not separate backbone and laterals
10.	3 year mid cycle, 6 year full trim

Table 15 - Question 5 Responses

If your vegetation management is on a trim cycle, please select the cycle for "laterals" off the main backbone.		
Answer Options	**Response Percent**	**Response Count**
Not on a trim cycle	15.4%	4
2 Year trim cycle	0.0%	0
3 Year trim cycle	11.5%	3
4 Year trim cycle	34.6%	9
5 Year trim cycle	3.8%	1
Greater than 5 Years	3.8%	1
Optimized	15.4%	4
answered question		26
skipped question		0

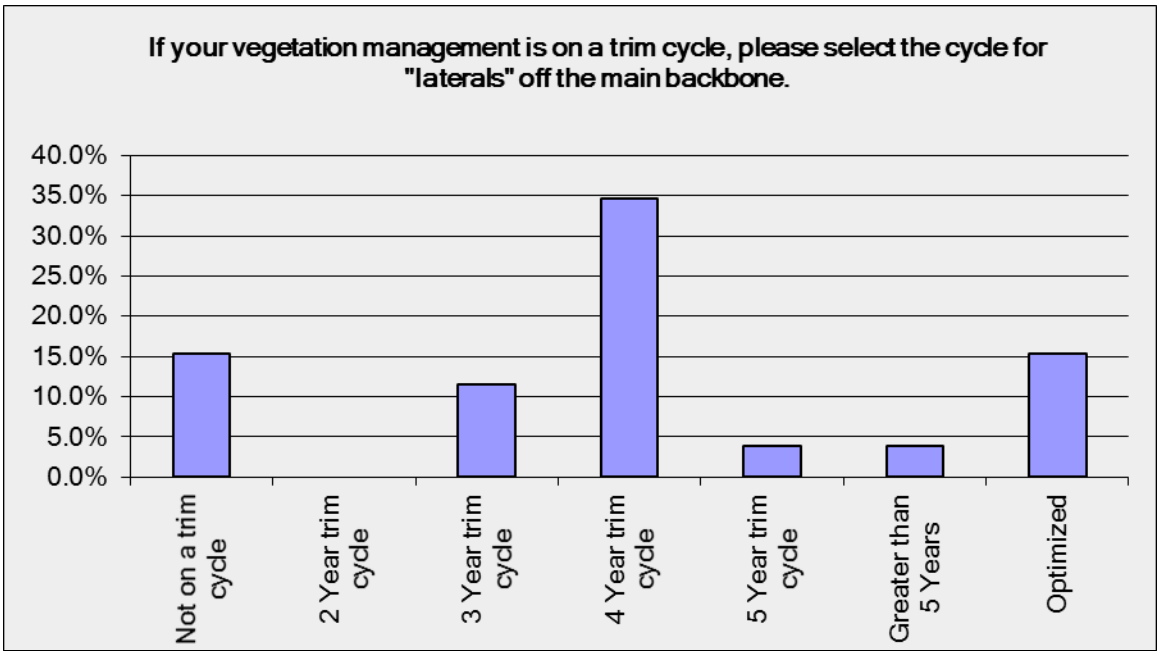

Figure 34 - Question 5 Responses

Free-Text Responses

1.	Same as Backbone
2.	Same as above
3.	System average is 3.5 years
4.	laterals are trimmed in conjunction with the main backbone. Trimming is done by feeder including laterals and secondary.
5.	see above
6.	We trim the entire circuit on the same cycle. The only exception is service lines
7.	Same as #4
8.	7 Operating Companies on a 4yr lateral schedule 3 Operating Companies on a 5yr lateral schedule
9.	Cycles vary by feeder location/easement/and vegetation growth patterns. We currently do not separate backbone and laterals
10.	same as above

Table 16 - Question 34 Responses

Does your vegetation management program include provisions for trimming secondary conductors?		
Answer Options	**Response Percent**	**Response Count**
Yes, secondary conductors are trimmed only in locations where primary conductors exist	19.2%	5
Yes, secondary conductors are trimmed regardless of the presence or absence of primary conductors	38.5%	10
We do not specifically trim secondary conductors	42.3%	11
answered question		26
skipped question		0

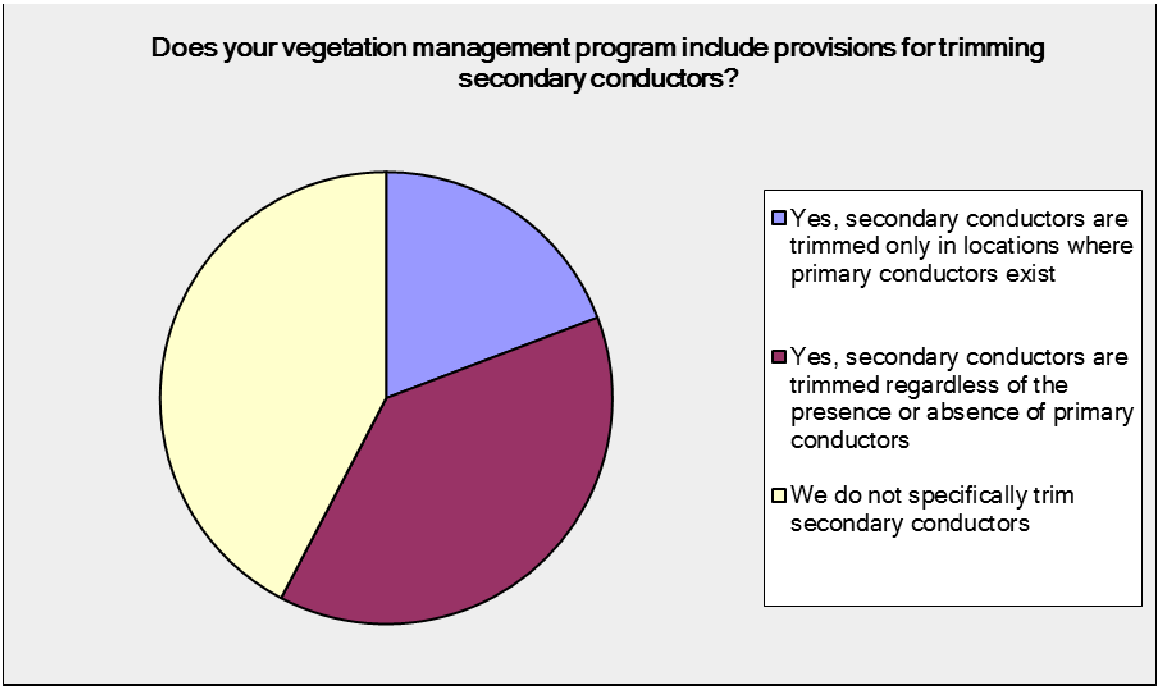

Figure 35 - Question 34 Responses

Free-Text Responses

1.	On road allowance only.
2.	limited clearance on secondary. Do not trim pole to house service.
3.	Here is an except from our guidelines book. Secondary (service/loop drops, street light wires) - If practical, ground personnel should identify and prune trees from the ground that are interfering with open secondary and service lines within the immediate area of the work site. Secondary, street light and service wires are not routinely pruned for clearance unless overbuilt primary exists. However, secondary or streetlight wires should be pruned if major interference, such as a broken limb, exists.
4.	We trim secondary where primary is located as well as we will trim secondary where there is no primary if it is open wire secondary and feeds more than one customer.

Table 17 - Question 24 Responses

Does your VM program include a formal mid-cycle vegetation patrol program? (This patrol would be done to idenitfy any vegetation issues such as dead/dying trees, storm damage potential growth issues, etc., that have occurred after the last maintenance trim cycle and will likely cause an outage before the next trim cycle.).		
Answer Options	**Response Percent**	**Response Count**
Yes	24.0%	6
No	76.0%	19
answered question		**25**
skipped question		**1**

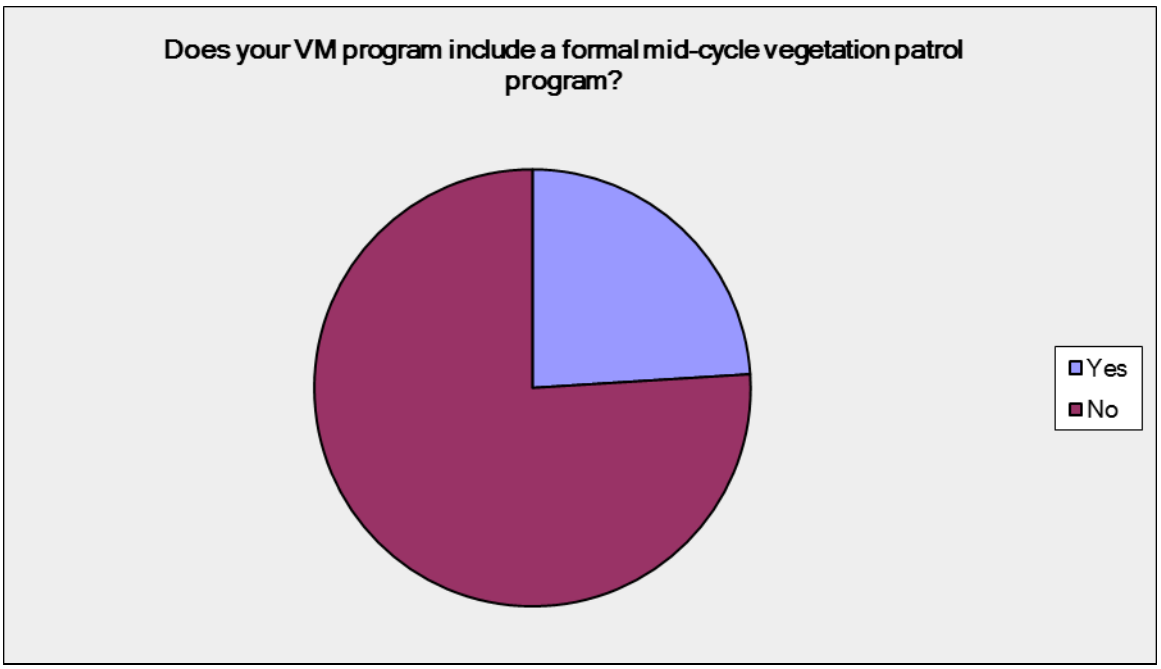

Figure 36 - Question 24 Responses

Free-Text Responses

1.	presently only done on Transmission
2.	We do not schedule mid cycle visits but management areas scheduled in the next cycle are inventoried up to 6 months in advance. Poor performing circuits may have a Hazard Tree analysis done off the pruning cycle.
3.	Yes in two jurisdictions. Inspections and work limited to multiphase portions of circuits. No in all other regions.
4.	Only circuits that historically have high numbers of dead trees are routinely patrolled.

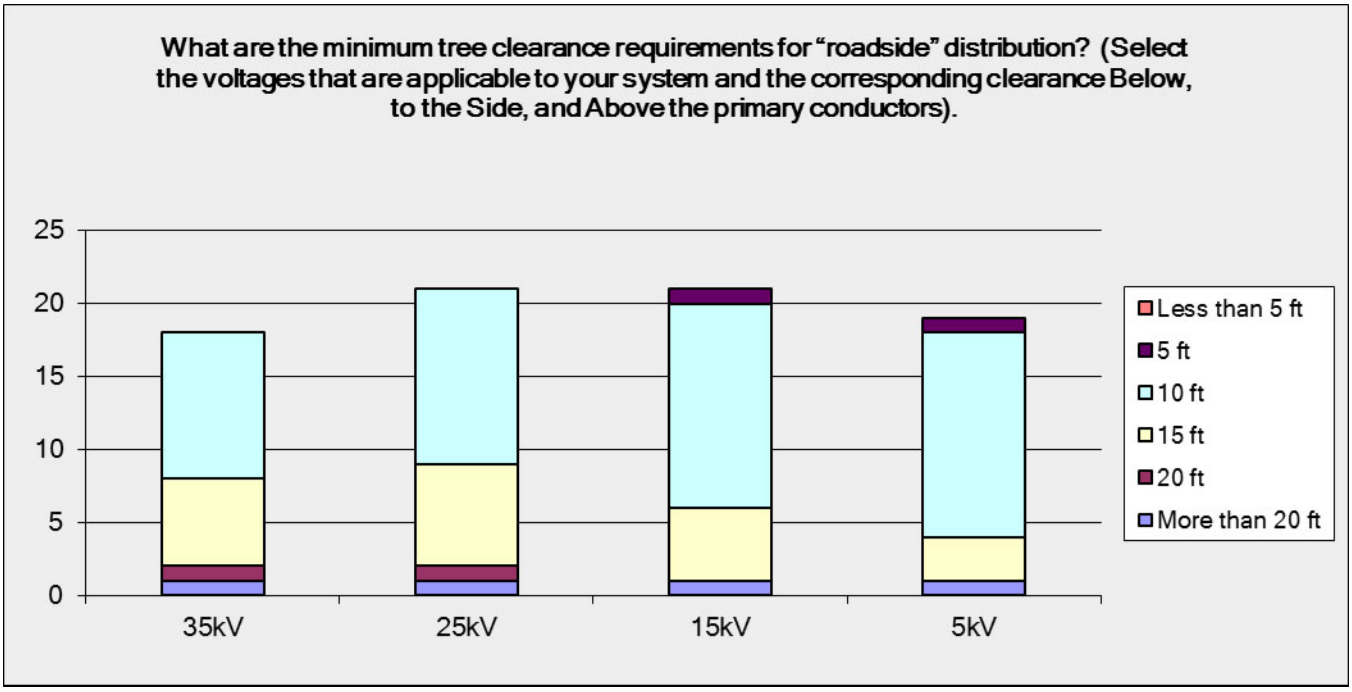

Figure 37 - Question 11 Responses

Free-Text Responses

1.	6' around primary distribution (13kV & 4kV) 18' on 23'kV 7 33kV (considered Transmission in our company)
2.	35kV-10' side, 15' below, no overhang above 12kV-7' side, 15' below, no overhang above
3.	5 meters (+/- 15 feet) for deciduous 3 meters (+/- 9 feet) for coniferous
4.	For 14 kV to 34.5 kV, the required clearance is 10 feet or four years growth whichever is greater. For <14 kV but > 600 V, the required clearance is four years growth.
5.	single phase line is 10 feet clearance and 15 feet for three-phase distribution feeder.
6.	Below, side and above clearances are not the same, and range between 6 and 12 feet depending on voltage and tree growth rates. 34kV allows no overhang.
7.	Per specs: crew should provide enough clearance from the conductor to prevent regrowth from contacting the conductors before the tree is pruned on the next designated cycle .....
8.	Suburban: 10' side, 10' below and 15' our wire. New Enhanced Specification for heavily tree'd feeders with poor SAIFI or CAIDI history, with Municipal and landowner agreement any branch or tree which may in extreme circumstances contact our equipment (aggressive removals) Urban Alternate Specification 6' side, 6' below and 10' above our wire all voltages
9.	Goal is 15' from centerline upon completion of reclearing / trimming
10.	Goal is 15' from centerline upon completion of reclearing / trimming

11.	Goal is 15' from centerline upon completion of maintenance
12.	Goal is 15' from centerline upon completion of maintenance
13.	Goal is 15' from centerline upon completion of maintenance
14.	Goal is 20' from centerline upon completion of maintenance
15.	Goal is 20' from centerline upon completion of maintenance
16.	Depends on the species of trees but the rule of thumb is 10 feet.
17.	On 3ph backbone in general no overhang. Above are the minimum clearances, on lines with broader easements we obtain further clearance.
18.	Multi Phase not to exceed 25' from center line, Single Phase not to exceed 15' from center line and 15' above conductor. We have a 12kV system.
19.	We do not define minimum clearance distances for distribution voltages. Here is the excerpt from our VM Guidelines: 3.1 – DISTRIBUTION CLEARANCE GUIDELINES – Our clearance guidelines are based on local tree growth rates, specific to individual trees on specific circuits. Specific clearances are determined based on species growth rates, as well as line voltage, construction of facilities, electric reliability performance and other factors. Therefore, each individual tree needs to be assessed to determine adequate clearance required from the conductor to prevent service interruption, damage to our facilities and threats to public safety. We expects qualified line-clearance tree workers to use their professional judgment to determine what these clearances will be in each situation, based on the proposed maintenance cycle for the circuit on which they are working.
20.	15kv- 12ft 5kv- 12ft
21.	Min for below primary is 15 feet; min for side clearance is 10 feet and overhang min is greater than 20 feet or limit of reach of bucket.
22.	15ft is our minimum however we have older easements that have less.
23.	<35kv is 10*10*10*15 (above) 35kv is 15*15*15*20 (above)

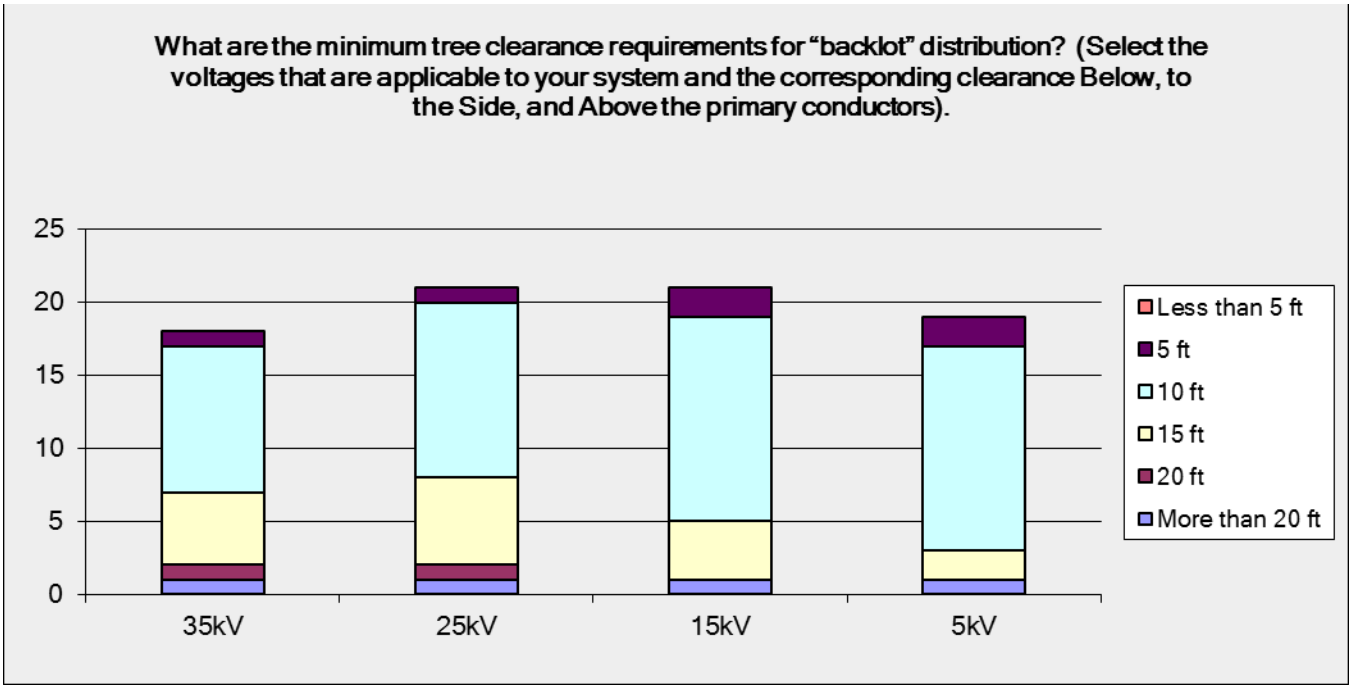

Figure 38 - Question 12 Responses

Free-Text Responses

1.	same as highway specified above
2.	35kV-10' side, 15' below, no overhang above 12kV-7' side, 15' below, no overhang above
3.	The standard applies to all distribution voltages no matter the location.
4.	For 14 kV to 34.5 kV, the required clearance is 10 feet or four years growth whichever is greater. For <14 kV but > 600 V, the required clearance is four years growth.
5.	single phase line is 10 feet clearance and 15 feet for three-phase distribution feeder.
6.	Below, side and above clearances are not the same, and range between 6 and 12 feet depending on voltage and tree growth rates. 34kV allows no overhang.
7.	Per specs: crew should provide enough clearance from the conductor to prevent regrowth from contacting the conductors before the tree is pruned on the next designated cycle .....
8.	Same as above (#11)
9.	Goal is 15' from centerline upon completion of reclearing / trimming
10.	Goal is 15' from centerline upon completion of reclearing / trimming
11.	Goal is 15' from centerline upon completion of maintenance
12.	Goal is 15' from centerline upon completion of maintenance
13.	Goal is 15' from centerline upon completion of maintenance

14.	Goal is 20' from centerline upon completion of maintenance
15.	Goal is 20' from centerline upon completion of maintenance
16.	Depends on the species of trees but the rule of thumb is 10 feet.
17.	On 3ph backbone in general no overhang Above are the minimum clearances,on lines with broader easements we obtain further clearance
18.	Multi Phase not to exceed 25' from center line, Single Phase not to exceed 15' from center line and 15' above conductor. We have a 12kV system.
19.	Same as #11.
20.	15kv- 12ft 5kv- 12ft
21.	Min for below primary is 15 feet; min for side clearance is 10 feet and overhang min is greater than 20 feet or limit of reach of bucket.
22.	15ft is our minimum however we have older easements that have less.
23.	<35kv is 10*10*10*15 (above) 35kv is 15*15*15*20 (above) or width of easement

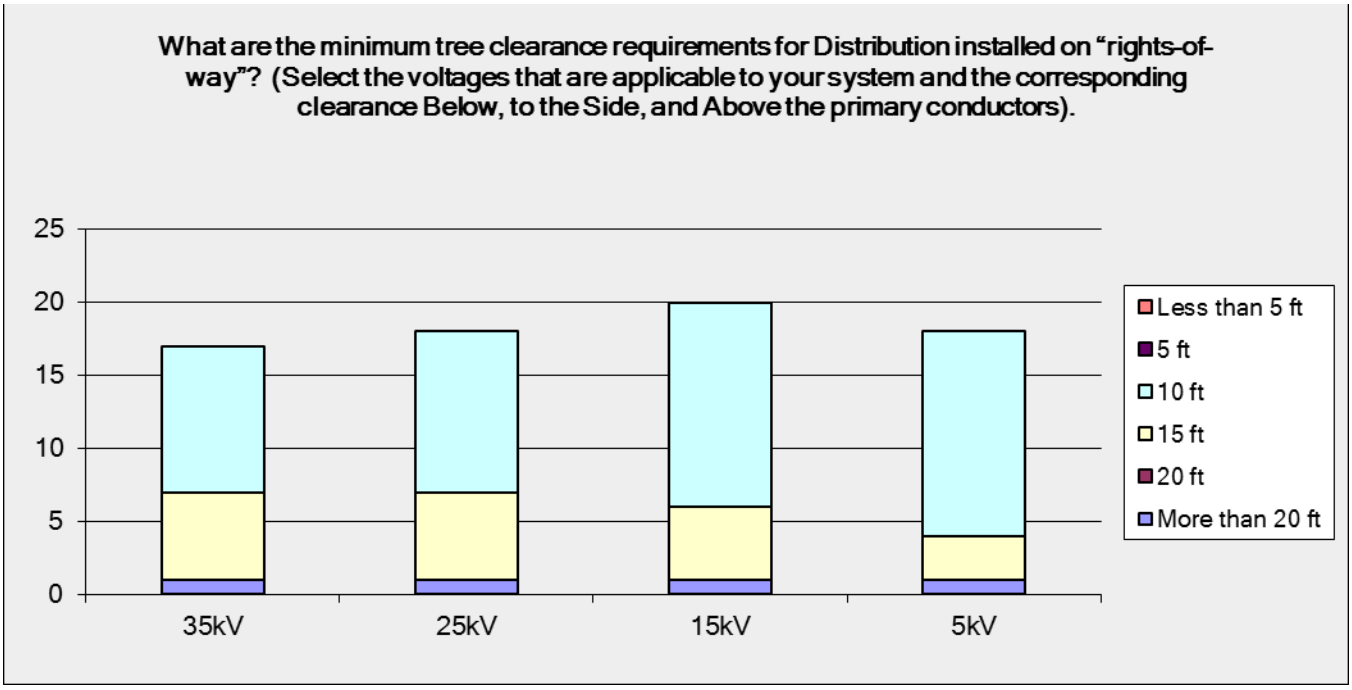

Figure 39 - Question 13 Responses

Free-Text Responses

1.	N/A- no distribution ROW's on LIPA system
2.	35kV-10' side, no overhang above 12kV-7' side, no overhang above trees located within right-of-way removed
3.	Distribution corridors for the most part do NOT have a 'right of way' for distribution lines within the Province of BC.
4.	For 14 kV to 34.5 kV, the required clearance is 10 feet or four years growth whichever is greater. For <14 kV but > 600 V, the required clearance is four years growth.
5.	Single-phase line is 10 feet clearance and 15 feet for three-phase distribution feeder.
6.	Below, side and above clearances are not the same, and range between 6 and 12 feet depending on voltage and tree growth rates. 34kV allows no overhang.
7.	Per specs: crew should provide enough clearance from the conductor to prevent regrowth from contacting the conductors before the tree is pruned on the next designated cycle .....
8.	Same as above (#11)
9.	Goal is 15' from centerline upon completion of reclearing / trimming
10.	Goal is 15' from centerline upon completion of reclearing / trimming
11.	Goal is 15' from centerline upon completion of maintenance
12.	Goal is 15' from centerline upon completion of maintenance
13.	Goal is 15' from centerline upon completion of maintenance
14.	Goal is 20' from centerline upon completion of maintenance
15.	Goal is 20' from centerline upon completion of maintenance
16.	Depends on the species of trees but the rule of thumb is 10 feet.
17.	Above are the minimum clearances, on lines with broader easements we obtain further clearance On 3ph backbone in general no overhang
18.	Multi Phase not to exceed 25' from center line, Single Phase not to exceed 15' from center line and 15' above conductor. We have a 12kV system.
19.	Same as #11, although there is additional work performed with mechanized equipment, e.g. mowers, jarraffs, herbicide spray rigs, etc.
20.	15kv- 12ft 5kv- 12ft
21.	Min for below primary is 15 feet; min for side clearance is 10 feet and overhang min is greater than 20 feet or limit of reach of bucket.
22.	15ft is our minimum however we have older easements that have less.
23.	<35kv is 10*10*10*15 (above) 35kv is 15*15*15*20 (above) or width of easement

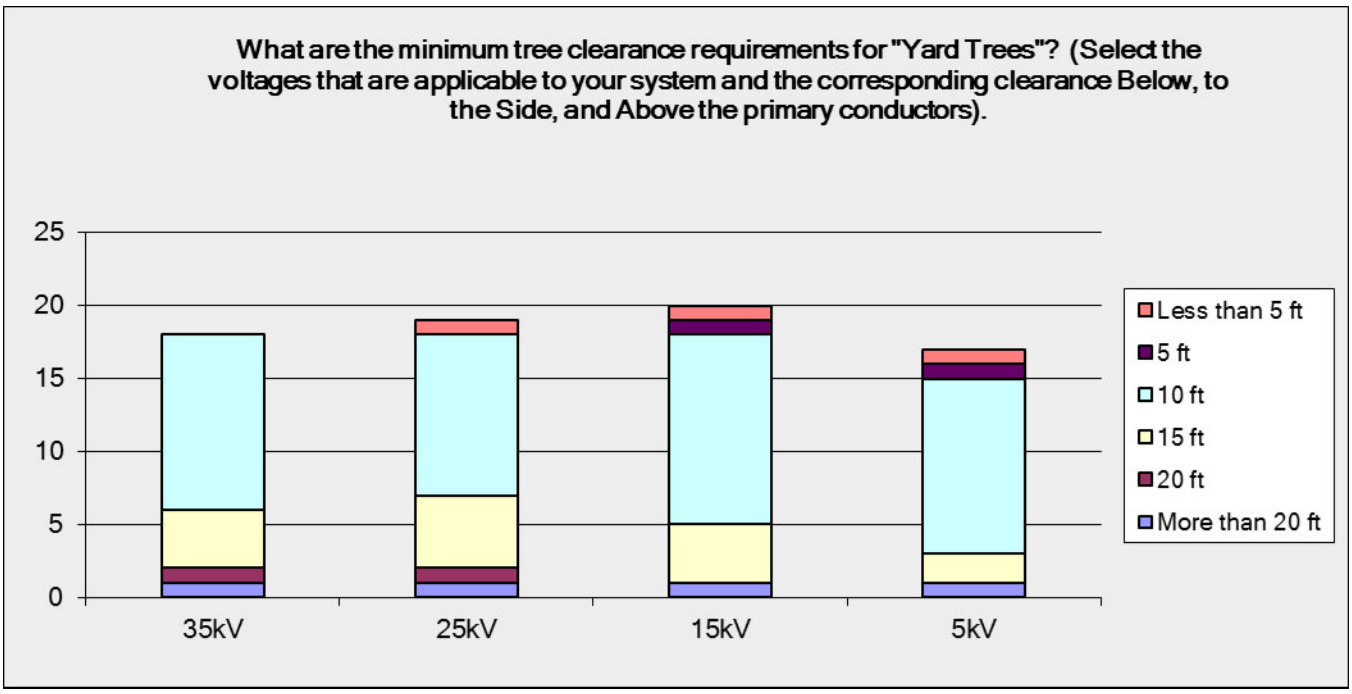

Figure 40 - Question 14 Responses

Free-Text Responses

1.	35kV-10' side, 15' below, no overhang above 12kV-7' side, 15' below, no overhang above
2.	Specifications for 'yard trees' are reduced to 0.5m below Telus (located approximately 1.5m ((+/- 4.5 feet) below secondary) as an acceptable variance to the standard. We will sometimes specify a reduced clearance based on anticipated growth of a specific species. Trees that pose a risk to the system are removed under Section 20 of the Hydro Power and Authority Act.
3.	For 14 kV to 34.5 kV, the required clearance is 10 feet or four years growth whichever is greater. For <14 kV but > 600 V, the required clearance is four years growth.
4.	Single-phase line is 10 feet clearance and 15 feet for three-phase distribution feeder.
5.	Below, side and above clearances are not the same, and range between 6 and 12 feet depending on voltage and tree growth rates. 34kV allows no overhang.
6.	Per specs: crew should provide enough clearance from the conductor to prevent regrowth from contacting the conductors before the tree is pruned on the next designated cycle .....
7.	Same as above(#11)
8.	Depends on the species of trees but the rule of thumb is 10 feet.
9.	Above are the minimum clearances, on lines with broader easements we obtain further clearance On 3ph backbone in general no overhang
10.	Multi Phase not to exceed 25' from center line, Single Phase not to exceed 15' from center line and 15' above conductor. We have a 12kV system.
11.	Same as #11.

12. 15kv- 12ft
5kv- 12ft

13. Min for below primary is 15 feet; min for side clearance is 10 feet and overhang min is greater than 20 feet or limit of reach of bucket.

14. we have older easements that have less.

Table 18 - Question 15 Responses

Does your company have a Hazard Tree program?		
Answer Options	**Response Percent**	**Response Count**
No	11.5%	3
Yes, how far from the conductors are you addressing hazard trees? 1) Full hazard tree distance (i.e. full length of tree)	42.3%	11
Yes, how far from the conductors are you addressing hazard trees? 2) Limited number of feet (please specify in text box)	15.4%	4
Other (please explain)	53.8%	14
answered question		26
skipped question		0

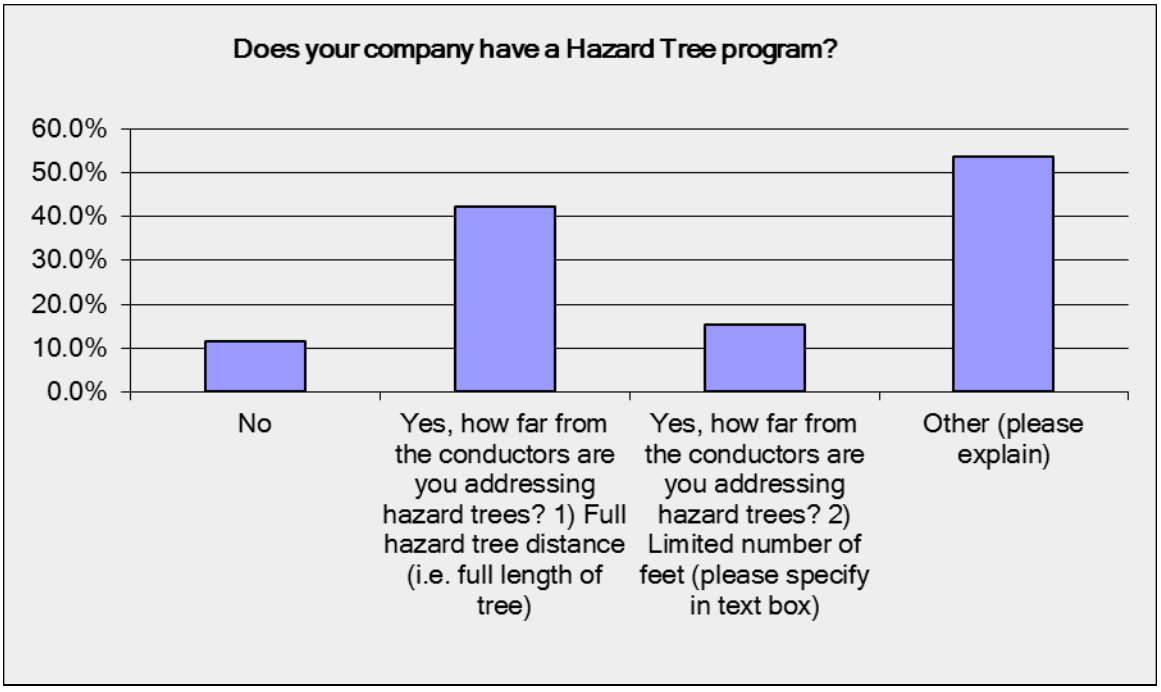

Figure 41 - Question 15 Responses

Hazard Tree Definitions:

- Within length of tree from conductors
- Width of Right of Way
- Within 40’ of conductors
- Varies by Voltage
- Capable of contacting conductors
- Varies – many factors

Free-Text Responses

1.	Distance varies depending on factors such as tree type, conductor type, conductor voltage, presence of buffer trees, etc...
2.	40 feet from the lines
3.	Performed in areas based on past reliability performance.
4.	Dead, dying or leaning trees are removed during routine maintenance Die off areas are addressed when they become a reliability problem
5.	Dead, dying or leaning trees are removed during routine maintenance Die off areas are addressed when they become a reliability problem
6.	1) Dead, dying or leaning trees are removed during routine maintenance 2) Die off areas are addressed as they become reliability issues
7.	1) Dead, dying or leaning trees are removed during routine maintenance 2) Die off arease are addressed as they become reliability issues
8.	1) Dead, dying or leaning trees are removed during regular maintance 2) Area die offs are addressed when thay become a reliability problem
9.	1) Dead, dying or leaning trees that can fall into the line are removed during normal maintenance 2) Areas with multiple die offs are targeted when they become a reliability issue
10.	1) Dead, dying or leaning trees that can fall into the line are removed during normal maintenance 2) Areas with multiple die offs are targeted when they become a reliability issue
11.	Depending on voltage of line(3ph/1ph/isolated secondary) determines the degree of clearance.
12.	There is some room for professional discretion on what trees to leave, here is a partial excerpt from the VM Guidelines: 3.2.2 – HAZARD TREE MITIGATION -Any tree on or off the right of way with the potential to contact electric supply lines is considered a “danger tree”. A “hazard tree” is a danger tree that has an unacceptable risk of failing before the next maintenance cycle. Hazard trees should be topped/pruned to eliminate the chance of the tree contacting electric supply lines, or felled, with the debris to be left on site for the tree owner’s disposal.
13.	Currently we have no funding for a hazard tree program, however we have had it in the past and will be requesting funding in the next rate case.
14.	The width of the right of way

Table 19 - Question 26 Responses

Does your company use Tree Growth Regulators (TGR's)?		
Answer Options	**Response Percent**	**Response Count**
Yes	50.0%	13
No	50.0%	13
answered question		26
skipped question		0

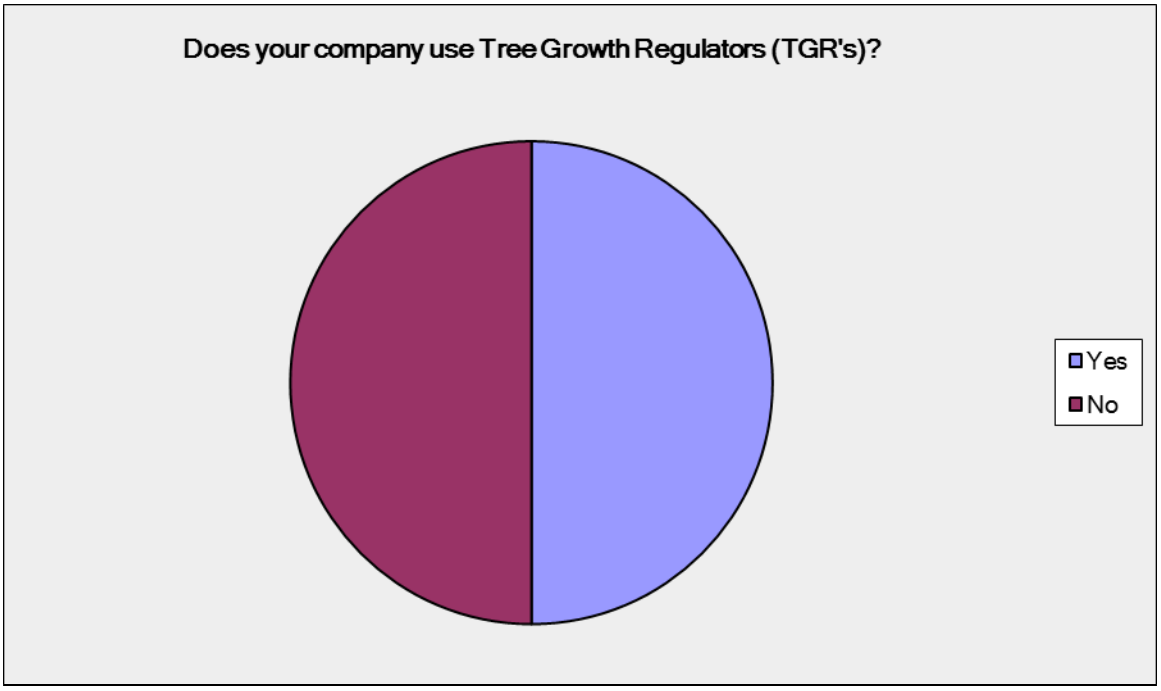

Figure 42 - Question 26 Responses

Free-Text Responses

1. There are none registered in Canada.
2. We are starting a pilot program to test TGRs in some areas and with some specific tree species.
3. have explored over the past 20 plus years and still actively putting out test plots-still an open question
4. We have done some test / trial areas, but have no plans of adopting into regular program.
5. Only on a limited basis.

Table 20 - Question 27 Responses

If "Yes" to using Tree Growth Regulators, for how long have you been using TGR's?		
Answer Options	**Response Percent**	**Response Count**
<5 yrs	25.0%	3
5-10 yrs	0.0%	0
>10 yrs	75.0%	9
answered question		12
skipped question		14

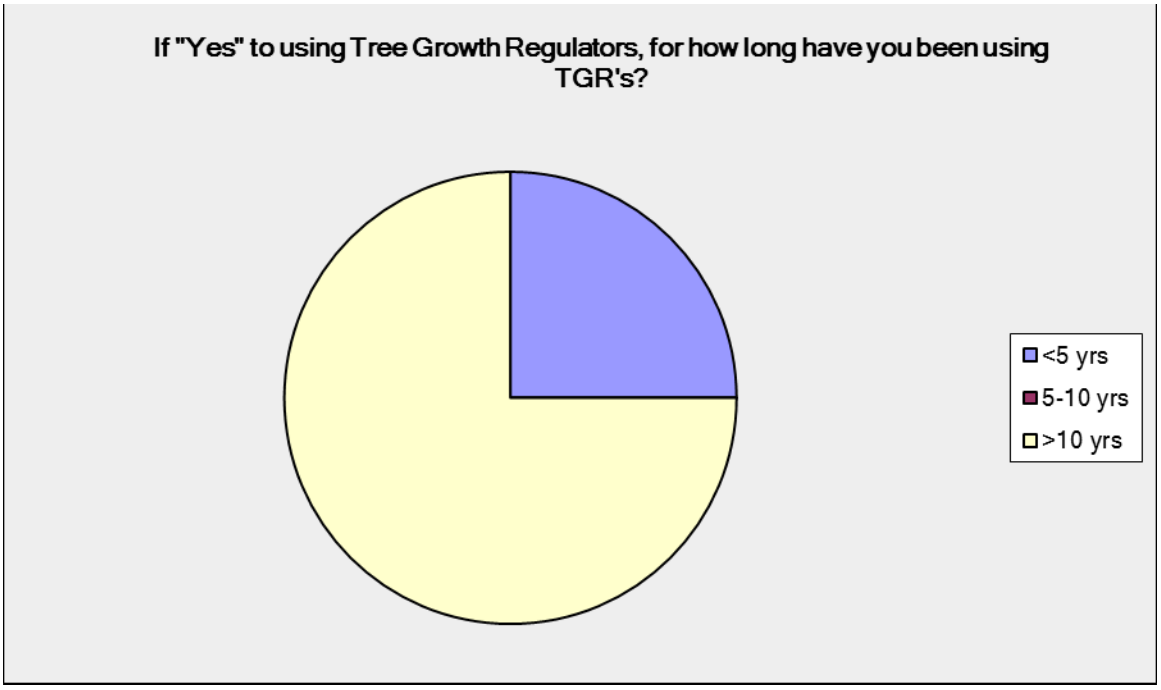

Figure 43 - Question 27 Responses

Free-Text Responses

1. N/A
2. Not sure
3. As mentioned above, we are just starting a pilot test program.
4. Not used
5. only on test plots
6. n/a

Table 21 - Question 10 Responses

Do you evaluate insect impact in certain areas to determine the likelihood of disease and mortality rate, if so how?		
Answer Options	**Response Percent**	**Response Count**
Coordination with local conservation agency	12.0%	3
Surveys or GIS data capture	4.0%	1
Forensic analysis of failed trees / limbs	36.0%	9
We do not evaluate insect impact	40.0%	10
Other (please explain)	24.0%	6
answered question		25
skipped question		1

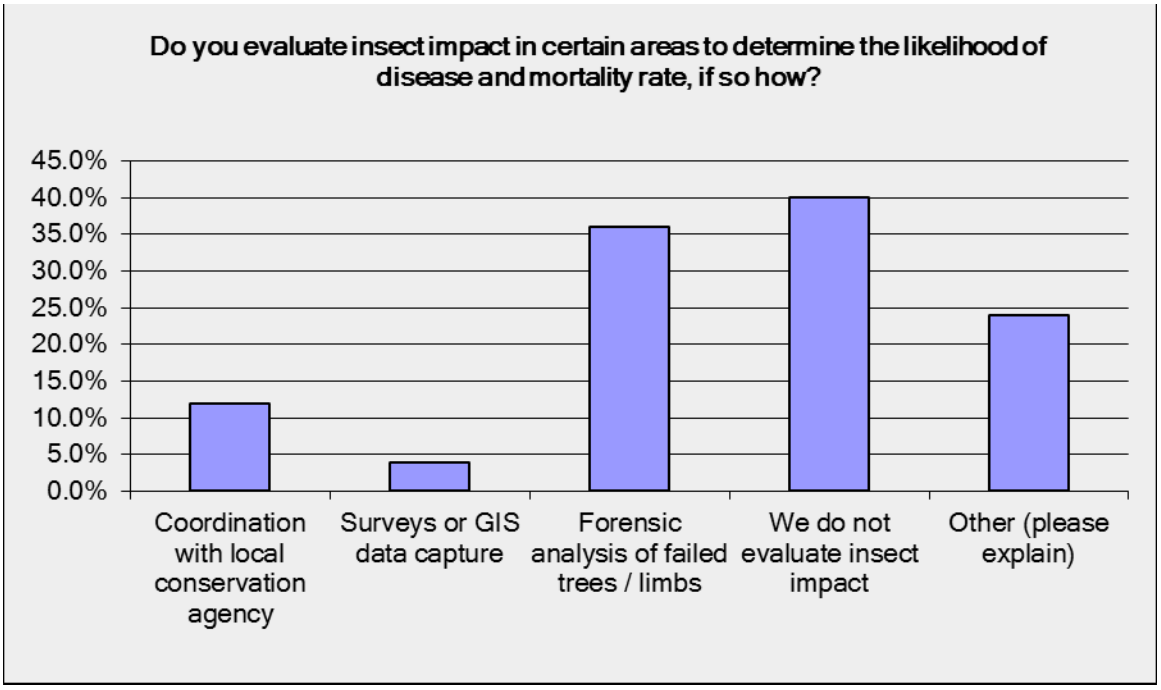

Figure 44 - Question 10 Responses

Free-Text Responses

1.	Done on a case by case basis
2.	Through routine observations and inspections, through discussions with other area utilities, and through discussions with the forestry divisions of local jurisdictions
3.	Insect impact information and data through state Department of Agriculture and Markets updates and annual meetings. ISA and UAA updates and seminars.
4.	With Department of Conservation/Extension Offices for emerging disease issues such as oak wilt, EAB
5.	For MPB dead tree mitigation, we have used surveys, GIS, and LiDAR data analysis, along with coordination with federal agencies to identify risk and areas for clearing.
6.	We are having an Urban Forest Assessment completed.

Table 22 - Question 28 Responses

Has your company found a successful treatment for the Emerald Ash Borer?		
Answer Options	**Response Percent**	**Response Count**
Yes (please describe in text box below)	8.7%	2
No	91.3%	21
answered question		**23**
skipped question		**3**

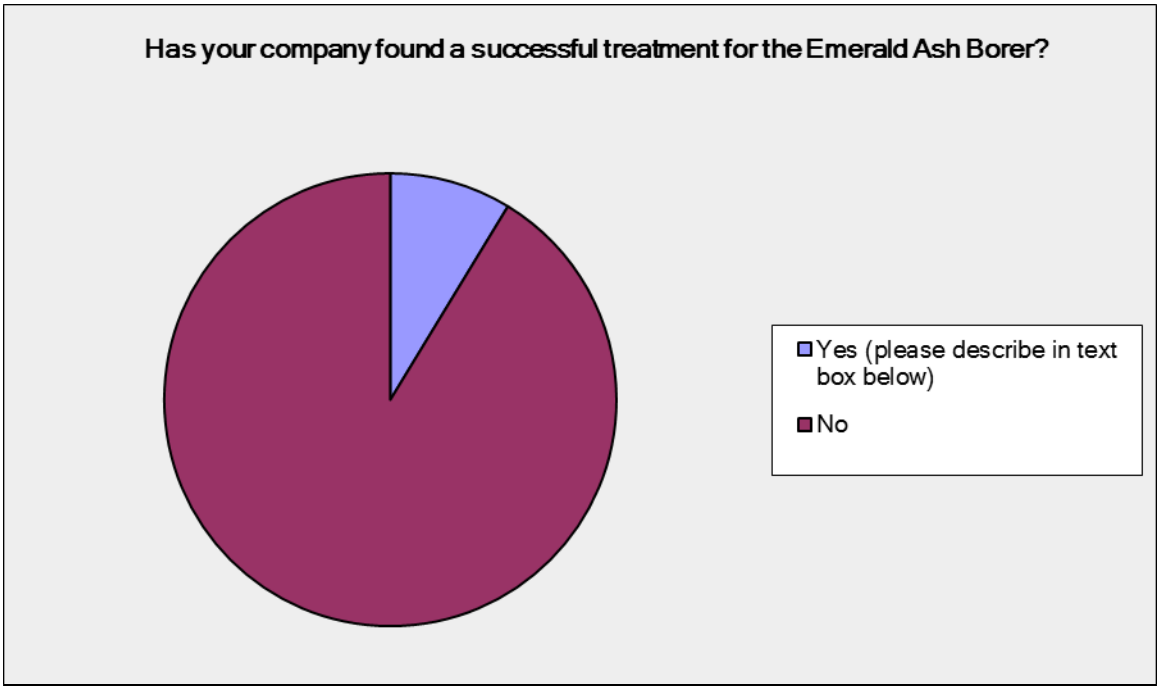

Figure 45 - Question 28 Responses

Treatments:

- Bayer Imidadoprim™
- Remove Trees
- Several respondents did not have exposure to Emerald Ash Borers.

1.	N/A
2.	Not identified in our territory and do not have any native Ash trees in our area.
3.	We are just starting to assess the threat and develop mitigation plans
4.	Directed by state Department of Agriculture & Markets
5.	Not an issue in this area
6.	Not an issue in this area

7.	not an issue in this area
8.	Affected trees are removed
9.	Affected trees are removed
10.	Not an issue in this area
11.	Not an issue in this area
12.	the only treatment will be cut the trees
13.	For our purposes we remove or "make safe" Ash trees - the chemical application that prevents ash borer infestation is Imidadoprin(Bayer Tree and Shrub)
14.	Removal

Table 23 - Question 16 Responses

Who owns the poles upon which you place your equipment?		
Answer Options	**Response Percent**	**Response Count**
The poles are owned jointly with multiple other utilities	48.0%	12
The poles are owned wholly by the electric utility	24.0%	6
The poles are jointly owned with one other utility	20.0%	5
The poles are owned by the municipalities in which they reside	0.0%	0
Other (please explain)	32.0%	8
answered question		25
skipped question		1

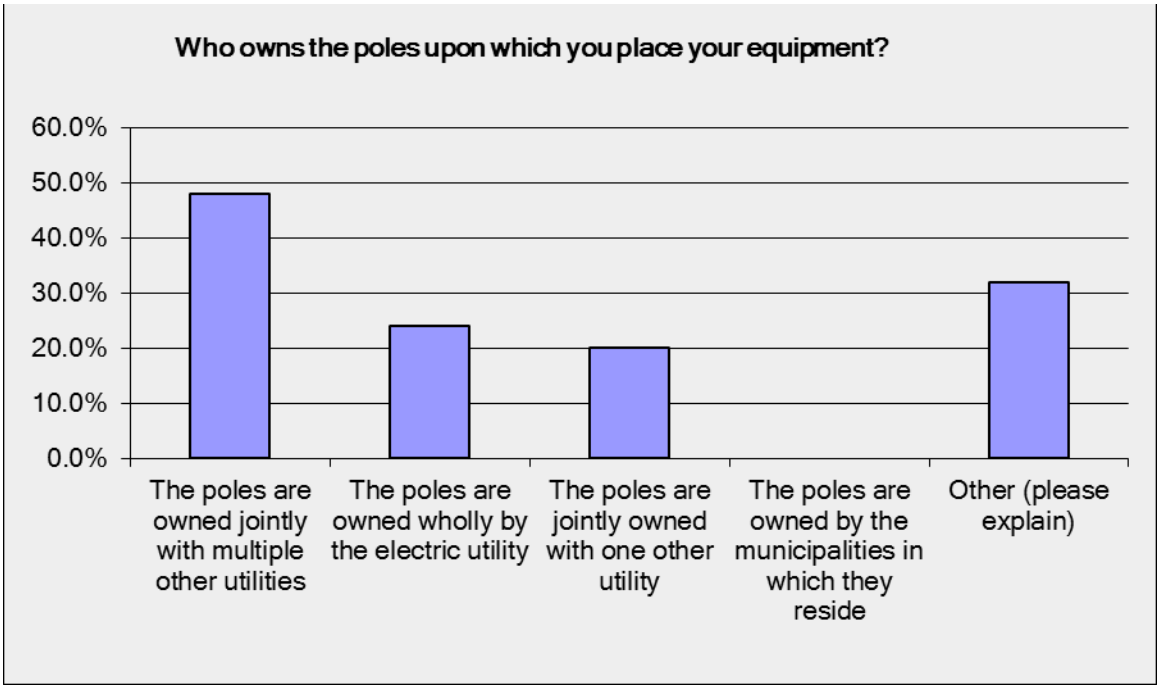

Figure 46 - Question 23 Responses

1. N/A
2. Will be used for work completion verification, but not for payment verification.

Table 24 - Question 17 Responses

Are rental fees / taxes paid to the underlying government agency that owns the property upon which the poles / equipment are placed, if yes, what are the fees / taxes based on?		
Answer Options	**Response Percent**	**Response Count**
The rental fees / taxes are based on the actual pole / equipment count or value	8.7%	2
The rental fees / taxes are based on the estimated pole plant in rate base	34.8%	8
No. Fees or taxes are not paid	34.8%	8
Other (please explain)	30.4%	7
answered question		23
skipped question		3

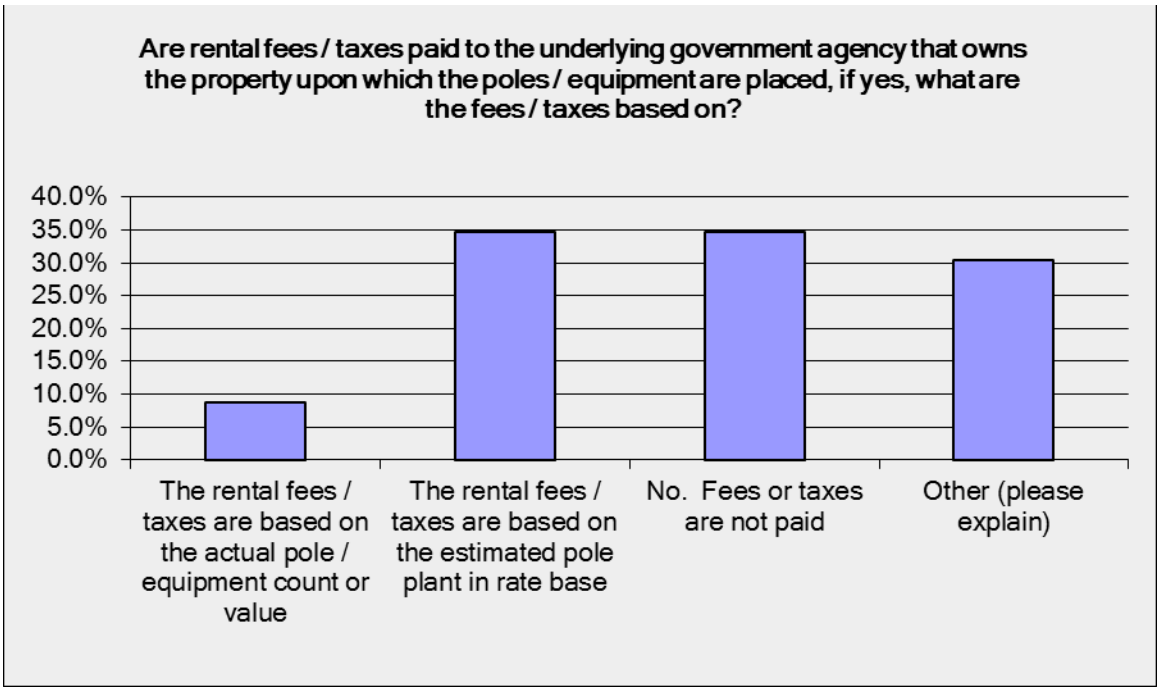

Figure 47 - Question 17 Responses

1. fees are paid to electric utilty by others with attachments.
2. We are not an IOU..
3. Do not know the answer at this moment
4. Municipality charges/taxes are paid for ROW based on agreement
5. No direct fees are paid but city franchise agreements cover our facilities within municipal boundaries.
6. Some areas have a franchise tax

7. We own some poles, share ownership of others or pay to attach. Those we own, we receive an attachment fee.

Table 25 - Question 32 Responses

Does our company hold properety owners accountable for hazard trees that damage distribution facilities when you have identified the hazard, offered to correct the hazard, and the propeerty owner prevented you from removing the hazard?		
Answer Options	**Response Percent**	**Response Count**
Yes	8.0%	2
No	92.0%	23
Comments		6
answered question		25
skipped question		1

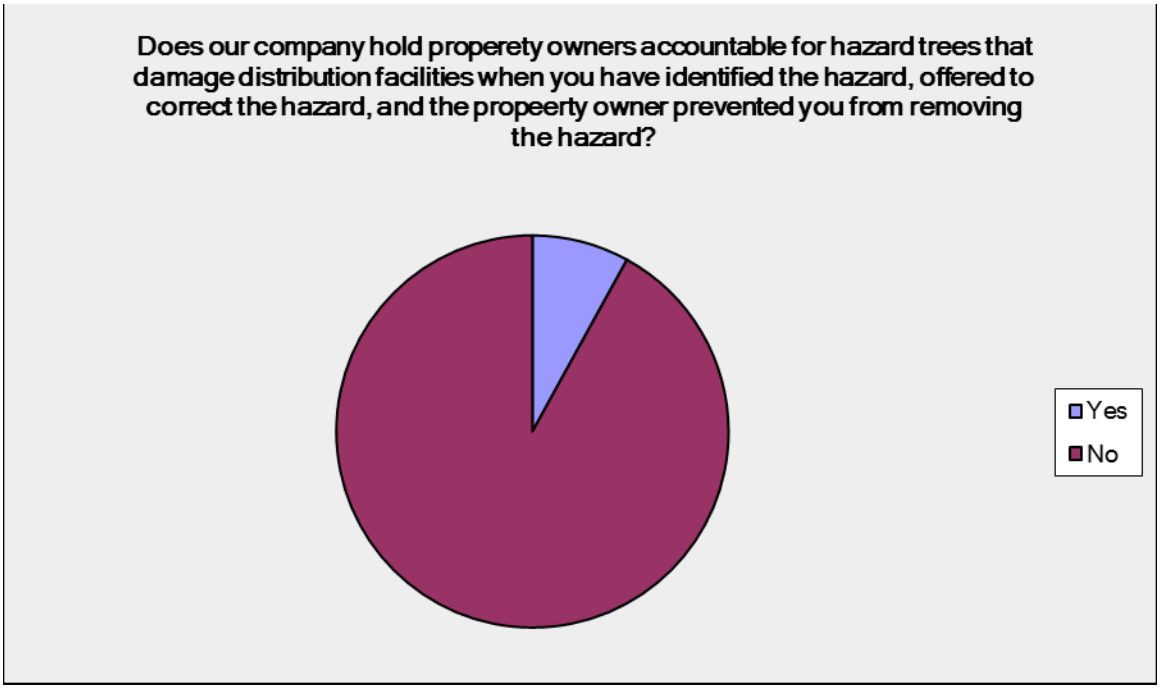

Figure 48 - Question 32 Responses

Note both 'Yes' responses and two 'No' responses were qualified:

- Yes, but not as often as we should
- Yes, but we have never collected
- No, but we reserve the right
- No, but we are collecting data

1.	not as often as we should
2.	N/A, no knowledge of this occuring

3. We reserve the right to pursue the customer but in practice, we do not.
4. We are in the process of developing and maintaining refusal data for future use.
5. (does someone actually do this effectively?)
6. have never had to collect actual damages

Contracting Strategy

Table 26 - Question 18 Responses

What's the basis for payment for your VM program?		
Answer Options	**Response Percent**	**Response Count**
Time & Equipment	38.5%	10
Units (please describe)	15.4%	4
Combination of each of these	65.4%	17
Other (please explain)	42.3%	11
	answered question	**26**
	skipped question	**0**

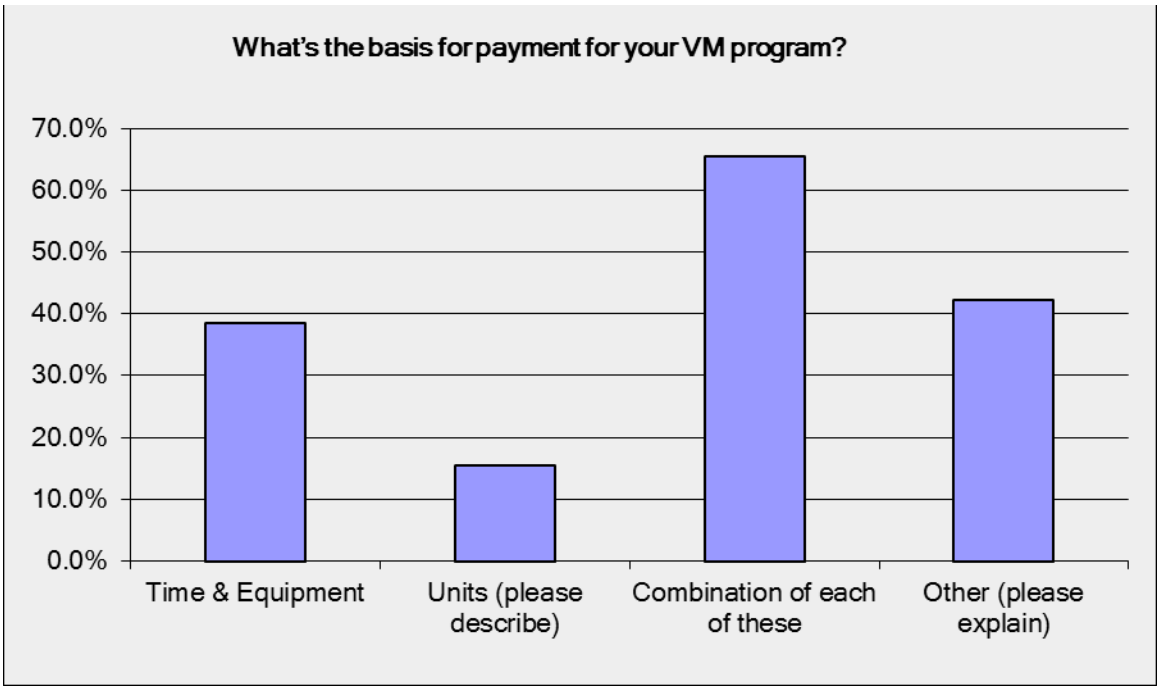

Figure 49 - Question 18 Responses

Free-Text Responses

1. fixed circuit price, unit price, and time and equipment utilized.
2. Distribution contracts are awarded based on lump sum bids. Units within bids are defined (depending on region) by # of trees, # of meters, # of kilometers and by hours of work.
3. Cycle trimming is fixed price per mile. Spot trimming, mid-cycle, other requests are T&E.
4. VM Contracts are unit based
5. Lump sum is also used to bid circuit work
6. Lump sum for circuit maintenance is also practiced
7. Operating unit also bids lump sum for certain circuits

8. Lump sum bids
9. T and E Performance based is the majority of contracts, limited amount of units.
10. Fixed price contracts are also employed
11. We do sum lump sum work based on project conditions.

Table 27 - Question 19 Responses

Does your VM contract include performance-based provisions for Incentive payments (by the utility, for good performance) or Penalty credits (by the contractor, for poor performance)?		
Answer Options	**Response Percent**	**Response Count**
Our contract provides for both Incentives and Penalties	42.3%	11
Our contracts provide for Incentives only	0.0%	0
Our contracts do not provide for Incentives or Penalties	38.5%	10
Other (please explain)	23.1%	6
answered question		26
skipped question		0

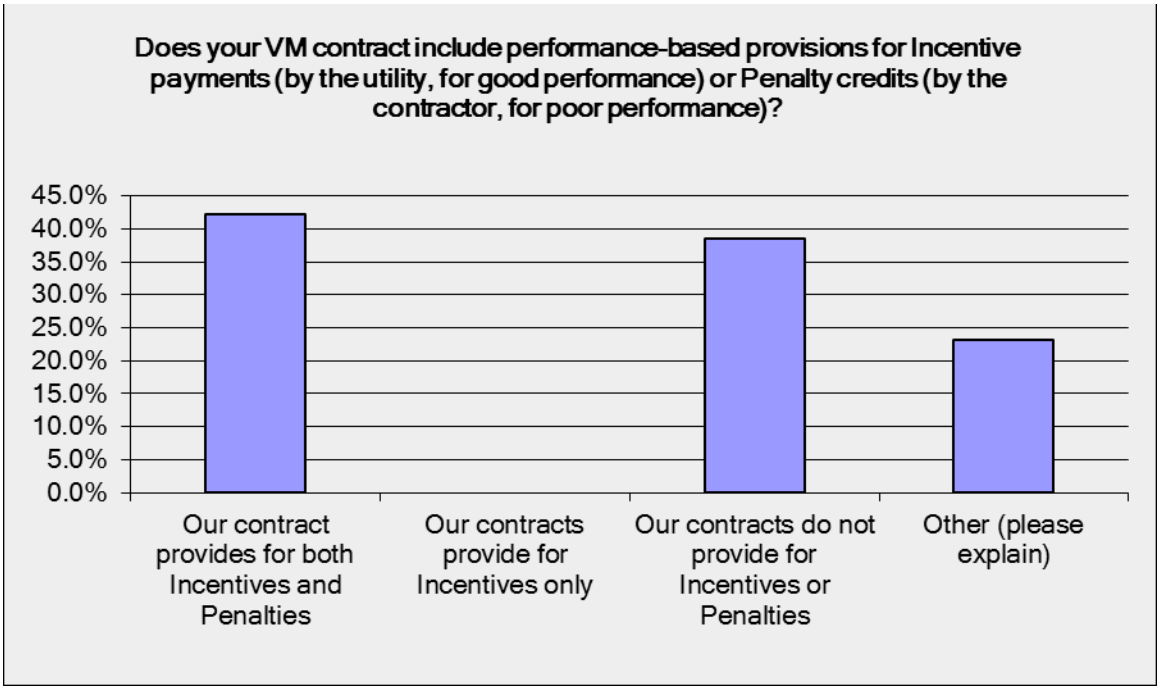

Figure 50 - Question 19 Responses

Free-Text Responses

1.	penalties based on completion deadlines
2.	We do not have an incentive program (bonuses) but a contractor performance based system that does provide a contractor rating that impacts future awards. Green = No restrictions on award. Yellow = Award of a contract with conditions that must be addressed on the contract awarded. Red = No contracts will be issued until deficiencies are addressed by a Corrective Action Plan (CAP) and a mandatory meeting with the Regional Manager.
3.	Penalties for not completing work on time

4.	Use to have cash incentives and credits have recently gone to volume base(number of crews) to reward/penalize performance.
5.	Annual evaluation system in place for each contractor based on metrics defined in monthly scorecards (production, safety, reliability). Adjustments typically made (budget award +/-) in following year's awards depending on their and competitors performance.
6.	Our agreements only have penalties assessed for contractor caused outages.

Table 28 - Question 33 Responses

What is the maximum number of contract tree crews you assign to a VM field supervisor?		
Answer Options	**Response Percent**	**Response Count**
1-3 tree crews	0.0%	0
4-6 tree crews	10.5%	2
7-9 tree crews	5.3%	1
10-12 tree crews	10.5%	2
13-15 tree crewas	5.3%	1
>15 tree crews	68.4%	13
Other (please explain)		15
answered question		19
skipped question		7

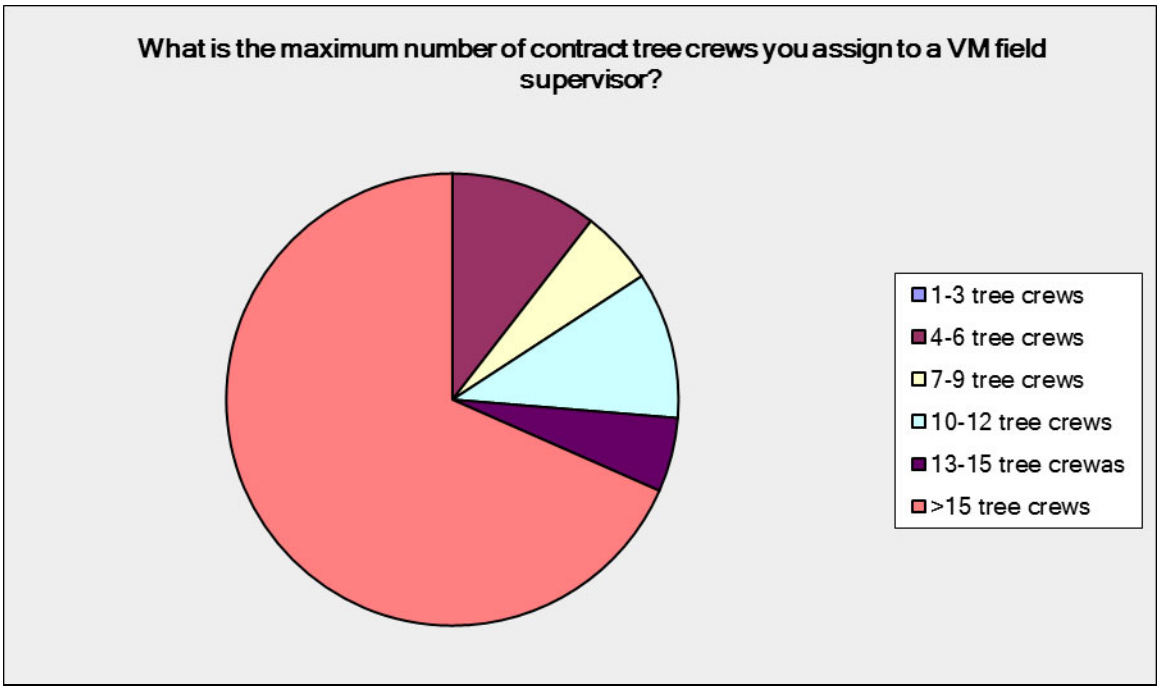

Figure 51 - Question 33 Responses

Free-Text Responses

1. we don't contract out this work
2. Vegetation Coordinators are assigned a specific geographic region. Vegetation maintenance is performed 100% by external vendors. The vendor is responsible for overall tree crew management.
3. VM Dept does not have field supervisors, contractors have General Foremen that oversee the contract tree crews.
4. No maximum set. 10 - 12 is the average but based on work plan and / or budget fluctuations there could be greater than 15 at times.
5. Response assumes VM Field Supervisor refers to a Forester employed by the company to

	manage an area IF VM Field Supervisors refers to field supervision provided by contractor then response is 7-9 crews
6.	Response assumes VM Field Supervisor refers to a Forester employed by the company to manage an area IF VM Field Supervisors refers to field supervision provided by contractor then response is 7-9 crews
7.	Response assumes VM Field Supervisor refers to a Forestey employed by the company to manage an area IF VM Field Supervisors refers to field supervision provided by contractor then response is 7-9 crews
8.	Response assumes VM Field Supervisor refers to a Forestey employed by the company to manage an area IF VM Field Supervisors refers to field supervision provided by contractor then response is 7-9 crews
9.	Response assumes VM Field Supervisor refers to a Forestey employed by the company to manage an area IF VM Field Supervisors refers to field supervision provided by contractor then response is 7-9 crews
10.	VM Field Supervisor - assuming this is a company employed Forester managing a region. IF this is general supervision from the contractor, answer is 7-9 crews per General Foreman
11.	VM Field Supervisor - assuming this is a company employed Forester managing a region. IF this is general supervision from the contractor, answer is 7-9 crews per General Foreman
12.	generally between 45-60 plus tree trimmers per vegetation supervisor
13.	Our contractors manage their crews, not our company
14.	30+, with some Sups having more than 50 crews.
15.	There is no set number. Much of our work is unit and the contractor sets the workforce.

Use of Technology

Table 29 - Question 20 Responses

Do you utilize GIS in the VM strategy? If so, select all applicable methods.		
Answer Options	**Response Percent**	**Response Count**
Defining and tracking work	64.0%	16
Tracking species of trees on circuits	4.0%	1
Incorporation into managing the overall program by linking with the OMS system	12.0%	3
Incorporating weather data into OMS and the VM strategy	4.0%	1
Other (please explain)	44.0%	11
answered question		25
skipped question		1

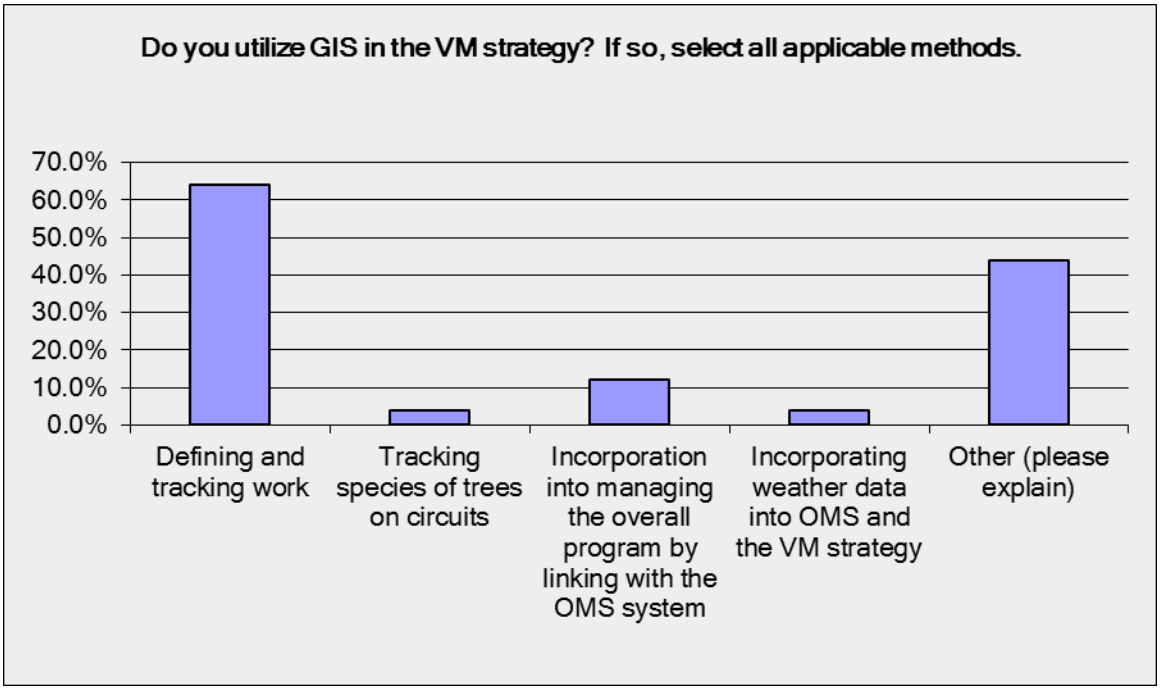

Figure 52 - Question 20 Responses

Free-Text Responses

1. pilot program effort started in 2013
2. Used for pre-work planning for geographic and customer information
3. None currently
4. Specific outage history, Species at Risk location information, Riparian areas, no machine zones, archeological zones, property ownership data are all included in the GIS system.
5. None

6.	Used in spot trimming and storm hardening work planning and tracking, as well as Quality Assurance inspections.
7.	Maps, Miles and exception locations
8.	No we do not use GIS for Distribution VM strategy.
9.	We don't have the technology
10.	No GIS is used
11.	Currently use GIS Smallworld. Polygons are drawn around each distribution maintenance map. Department working on an RFP to send out to VM software vendors and plan on purchasing a system in 2014. GIS Smallworld will be the source of asset data in the future VM software system. As part of the tracking of MPB mitigation in one state, we are currently working with Clearion VM software. It will be this type of system (not necessarily Clearion) that we deploy to the entire distribution maintenance program in the future.

Table 30 - Question 21 Responses

If your company uses GIS for defining and tracking vegetation management work, are handhelds or laptops used in the field.		
Answer Options	**Response Percent**	**Response Count**
We do not use handhelds or laptops	8.7%	2
Laptops	56.5%	13
Handhelds	13.0%	3
Both handhelds and laptops are used in the field	8.7%	2
Other (please explain)	26.1%	6
answered question		23
skipped question		3

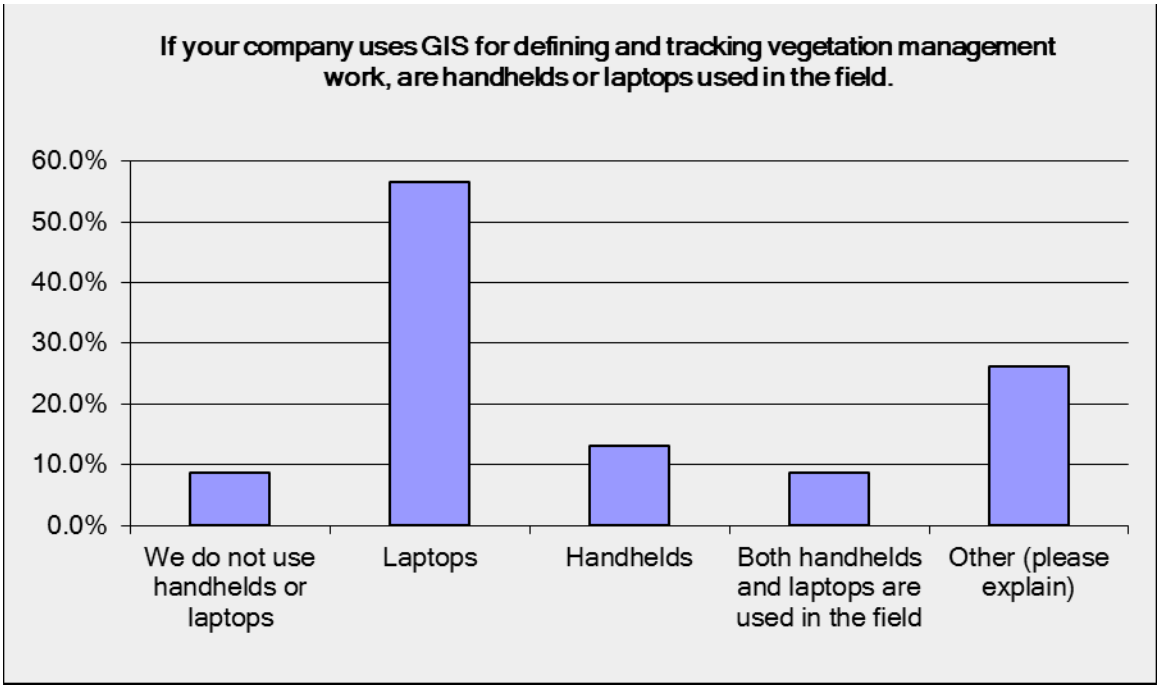

Figure 53 - Question 21 Responses

1.	this is a pilot program in 2013
2.	N/A
3.	Trials in progress for other platforms (ToughBook Tablet).
4.	We are currently implementing a system that will use toughbooks.
5.	Not used
6.	no laptops / handhelds used in maintenance program except – they are used in CO for use with the MPB mitigation.

Table 31 - Question 23 Responses

If your company uses GIS for defining and tracking vegetation management work, are you also using your GIS for work completion and		
Answer Options	**Response Percent**	**Response Count**
Yes	9.5%	2
No	90.5%	19
answered question		**21**
skipped question		**5**

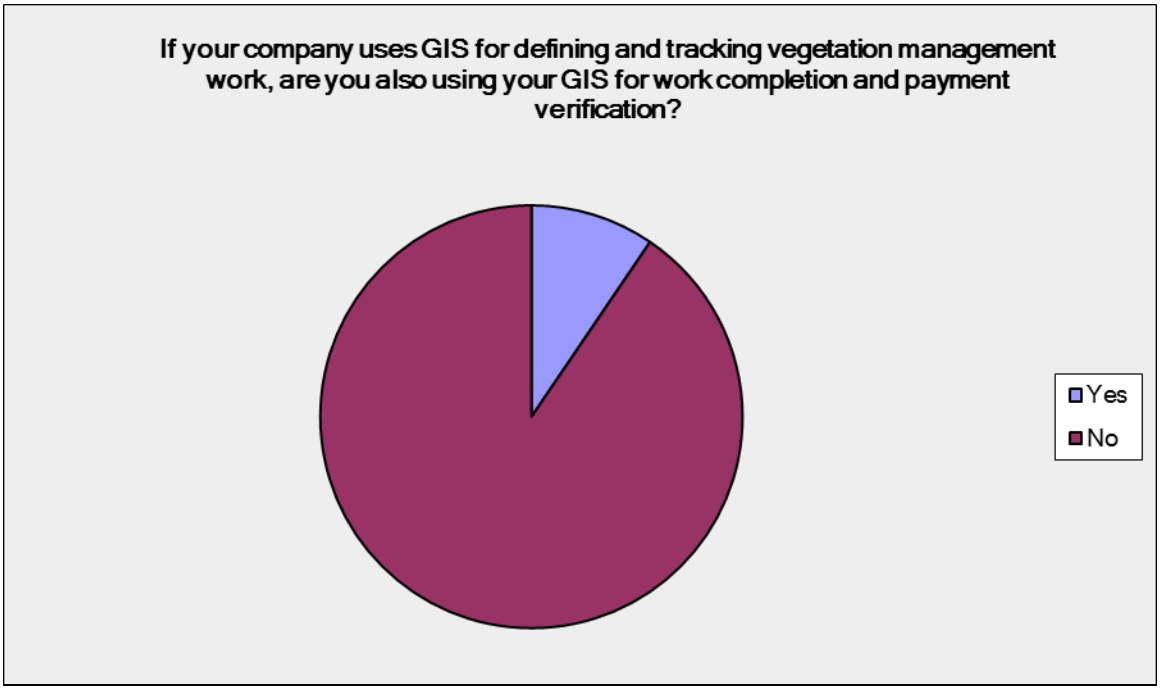

Figure 54 - Question 23 Responses

1.	N/A	Thu, Oct 17, 2013 12:13 PM	Find...
2.	Will be used for work completion verification, but not for payment verification.	Mon, Oct 7, 2013 7:16 AM	Fin

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Appendix C: Industry Scan Report: VM Literature Search (2013)

ELECTRIC POWER RESEARCH INSTITUTE

EPRI Distribution Grid Resiliency:

Vegetation Management

Literature Review of Vegetation Management Concepts, Methods and Management in Support of Improved Distribution Grid Resiliency

Technical Update, December 2013

EPRI Project Manager

R. Litwin

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Appendix C

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Appendix C

ABSTRACT

Vegetation management continues to be a significant challenge to providing safe and reliable and resilient service in overhead electric distribution systems throughout the US. This Vegetation Management (VM) literature review is being conducted by EPRI on behalf of its member utilities which desire a reference and understanding of new practices and standards in the VM industry, and are being applied by their peers. Accordingly, this review will not focus on traditional and widely used practices such as cycle based trimming or hazard tree removal, but instead, will identify less traditional strategies and efforts that are being undertaken to address the significant challenges posed by vegetation.

Due to the increased frequency and severity of recent major storms Distribution grid resiliency has become a critical issue surrounding society and modern life, due in large part to cultural dependency on electricity. The environment within which utility companies reside and operate in, continually challenge electric distribution systems throughout the United States especially in the area of vegetation and the management of its impact on system resiliency. Indeed, vegetation interference is one of the main contributors to outages on overhead distribution systems. Today, even short outages have a significant impact upon society's ability to function safely and efficiently. It is with this backdrop that EPRI has undertaken a review of significant efforts being used throughout the United States, seeking to identify opportunities that can be leveraged and replicated to help overcome the challenges posed by vegetation interference.

In support of the EPRI Distribution Grid Resiliency project, this document provides visibility on recent advances in vegetation management concepts and programs, and identifies approaches that may improve VM program effectiveness. This document also provides an overview of recently published American National Standard Institute's (ANSI) and the International Society of Arboriculture's (ISA) standards and guidelines; and a high level review of state requirements regarding utility vegetation management practices.

Keywords
Distribution Grid Resiliency
Integrated Vegetation Management
Risk Assessment
Vegetation Management

Appendix C

EXECUTIVE SUMMARY

Throughout the last decade, the impact of outages has become more severe as society has become more dependent upon electricity and advanced technologies that require electricity. The subsequent regulatory, customer and industry focus on electric grid resiliency has heightened the focus upon vegetation management because of its overall impact during adverse weather events. It is critical in grid resiliency strategy development that utility companies develop and implement an integrated vegetation management strategy. Each company should apply transparent, repeatable and consistent decision making processes to manage constrained budgets. In doing so, this ensures that a utility is achieving its strategic goals and objectives through informed investment decisions, of which, resilience of the electric system continues to grow in significance.

There are millions of miles of overhead distribution throughout the US and the vast majority share the right of way space with mother nature; most notably vegetation. While vegetation and the distribution system can co-exist, there are some significant challenges that are posed by vegetation. Complicating the management of vegetation is the vastness of many distribution systems, vegetation growth patterns which are substantially influenced by weather, multiple species of vegetation within any right of way, property owners who own the vegetation, funding and governmental requirements. In addition, many vegetation events that interfere with the integrity of the distribution system are caused by vegetation that resides outside of the right of way easement and therefore is legally outside the control of the utility. Furthermore, the various types of vegetation growth and right of way easements necessitate different strategies to effectively manage the potential interference. Each of these strategies requires different prioritizations, skill sets and management oversight.

Recently, the American National Standards Institute (ANSI) updated its Vegetation Management Standards and established an Integrated Vegetation Management (IVM) standard which incorporates asset management principles as they relate to risk management.

In 2006 Part 7 of the ANSI A300 introduced the concept of Integrated Vegetation Management (IVM); two years after the catastrophic blackout of 2004. In 2012, this section was updated to incorporate some of the risk concepts published in ANSI A300 part 9 which was first published in 2011. The IVM differs from previous vegetation management strategies in that it necessitates more sophistication and more comprehensive management oversight. Outlined in six steps, ANSI A300, Part 7, is a methodology for continuous improvement which begins by establishing succinct objectives and involves; information gathering and evaluation, planning, optimally selecting compatible treatments based upon pertinent factors, executing the plan and ultimately evaluating the plan against the objective(s) based upon results.

In 2011 Part 9 of the ANSI A300 introduced the general concept of Risk Management as part of the IVM concept. Fundamentally, this section introduces the concept of treating the system's infrastructure as assets and the corresponding vegetation as a risk element that needs to be managed. It proposes concepts that are well accepted and utilized in the utility industry as it relates to the overabundance of infrastructure that utilities are responsible for and the asset management processes that have been utilized for decades. This section has taken the natural next step of correlating the two components that are generally occurring in the utilities right-of-

ways; vegetation and infrastructure. This standard incorporates advanced understanding of the science and practice of vegetation risk assessment.

The stated purpose for the tree risk assessment is "to provide guidelines for the practice of tree assessment and standards for writing specifications". The reason for the tree risk assessment standard is "to assess structural integrity and other factors that affect the level of risk to people or property and to provide information for mitigating risk". The ISA best management practices associated with the ANSI A300 Part 9 standard outline a systematic process that treats trees and coincident trees as assets. This facilitates the use of a tree risk assessment process which is a familiar process to utilities by virtue of the millions of infrastructure assets that require significant oversight and management. This process ultimately helps to ensure that the investments made in managing vegetation are efficient and effective.

Throughout the research undertaken by this literature research it is evident that a significant number of utilities are addressing vegetation management in traditional and similar ways. These traditional methods and philosophies include: trimming practices focused on eliminating opportunities for vegetation to adversely impact utility infrastructure, targeted cycle trimming with average cycle periods where certain critical facilities, based generally upon condition surveys, are trimmed more often and often include mainline or high impact feeders, and reliability centered programs based upon feeder inspections or hot spot inspections as realized through reliability performance.

There are a number of initiatives that are being utilized within the industry that are notable and include new strategies or different approaches to addressing vegetation management. They are grouped in the general categories of Process Enhancements, Technology Utilization, and Tree Growth Regulators (Herbicides). These sections identify various initiatives that are being undertaken in each category.

Specifically, as it relates to Process Enhancements; several utilities have embraced the updated ANSI standards and ISA best management practices. Other utilities have continued to advance their programs by conducting detailed analysis regarding underlying causes for tree related outages. Specifically as it relates to Technology Utilization, several utilities have begun to take advantage of the opportunities that are provided by technologies like GIS and computer-based management tools. Lastly, as it relates to Tree Growth Regulators (Herbicides), significant research has been done that provides utilities opportunities to capitalize on another tool to address, what is to many utilities the leading cause of outages during adverse weather events.

In summary, while traditional methods to manage vegetation management remain the mainstay of utilities efforts throughout the industry, changes in expectations, standards and technologies will continue to drive improvements that will alter the landscape for utility vegetation management programs.

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Appendix C

1 INTRODUCTION

The purpose of this report is to document and highlight modern practices used by utilities to manage vegetation. It is generally understood that throughout the majority of the US, tree related outages, whether falling limbs or entire trees, are the largest contributor to the overall damage realized by the electric system during adverse weather events; especially considering the last few years, which have seen increased frequency and severity of major storms.

As a result of the significant impact created by these power outages it is important that utilities develop vegetation management programs that appropriately address the risks associated with the results of tree related outages. Although trees are not generally owned by utilities, an effective vegetation management program is integral to meeting the regulatory obligation of the utility to provide safe and reliable power. Each utility has its unique challenges based upon, among other things, geography, topography and arboricultural attributes, regulatory environment, budget constraints, environmental sensitivities and weather.

Throughout the last decade, the impact of outages has become more severe as society has become more dependent upon electricity. Thus, the focus on electric grid resiliency has heightened the focus upon vegetation management because of its overall impact during adverse weather events. Each company should apply transparent, repeatable and consistent decision making processes to manage constrained budgets within and across competing priorities that grid resiliency investments typically reside. In doing so, this ensures that a utility is achieving its strategic goals and objectives through informed investment decisions, of which, resilience of the electric system continues to grow in significance.

The purpose of this report is to provide a document review of current leading practices specific to integrated vegetation management initiatives that ultimately support Distribution Grid Resiliency (DGR).

This document is a reference for readers to use as a tool as they develop an integrated vegetation management program. The document highlights applicable standards and integrates risk mitigation and vegetation leading management practice concepts.

In addition this report provides the Distribution Grid Resiliency (DGR) project participants with an understanding of integrated vegetation management and its leading practice application. This document can serve as a guide for utilities seeking to align its internal prioritization methodologies against an industry framework through the development of processes, procedures and methodologies that allow the utility to evaluate distribution grid resiliency options, and select a collection of options (portfolio) that produces the optimized business value for the utility particularly when dealing with a constrained budget.

Some specific objectives of this phase of the project are:

- Identify integrated vegetation management initiatives that can be utilized by other utilities;
- Identify where principles of risk management are incorporated into integrated vegetation management;

- Identify where asset management processes and modern technologies are being utilized as part of integrated vegetation management programs; and,
- Identify where initiative that are being used to address distribution grid resiliency are incorporated into integrated vegetation management programs.

2 OVERVIEW OF US ELECTRIC DISTRIBUTION SYSTEMS

Generally, in the United States the distribution system begins with a primary alternating current circuit or feeder which emanates from a substation and terminates at an end user or customer. Effectively, distribution circuits are the bridge between the transmission systems which are used to broadly disseminate power at high voltages (138kV, 345kV, 500kV etc.) over great distances and the end user or customer. Distribution circuits are fed from a power transformer located at a distribution substation which "transforms" the transmission level voltage to distribution level. On the distribution system, the voltage used is lower because there is usually less distance to transport the power and thus there are many distribution substations throughout the US. Typical voltages range from 2kV to about 35kV depending on utility standard design, distance to load, and the amount of load to be served.

Feeders generally consist of three single conductors which are utilized to transport or conduct the three phases that are generated at the generation station. Usually there is an additional conductor used as a ground reference which very broadly is designed to minimize electric shock during abnormal conditions. Distribution systems utilize overhead pole lines, or in densely populated areas, underground conduit systems, to transport power to end use customers.

While three phase power is utilized in densely populated areas, single phase distribution is often provided in less densely populated areas. Residential, commercial, and industrial loads are addressed via both of these means and the use of three-phase or single-phase service is usually determined by the amount of load needed to be served. Further, while very large loads may be provided service at distribution voltages, most utility customers are provided service at secondary voltages (120V/208V, 120V/240V, 277V/480V) through the use of a distribution transformer which converts the distribution voltage to secondary voltage. Throughout the US, the majority of these transformers are pole-mounted or pad-mounted and are supplied by overhead distribution systems. However, in very dense areas, like most of the major cities throughout the US, secondary networks are created where the transformer which converts distribution voltage to secondary voltage is placed in a conduit system underground.

Consequently, across the nearly 4 million square miles of land in the United States are millions of miles of overhead distribution wire owned by many utilities used to distribute ubiquitous electric service throughout the United States. These distribution systems supply power to hundreds of millions of residential, commercial and industrial customers and as such are an integral part of the infrastructure necessary to ensure that the United States remains, among other things, economically, and financially viable. In order to build the overhead electric system tens of millions of poles are installed along roadways or through land through the use of Right-of-Way (RoW) access easements. As one might expect, because of the nature of the locations where poles are placed there are challenges that interfere with the use of the RoW; most notably vegetation.

Vegetation and its Impact on Distribution Systems

There are millions of miles of overhead distribution throughout the US and the vast majority share the RoW space with Mother Nature; most notably vegetation. While vegetation and the distribution system can co-exist, there are some significant challenges that are posed by vegetation. As noted earlier, distribution systems distribute power along conductors. As part of the design and electrical requirements, these conductors are electrically isolated to avoid the uncontrolled flow of power. Generally, at each pole, the conductor is electrically isolated through the use of insulators which isolate the conductor from the pole; which is considered grounded via its placement in the ground. Additionally, each phase of the conductor is electrically isolated from the other phases to eliminate the uncontrolled flow of power due to the potential across phases. Notwithstanding the isolation efforts, vegetation may interfere in a variety of ways with the design efforts utilized by utilities to ensure the distribution of safe and reliable power.

The two primary interferences caused by vegetation are normal growth that encroaches on the primary voltage conductor(s) and limbs or trees that fall on the conductor(s). Either of these scenarios can create situations where there is uncontrolled power flow, by acting as a ground path, establishing a conductive path between otherwise electrically isolated phases; or damaging the equipment that normally provides the necessary electric isolation. In any of these events, the safety and reliability of the overhead distribution system may be compromised.

Challenges Associated with Managing Vegetation

There are several factors that influence a utility's ability to manage vegetation. It should be noted, utilities generally do not own the vegetation that often co-exists in its right of ways. However, by virtue of its RoW easement the utility generally has certain rights to manage and control those things that may reasonably interfere with its RoW rights. Managing this however is complicated by the vastness of many distribution systems, growth patterns which are substantially influenced by weather, multiple species of vegetation within any RoW, property owners who own the vegetation, funding and governmental requirements. In addition, many vegetation events that interfere with the integrity of the distribution system are caused by vegetation that resides outside of the RoW easement and therefore is legally outside the control of the utility. Furthermore, the various types of vegetation growth and RoW easements necessitate different strategies to effectively manage the potential interference. Each of these strategies requires different prioritizations, skill sets and management oversight.

History of Vegetation Management

Historically, vegetation has been a leading cause of outages in the US. Indeed, as a result of the Rural Electrification Act (REA) in the 1930s, overhead distribution systems throughout the US began to quickly expand, inadvertently increasing their exposure to the deleterious effects of vegetation. Utilities of all types; cooperatives, municipal and investor owned, began to realize that vegetation needed to be managed in order to provide the desired reliability contemplated by the REA.

For at least 50 years, many utilities throughout the US have focused on managing vegetation mainly through the establishment of RoWs during initial infrastructure installation, subsequent

maintenance trimming programs and targeted removals. In addition herbicide application have also been widely used, often in conjunction with local municipal governments who have responsibility for managing roadside vegetation.

While these efforts have been highly successful, as evidenced by the reliability of the distribution system measured by overall availability of service, the negative impact of vegetation, particularly during severe weather events is notable and significant.

Appendix C

3 STANDARDS AND GUIDELINES FOR VEGETATION MANAGEMENT

Overview

Despite the importance of distribution vegetation management there has been, until recently with the 2012 publication of ANSI and ISA standards and guidelines, little guidance to the electric utility industry.

There are no federal standards set forth by the Federal Energy Regulatory Commission or the Department of Energy for distribution level voltages. However, as a result of the 2004 blackout, the North American Electric Reliability Corporation (NERC) standards, consistent with the provisions of section 1211 of the Energy Policy Act of 2005 (US Congress Public Law 109-58, enacted August 8, 2005), were established but only apply to transmission level voltages. Thus, distribution voltage vegetation management requirements are the jurisdiction of state regulatory agencies.

Not surprisingly, the Occupational Safety and Health Administration also does not provide any specific guidance as it relates to vegetation management; but, does address the safety of workers who work in the proximity of hazards. Though not specific to vegetation management, the only real guidance provided by OSHA involves the safe work practices necessary to work near energized conductors.

The National Electric Safety Code (NESC) by contrast does generally establish the requirement for vegetation management practices to be determined by each utility, and it does establish guidelines for line maintenance and worker safety. The NESC is not prescriptive regarding the frequency or determination for vegetation management nor does it establish clearance standards. Rather, it provides general guidance that acknowledges that vegetation may interfere with the safe operation of overhead conductors and recommends that these situations be addressed according to the needs of the specific utility.

In jurisdictions that are concerned with wildfires requirements set forth in the *Wildland-Urban Interface Code* are often mandated. These regulations may be voluntarily adopted by any given governmental jurisdiction seeking to utilize the efforts of the International Code Council. This code seeks to establish minimum regulation for land use and infrastructure that exists where wild land abuts urban locations. There is minimal discussion regarding vegetation management and it is focused on site-specific locations. The intention of this code is to bridge the gap between applicable building and fire codes within a jurisdiction.

In the United States in 1991 a committee of arboricultural professionals organized and developed tree maintenance standards focusing on improving public safety and establishing uniform standards to be utilized in arboricultural operations. These efforts resulted in the development, recommendation and acceptance as a standard by the American National Standards Institute (ANSI) and have been used throughout the industry for the last twenty years. Fundamentally,

these standards address safety requirements for vegetation management and identify best practices for trimming and pruning practices.

Recently however, the ANSI standards were updated and establish an Integrated Vegetation Management standard which incorporates asset management principles as they relate to risk management. Below is a summary of the ANSI standards and the associated ISA best management practices.

American National Standard and International Society of Arboriculture

The American National Standards Institute is a private non-profit corporation that oversees the development of voluntary standards for products, services, processes, systems, and personnel in the United States and coordinates international standards to ensure worldwide inter-operability.

ANSI accredits standards that are developed by representatives with extensive knowledge in the specific fields where standards are being developed with the goal of ensuring that the characteristics and performance of products are consistent, that people use the same definitions and terms, and that products are tested the same way. ANSI also accredits organizations that carry out product or personnel certification in accordance with requirements defined in international standards.

Since 1991 the Tree Care Industry Association (TCIA) has, working as an accredited Standards Developing Organization for ANSI, been providing guidance to, among others, property managers and owners, government agencies and utilities.

In August of 2012, ANSI published a revised A300 with a mission "to develop consensus performance standards based on current research and sound practice for writing specifications to manage trees, shrubs and other woody plants".

Fundamentally, the ANSI standards indicate requirements, and the companion International Society of Arboriculture (ISA) best management practices provide a more detailed and practical discussion regarding how to accomplish the requirements set forth by the standards.

Tree, Shrub, and Other Woody Plant Management - Standard Practices (Integrated Vegetation Management, a. Utility Rights-of-Way)

In 2006 the section of the ANSI A300 that addresses Tree, Shrub, and Other Woody Plant Management - Standard Practices (Integrated Vegetation Management, a. Utility Rights-of-Way) introduced the concept of Integrated Vegetation Management (IVM) only a couple years after the catastrophic blackout of 2004. In 2012, this section was updated to incorporate some of the risk concepts published in ANSI A300 part 9 which was published in 2011. The IVM differs from previous vegetation management strategies in that it necessitates more sophistication and more comprehensive management oversight.

The stated purpose for the IVM is "to provide standards for developing specifications to implement an integrated approach to management of vegetation on utility right-of-ways". The reason for the IVM "is to create, promote, and conserve sustainable plant communities that are compatible with the intended use of the site and discourage incompatible plants that may pose concerns, including safety, security, access, fire hazard, utility service reliability, emergency

restoration, visibility, line-of-sight requirements, regulatory compliance, and environmental or other specific concerns."

As defined, IVM is "a system of managing plant communities in which compatible and incompatible vegetation is identified, action thresholds are considered, control methods are evaluated, and selected control(s) are implemented to achieve a specific objective. Choice of control methods is based on effectiveness, environmental impact, site characteristics, safety, security and economics".

ANSI Best Management Practices

Not intended to supplant the expertise of a qualified vegetation manager, ISA intends to provide best management practices to guide arborists, and the people who employ them, toward the most appropriate arboricultural techniques. The repeatable steps outlined as part of the IVM offer a scientific basis for utility companies to manage vegetation.

ANSI A300, Part 7 offers a systematic way of planning and implementing a vegetation management program which consists of six steps:

1. Set Objective
2. Evaluate the site
3. Define action thresholds
4. Evaluate and select control methods
5. Implement IVM
6. Monitor treatment and quality assurance

The term integration as it relates to IVM is a recognition that each of the steps is integrated into the other and that the process is principled on continual improvement since each successive application will necessarily build upon the lessons learned from the previous application of the process.

Set Objectives

Objectives are set by each utility and may be utility specific or even project specific. The objective(s) is meant to establish the overall vision of the remaining steps and may be broad or narrow. Regardless, the results of the IVM must be evaluated to determine if the objective(s) has been met. It is important to establish appropriate metrics and the processes necessary to ensure the requisite data is available to evaluate whether the objective(s) has been met.

Evaluate the Site

Evaluating the site is fundamentally a planning function that recognizes the dynamic nature of areas where IVM programs will be employed. Site evaluations are utilized to identify risks and opportunities and may include, among other things; identifying safety concerns, identifying applicable regulations based upon location, political and budgetary concerns, the amount of work necessary to effectuate the plan, unique equipment or labor capabilities required by the site,

right-of-way conditions and constraints, adjacent land uses and constraints, the likelihood of fire risk, environmentally vulnerable or protected areas, access restrictions, and weather or time or year restraints. This information is useful for constructively challenging the objective(s) and defining future steps.

Define Action Thresholds

Action thresholds are determined by the results of the site evaluation and establish vegetation height and density targets that trigger specific control measures necessary to meet the objective(s).

Evaluate and Select Control Methods

A variety of control measures may be necessary to achieve the overall objective(s) set forth for the site or project, but each control method should optimally be chosen to suitably meet the objectives. There are a variety of control methods available to vegetation managers, including; manual, mechanical, biological, tree growth regulators, and a variety of herbicide applications, including individual stem treatment, broadcast treatment, and aerial treatment.

Each of these control methods are designed for specific applications and must be chosen to optimally meet the objectives and take into consideration needs identified during the site evaluation.

Implement IVM

This step highlights the integration of the previous steps and re-emphasizes the need to ensure systematic work scheduling using pre-determined control methods which considers relevant factors to inform the execution of the IVM, including workloads, accessibility, and importance of infrastructure and growth rates. It also superficially addresses, initial clearing and reclamation considerations, clearances following work completed predominantly focused on transmission level voltages and debris removal – most relevantly, as it relates to disease or insect infected debris.

Monitor Treatment and Quality Assurance

Consistent with good asset management practices, evaluating the results of decisions made and actions taken is critical for improving the plan. An important aspect related to evaluating the results is ensuring that the work defined to meet the objectives was executed as planned. As noted in the best management practices, “utility vegetation management programs should have systems and procedures in place for documenting and verifying that vegetation management work was completed to specification”. The management of vegetation is data intensive and thus it is important that appropriate processes are established early in the IVM process (ideally when establishing objectives) to ensure that pertinent data is defined and appropriately captured – this information is critical for further developing future IVM strategies.

Outlined in six steps, ANSI A300, Part 7, is a methodology for continuous improvement which begins with establishing succinct objectives and involves information gathering and evaluation, planning, optimally selecting compatible treatments based upon pertinent factors, executing the plan and ultimately evaluating the plan against the objective(s) based upon results.

Tree, Shrub, and Other Woody Plant Management - Standard Practices (Tree Risk Assessment, a. Tree Structure Assessment)

In 2011 this section, ANSI A300 Part 9 introduced the general concept of Risk Management as part of the IVM concept. Fundamentally, this section introduces the concept of treating the system's infrastructure as assets and the coincident vegetation as a risk. It proposes concepts that are well accepted and utilized in the utility industry as it relates to the plethora of infrastructure that utilities are responsible for and the asset management processes that have been utilized for decades. This section has taken the natural next step of correlating the two components that are generally occurring in the utilities right-of-ways, vegetation and infrastructure. This standard incorporates advanced understanding of the science and practice of vegetation risk assessment.

The stated purpose for the tree risk assessment is "to provide guidelines for the practice of tree assessment and standards for writing specifications". The reason for the tree risk assessment standard is "to assess structural integrity and other factors that affect the level of risk to people or property and to provide information for mitigating risk".

ANSI Best Management Practices

The best management practices promulgated by the ISA were developed consistent with, among other International Standards Organization (ISO) standards, ISO 31000:2009 Risk Management – Principles and Guidelines. Thus, it is not surprising that the information contained in this publication are remarkably similar to guidelines set forth in traditional risk management processes. As noted in the publication, this standard, like the ANSI standard, different from other standards, focuses solely on tree risk assessment and not the overarching goals and issues of tree risk management; and thus, it is geared toward guiding the arborist.

The purpose of the publication is "guide arborist to assess tree risk as accurately and consistently as possible, to evaluate that risk, and understand which treatments can achieve an acceptable level of risk". Similar to traditional risk management principles, risk is the combination of likelihood of an event and the severity of the potential consequences of that event. Thus, unlike the traditional and loosely applied terms, a tree is only considered "hazardous" when it has been appropriately assessed, found likely to fail and whose consequences of failure create an unacceptable degree of consequence.

Tree risk assessment is the systematic process to identify, analyze, and evaluate tree risk. The manner in which this process is applied depends on the context. The parameters of the risk assessment which may include objectives, applicable policies and legal requirements or communication flow, and the methods used to carry out the risk assessment. Generally, there are two approaches to undertaking risk assessment; quantitative and qualitative. While each has its limitations there are, depending on the objectives, requirements, resources and uncertainties, advantages and limitation to each. Regardless of the approach taken it must be understood that there are limitations inherent in the process due to the nature of the unknowns that are inextricably tied into the process of managing trees; weather, traffic issues, and rates of

progression of decay. And, it should be noted, that there are generally two general types of risk associated with trees: conflicts and failures. Conflicts are the result of a mismatch between a trees natural tendencies and its societal impact and function – these are not often the concern of utilities. Failures however, are the cause of much utility consternation and involves, as one might expect, mechanical failure of trees and tree parts.

Level and Scope of Tree Risk Assessment

The best management practices define three levels of risk assessment which should be specified in the scope-of-work and should be appropriate for the assignment. There are three levels of assessment.

Level 1 – Limited Visual Assessment

Level 1 assessment is a visual assessment from a specified perspective focused on identifying obvious defects or specific conditions. Because of the limited nature of some level 1 assessments, they may not even qualify as a "risk assessment" because of the lack of analysis or evaluation of individual trees. Level 1 assessments, though limited in value, do have important uses by a utility such as post-storm assessments or quick evaluations of a large population of trees.

Level 2 – Basic Assessment

Level 2 assessment is a detailed visual inspection of a tree and its surrounding site and a synthesis of the information collected. This level of assessment is the standard performed by the arborist in response to a request for a tree risk assessment. It should be noted, however that this level of assessment includes only conditions that are detected from a ground based inspection and thus many risks may go undetected.

Level 3 – Advanced Assessment

Advanced assessments provide detailed information about specific tree parts, defects, targets or site conditions. Specialized equipment, data collection and analysis, and expertise are usually required for advanced assessments. Advanced assessments may include a variety of techniques such as: aerial inspection and evaluation of structural defects in branches, using load and decay testing; detailed target analysis identifying use and occupancy of surrounding areas, taking into consideration the potential disruption of activities; detailed site evaluation including a soil profile inspection to determine root depth; decay testing including single path sonic stress testing and electrical impedance tomography; heath evaluation involving starch assessment and shoot length measurements; root inspection using ground penetrating radar; and wind load analysis using computer based estimations against engineering standards. Accordingly, prior to undertaking a advanced assessment the tree or area to be evaluated should be defined, the level and detail of the assessment should be established, the methods to report findings should be defined including the timeframe and the risk rating methodology and mitigation limitations and expectations should be discussed.

Assessing and Evaluating Risk from Tree Failures

This section of the publication outlines the basic expectations that are consistent with typical risk assessments utilized in traditional asset management processes, a likelihood versus consequence analysis. In this instance, the arborist defines the target(s) that are to be evaluated from a consequence perspective. Targets relevant to this discussion mainly involves utility infrastructure, vehicles and buildings, though targets may also include people, activities or other property. Once targets are defined, a risk assessment of nearby trees is undertaken to evaluate the likelihood of failure and the likelihood of the tree impacting a target. Obviously, the determination of the likelihood of a tree failure is very challenging; and consequently guidance is provided within the publication which focuses on the physics associated with environmental forces like wind and stresses within the structure of the tree itself, including compression, tension, shear and torsion. Similarly, understanding the potential impact of the tree failure is equally challenging because it may be dependent on the time of day of the tree failure, electrical loading needs of customers and weather conditions. As might be expected, various factors may influence either the likelihood or consequence of a tree failure, including site conditions and factors, potential wind excursions based upon things like topography or removal of other surrounding trees and tree species and their respective failure profiles.

Tree Risk Categorization

The tree risk categorization is similar to the categorization of risk used as part of traditional asset management programs. It relies on developing a matrix which estimates the likelihood of the combined events of a tree failure occurring and the tree impacting a specific target against the consequence of the resulting event.

The likelihood of an event taking place may consider, to varying degrees, the health of the tree, site conditions, species failure profiles, susceptibility to weather events and the experience of the assessor. The likelihood of failure is classified into four basic categories: improbable, possible, probable and imminent. Similarly, the likelihood of impacting the specified target considers various factors and is categorized into four levels: very low, low, medium and high. Thus the matrix using these four categories for each results in a 4-by-4 matrix which helps illustrate the likelihood of a tree failure impacting a specified target. The four levels used for populating this matrix are: very likely, likely, somewhat likely and unlikely.

This likelihood of failure and impact is then contrasted with the consequence of the resulting event to ultimately develop a risk rating matrix which demonstrates the level of risk as the combination of likelihood of a tree falling and impacting a specific target, and the severity of the associated consequence. Again, determining the consequence of an event occurring can be challenging because of the variety of factors to be considered. The consequences of an event are evaluated in four categories: negligible, minor, significant and severe. The four terms used to define the levels of risk in the resulting matrix are: extreme, high, moderate and low.

Similar to asset management risk profiles the risk matrix outlined in this publication appears in Table 1, below:

Table 1 - Risk rating matrix showing the level of risk as the combination of likelihood of a tree failing and impacting a specified target, and severity of the associated consequences.

		Consequence			
		Negligible	**Minor**	**Significant**	**Severe**
Likelihood of Failure and Impact	***Very Likely***	Low	Moderate	High	Extreme
	Likely	Low	Moderate	High	High
	Somewhat Likely	Low	Low	Moderate	Moderate
	Unlikely	Low	Low	Low	Low

It should be noted that the use of this matrix has limitations due to the subjectivity associated with the selection of both the likelihood and consequence factors, and the lack of comparability to other types of risk assessed using other means. Likewise, there are a variety of other limitation that are inherent in the process of risk assessment: tree assessment considers known targets and detectable tree conditions, the condition assessment is a snap-shot in time, and the scope of the risk assessment is defined early in the process.

Risk Mitigation: Preventative and Remedial Actions

Once the risk is understood, mitigation efforts can be developed. These mitigation efforts may address the likelihood of the failure, the likelihood of impact or the consequence of the failure. Mitigation efforts may be quite varied and may include: target management, which focuses on evaluating options for doing something to the target to mitigate the risk; pruning, installing structural support systems; adding lightning protection to trees, modifying the site; and using tree growth regulators. As might be expected the immediacy and type of response to developing mitigation plans is guided by the severity of the risk associated with the situations. For example, extreme risk situations necessitate immediate response, while low risk trees may be retained and monitored, if deemed necessary. It is important to note, that not all mitigation efforts completely eliminate the risk and thus it is important to be aware of and prepare for any residual risk that may remain, if necessary.

Risk Reporting

As noted in the publication the information, conclusions, recommendations and mitigation efforts should be appropriately documented. This documentation is necessary to help inform future decisions as well as ensure that communications with stakeholders are effective. Incidentally, in the wake of severe weather events, documented risk assessments and mitigation

efforts are valuable to convey the due diligence expected of utilities to meet the delivery of safe and reliable power.

Summary of Best Management Practices Associated with ANSI A300 Part 9

The ISA best management practices associated with the ANSI A300 Part 9 standard outline a systematic process that treats trees and coincident trees as assets. This facilitates the use of a tree risk assessment process which is a familiar process to utilities by virtue of the millions of infrastructure assets that require significant oversight and management. This process ultimately helps to ensure that the investments made in managing vegetation are efficient and effective.

Appendix C

4 UTILITY INDUSTRY HIGHLIGHTS

Throughout the research of this literature review, it is evident that a significant number of utilities are addressing vegetation management in traditional and similar ways. These traditional methods and philosophies include: trimming practices focused on eliminating opportunities for vegetation to adversely impact utility infrastructure; targeted cycle trimming with average cycle periods, where certain critical facilities, often prioritized by condition assessments, are trimmed more often and generally focus on mainline or high impact feeders; and reliability centered programs based upon feeder inspections or hot spot inspections as realized through reliability performance.

There are a number of initiatives that were evident throughout the review. They include the establishment of reliability indices and vegetation management metrics within utilities that have VM programs that focus on understanding the SAIFI impact of tree related outages. Also, most utilities focus on targeting mainline distribution because of the potential SAIFI impact of those type of outages as compared to fused laterals. Most VM programs have used cycle-based trimming for long enough periods that the adverse impact of outages caused by tree growth is minimal as compared to limbs, branches and trees; thus, most programs focus on addressing these types of issues. Similarly, maintaining mandated minimum clearances does not seem to be generally acknowledged as being useful and instead targeted trimming for identified risks seems more utilized.

Many utilities have hazard or danger tree identification and removal / mitigation strategies. During adverse weather events, trees and tree limbs are generally the major contributor to outages. Accordingly, many utilities have developed programs to identify these hazards and on a prioritized basis remove or mitigate the risk associated with these trees. The processes in these programs vary but generally the process is reasonably dovetailed into the cycle-based trimming, at least from an identification methodology. Generally, removal of these hazard tree locations is prioritized by its ability to adversely impact the reliability of service, thus mainline distribution often is the target. This is also reinforced because of the expense associated with full removals where necessary and the financial challenges realized by this Operations and Maintenance (O&M) expense.

An area where there was reasonable consensus is regarding public education. Generally, most utilities provide vegetation management education awareness. As part of this program, nearly all utilities provide some information regarding safety especially during storms and highlight the risk of downed wires. Many utilities are now using arborists to interact with stakeholders and work with property owners to facilitate the vegetation management process. Most utilities who utilize this process believe that the efforts of the arborist are important to stave the negative reaction that many property owners have to vegetation management initiatives, especially where their tree is being impacted.

There are a number of initiatives that are being utilized within the industry that are notable and are included below in the general categories of Process, Technology, Tree Growth Regulators and Noteworthy Efforts.

Process Enhancements

Unitil Corporation – (Fitchburg Gas and Electric Company, a subsidiary of Unitil Corporation)

In May of 2013 Unitil developed and submitted to the Department of Public Utilities in Massachusetts a five-year vegetation management plan[1]. This plan embraces the standards set forth in the ANSI A300, Part 7 standard.

The plan incorporates, consistent with the ANSI standards and ISA best management practice, various sections with significant relevant detail. Sections included in the plan are; The Primary Goals and Objectives of the VMP, Right-of-Way Vegetation and Identification of Target Vegetation, Integrated Vegetation Management Methods, Integrated Vegetation Management and Justification for Herbicide Use, Identification and Vegetation Management Methods in Sensitive Areas, Operational Guidelines for Applicators of Herbicides, Identification and Qualification of Individuals Preparing and Submitting this VMP and Supervision of the IVM Program, Description of Alternative Land Uses of Right-of-Way, and Remedial Spill and Emergency Plan.

The Primary Goals and Objectives section of the VMP defines eight objectives that guide the development and execution of the Integrated Vegetation Management Plan.

The Right-of Way Vegetation and Identification of Target Vegetation section acknowledges that a successful IVM approach to vegetation management leads to establishment of vegetative communities that are compatible with the electric facility. This section further defines target vegetation, as envisioned by the ISA VMPs, both for potential interference with electric infrastructure and plant species that present an environmental or safety problem especially where humans are the impacted target.

The Integrated Vegetation Management Method section outlines the expected methods that will be utilized to address the target vegetation and provides a detailed assessment of how each of the methods will be utilized.

The Integrated Vegetation Management and Justification for Herbicide Use section outlines its regulatory compliance strategy relating to application of herbicides and contemplates the transition from a historic use of mechanical methods to one that incorporates the use of herbicides.

The Identification and Vegetation Management Methods in Sensitive Areas defines sensitive areas, including; water supplies, surface waters, cultural sites, and wildlife areas and addresses restrictions in these areas, specifically as they relate toe herbicides.

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1 “Five Year Vegetation Management Plan.” Prepared by Unitil Corporation; http://www.unitil.com/sites/default/files/pdfs/UnitilVMPMay-1-2013.pdf

The Operational Guidelines for Applicators of Herbicides section fundamentally establishes the Vegetation Management Guidelines for the application of herbicides as part of the IVM. It is primarily focused on providing information to a third-party service provider.

The Identification and Qualification of Individuals Preparing and Submitting this VMP and Supervision of the IVM Program simply outlines who has overall responsibility for the development and implementation of the VMP. It notes, that this responsible person has ultimate responsibility for the preparation, implementation and compliance with all aspects of the VMP.

The Description of Alternative Land Uses of Right-of-Ways section addresses the concept of using right-of-way land differently as a cultural control method. Specifically, this aspect of the plan contemplates using right-of-way property for alternative uses which may include, farming, pasture land, orchards, golf course and paved roads, all which reduce the need to address target vegetation.

The Remedial Spill and Emergency Plan proactively anticipates hazards associated with the use of chemicals and other hazardous materials. It includes reference material, outlines notification contact information and establishes an herbicide spill checklist.

In all, the IVM set forth by Unitil provides tremendous insight to the objectives of the plan and the actions necessary to achieve these objectives. It is aligned with the anticipated format included in the ANSI and ISA documentation.

Northeast Utilities System

Similar to Unitil, Northeast Utilities outlines, in its 2014-2018 IVM plan, efforts consistent with the requirements of the ANSI A300 standard. One notable difference between the plans involves the alternate use of right-of-ways. At Northeast, the IVM establishes a process whereby a party may contract with the company to use the land for certain purposes which ultimately precludes the company from having to maintain vegetation management in that area.

Specifically, as set forth in the IVM, this is an agreement between the Company and another party (an individual, state or local government agency, or corporation), regarding property owned by the Company. A party may enter into an agreement with the Company (through a Company Representative) which allows them to use Company owned land for their purpose (e.g., commercial or agricultural use) in exchange for some agreed to compensation. Certain land uses preclude or reduce the need for brush control. License agreements are negotiated on a case-by-case basis via the Company's Real Estate Department.

Long Island Power Authority

LIPA has a high tree density per circuit mile which is one of the several challenges that it faces with regard to vegetation management[2]. As of June 2013, LIPA's VM program identified 1,600 circuit miles on its distribution trim list and 200 circuit miles on its transmission trim list. In the process of identifying the vegetation management and the acquisition of contracts, LIPA's

2 "LIPA Vegetation Management Program." Prepared by Long Island Power Authority; http://www.lipower.org/pdfs/company/papers/board/062713-op-veg.pdf

reliability engineers perform an analysis of tree caused interruptions and consult with vegetation management supervisors with regard to the field conditions.

With regard to vegetation management related to storm hardening, LIPA's reliability management provides analysis on where entire trees and large limbs impact the system. Moreover, LIPA's vegetation management supervisors work with contractors and municipalities to identify hazard trees. Following a more innovative approach, LIPA is currently experimenting with a pilot iPad Application that can improve monitoring and efficiency of hazard tree management.

LIPA's right of way and substation maintenance activities include grounds maintenance and selective herbicide spraying in substations in addition to developing plans and monitoring field crews on a daily basis. In addition to utilizing "directional pruning", LIPA's tree trimming activities are performed in compliance with ANSI A300. Moreover, LIPA holds an annual contractor workshop to review all trim specifications. Furthermore, LIPA's Line Clearance Supervisor monitors field work during trimming jobs, performs a full inspection at the end of jobs and electronically files Contractor Evaluation assessments upon the completion of each circuit.

Orange and Rockland Utilities

Orange and Rockland has had an aggressive Distribution vegetation management program in active practice for over twenty years. Beginning about 1991, Orange and Rockland committed to a consistent cycle-based approach to Distribution vegetation management of its primary electric facilities. Since making this commitment, Orange and Rockland has employed a distribution clearance specification of (10') under, (10') to the side, and (15') feet over top of all primary facilities of all construction types. This specification has been implemented over a consistent cycle length of four-years and slightly quicker in more customer-dense areas. This standard pruning specification and commitment to maintaining the cycle length has led to a more reliable electrical infrastructure and quicker repairs when tree-related incidents do occur. When Orange and Rockland first began to introduce the new distribution vegetation management concept and pruning standards, it was not received well by all customer or municipalities within its service territory. Through a consistent message, outreach, education, and informational meetings, Orange and Rockland has made tremendous strides forward and currently both customers and municipalities view Orange and Rockland as a partner and an asset in terms of maintenance of the shared community forest.

In June 2013, Orange and Rockland enhanced its long standing Distribution vegetation maintenance program with advancements that are designed to further improve the program. These enhancements include a larger pruning specification for selected areas of the overhead system. The first area that will receive additional treatment is the primary conductor from the substation out to the first set of protection. The philosophy is that from the substation exit to the first protective device the entire customer base on the circuit has exposure to a tree-caused event. To mitigate that risk, Orange and Rockland has introduced an expanded pruning specification 33% larger than the standard pruning specifications. Orange and Rockland now achieves clearance specification of (15') under, (15') to the side, and (20') feet over top from the substation out to the first protective device, or a mile should no protective device be present. After the protective device (or the mile), the pruning clearance reverts back to the standard

clearance specification of (10') under, (10') to the side, and (15') feet over top. This expanded pruning clearance is also now applied to entire length of the 34.5kV distribution system.

Following the major storm events that Orange and Rockland endured, another vegetation management program enhancement in terms of pruning techniques called Branch Reduction has been developed. Over the successive maintenance cycles since 1991, Orange and Rockland has done a very good job of first establishing and then maintaining the aerial space through and near adjacent tree canopies. Limbs, especially over top of the conductor that are outside of the normal maintenance zone, have continued lateral growth over the conductors. Orange and Rockland participated in a study following the 2011 storms evaluating these long, extended limbs and their potential to break under snow, ice, or wind loading. Among the conclusions of this study is to look at these long limbs as levers, and by shortening these extended limbs (reducing the lever), targeted pruning can stiffen and make the remaining limb less prone to breakage thereby lessening potential damage in a loading situation like a storm event. Accordingly, Orange and Rockland is undertaking worker training to assist its vegetation contract workers in identifying these potential limbs and reduce their length through appropriate branch reduction pruning.

Another program Orange and Rockland has instituted following the 2011 and 2012 storm events is the Hazards Tree Program. Evaluating tree failures following the storm events led to the assumption that a significant portion of the tree-related damage was not caused by vegetation immediately alongside the conductors, but by trees rooted well back from the conductors and outside the normal maintenance zone. When these larger, well out of the maintenance zone trees fail, the resulting outages likely included greater infrastructure damage including broken poles. To address this issue, Orange and Rockland instituted a modified Hazard Tree Program. This program entails looking at and evaluating identified Hazard Trees rooted well back from the conductors. A Hazard Tree is a tree that has the ability to contact an energized conductor combined with a defect of some type, such as being a dead or declining tree, rot, upheaving or unstable soils, root decay, cavities, or other condition contributing to potential tree failure. These trees are identified and the municipality or property owner is attempted to be contacted by a door hanger requesting contact to discuss the identified hazard tree. The objective is to continually cull out identified Hazard Trees during the scheduled maintenance cycles and remove these trees to harden the overhead electrical system and make it more resilient in storm conditions.

One other initiative Orange and Rockland is undertaking is a comprehensive evaluation of the health of the urban forest. Orange and Rockland is currently involved with this study to evaluate several parameters of the urban forest in which their service area exits, including stocking densities of tree species, sizes and heights, overall health condition, and potential to contact the electrical system. The objective of this evaluation is to get a better knowledge basis of the local urban forest and use this information to assure the Orange and Rockland vegetation program has the ability to address emerging issues be they cultural or environmental. The results of this study will be delivered to Orange and Rockland early in 2014.

Pacific Gas and Electric

As part of their tree trimming program, PG&E inspects five million trees over 113,500 miles of distribution lines and takes action on over one million trees per year in addition to clearing vegetation around 120,000 utility poles. Hazard trees are identified during annual inspections,

they are pruned or removed to prevent contact with power lines[3]. With a tree related customer outage SAIFI at 0.087, their efforts are noteworthy.

The activities of the VM Program that were once viewed as incidental, and therefore not having significant impact on the environment, are increasingly being viewed as having a significant impact. PG&E now works closely with the US Forest Service and Fish and Wildlife Service in areas where endangered species are known to live, and to limit work at certain times of year to minimize the disturbance on wildlife. An environmental specialist was added to assist VM contractors and PG&E personnel in evaluating and addressing environmental sites. They also use techniques recommended by International Society of Arboriculture in order to prune responsibly. Contractor personnel must attend training to be able to identify when they are working in environmentally sensitive areas, and be familiar with the expectations for protective practices associated with sensitive habitats and species. However, overall cost for the VM program are increasing as new environmental permits are becoming required.

Wildfires have been recognized as a risk to the system; vegetation management can mitigate the risk. This has entailed hiring a consultant that specializes in fire risk modeling who has created a modeling tool to predict the most at risk areas in the PG&E service territory for wildfires. This allows the VM program to focus efforts on maintaining facilities within these high priority areas.

PG&E maintains an annual trim and patrol program which can be described as "just in time" trimming. Its operations group is in charge of field management and is organized into eight areas, each with two designated foresters. The state of California has a number of different fire areas, each with different minimum trim standards and regulations. PG&E's trimming activities are in compliance with all the regulations in all the areas and no area is allowed to drop below the standard. PG&E's trimming process includes an annual pre-inspection of all overhead power lines utilizing handheld devices for trim data collection and performing trims within four to six weeks from the pre-inspection. They input information on trees that need to be pruned or removed in the current year. This information includes tree species, tree size, trim type, clearance required, permission from the property owner for a removal, and location of the tree.

Moreover, PG&E has a quality control sampling process as well as a quality assurance audit process to provide details on the work review. In addition, PG&E investigates every vegetation related outage on its system.

Lastly, public education is an integral part of PG&E's VM Program and includes: communication materials, outreach efforts, and tree planting events. Randomly selected customers who recently had tree work done on their property are sent the "VM Customer Satisfaction Survey." More than 75 percent of responding customers rated the work as either excellent, very good, or good.

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3 "Pacific Gas and Electric Company: 2014 General Rate Case Prepared Testimony Exhibit (PG&E-4) Electric Distribution" Prepared by PG&E; https://www.pge.com/regulation/GRC2014-Ph-I/Testimony/PGE/2012/GRC2014-Ph-I_Test_PGE_20121115_254321.pdf

National Grid

Like Unitil and Northeast Utilities, National Grid has a formalized IVM plan which mirrors the requirements outlined in the ANSI standard and ISA best management practices[4]. From steep mountainous topography to rolling hills and level lowlands, and from remote, relatively inaccessible locations right through high density population centers, National Grid manages a diverse terrain in its 20,000 acres and 1,500 miles of rights of way within the Commonwealth of Massachusetts. Their integrated vegetation management (IVM) approach relies on reducing the amount of herbicides used, using selective herbicides/application techniques, timing applications for maximum effect, avoiding fixed application schedules, using mechanical control techniques where appropriate, encouraging low growing plant communities, and encouraging wildlife destruction and other ecosystem processes to reduce the overall dependence on chemical and mechanical controls. This multi-faceted approach minimizes the disadvantages and maximizes the benefits of each IVM component, thereby reducing the environmental impact and the financial cost of vegetation management while simultaneously increasing the overall effectiveness of the program.

Essential Energy, Australia

Essential Energy is a government-owned corporation, with responsibility for building, operating and maintaining Australia's largest electricity network - delivering essential network services to more than 800,000 homes and businesses across 95 per cent of parts of southern Queensland and northern Victoria. One of the major focuses of their vegetation management is brush fires and in high risk areas of their territory they require much larger right of ways in order to ensure the lines themselves do not spark any fires. Another unique feature of their process is to involve the landowners in risk reduction. **The landowners are responsible for reporting any clearance issues to Essential Energy who will then ensure trimming to the proper distances.** The landowner can also be responsible for the cost of trimming if they planted the plants after the utility lines were installed and did not follow proper guidelines on location and species of plants to use.

NSTAR

The use of mechanical and chemical controls in vegetation management of right of way corridors along transmission and sub-transmission lines can be an environmentally damaging and costly process. NSTAR recognizes the importance of the Massachusetts Endangered Species Act, ROW wetlands impact studies, and the Rights of Way Management Regulations set forth in 333 CMR 11.00. In so-called "Sensitive Areas," NSTAR tailors its use of mechanical controls and herbicides to have minimal impact on the health of the environment and safety of the local area residents. NSTAR only uses Sensitive Area approved herbicides for its integrated vegetation management (IVM) program. To help ensure the protection of endangered wildlife, NSTAR uses GIS data to identify Priority Habitats and Sensitive Areas and trains its crews and contractors in the use of GPS equipment and GIS systems so that they are able to recognize these areas in the field. NSTAR also uses the GIS data to identify public water supplies and private wells.

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4 "Five Year Vegetation Management Plan 2014-2018." Prepared by National Grid; http://www.nationalgridus.com/non_html/National%20Grid%20VMP%202014%20-%202018.pdf

Sacramento Municipal Utility District

Known as the "City of Trees," Sacramento Municipal Utility District (SMUD) services nearly a quarter million trees across a services territory of 900 square miles. Rigorous adherence to guidelines and tree pruning practices set forth by the American National Standards Institute (ANSI), International Society of Arboriculture (ISA), and the National Arbor Day Foundation has earned SMUD the Tree Line USA award for its vegetation management practices by the National Arbor Day Foundation each year since 2001. While their standard inspection schedule requires each tree be inspected once every three years, for fast growing trees, inspectors make it a point to return every year and a half. To ensure a knowledgeable workforce, all SMUD employees are required to complete a certified course of study to become a member of the ISA. In addition, all SMUD arborists are members of both the ISA and the Utility Arborist Association.

Baltimore Gas and Electric Company

Baltimore Gas and Electric Company (BGE) developed a "Less Than 200kV Vegetation Management Program", which was effective in May, 2012. This plan includes a variety of practices to manage vegetation adjacent to its electric facilities, including: inspections, tree pruning, tree removal, mowing, and herbicide or other cultural control practices." [5] Inspections for BGE target the vegetation on and in proximity to the utility easement or free-owned land, tree pruning and removal, mowing, herbicide application and interim tree work. Tree pruning and removal is performed based upon various operational and environmental characteristics of the ROW. BGE operates a practice to leave as much of the remaining tree crown as possible to help maintain the health of the tree. If a large amount is recommended to be removed, the entire tree may be removed instead. Machine mowing is a maintenance practice used to maintain woody vegetation and other unwanted vegetation along the electric facility's rights-of-way and is usually performed on an annual basis. As an alternative, BGE may hand-cut and/or apply herbicides to control growth of all brush, grasses, vines and other unwanted vegetation. Cultural control practices involve management of vegetation through the establishment of compatible stable plant communities or the use of crops, pastures, mulching, or other managed landscapes. Finally, debris removal of all wood pieces less than eight inches in diameter and brush are typically chipped, lopped, or disposed of, unless requested or approved by the property owner or occupant. [6]

BGEs plan does not address the program or method it uses to maintain its record keeping or technology specifically utilized to accomplish and meet the objectives of the vegetation management plan.

However, the plan emphasizes the importance of communication and notification with implementing its program. BGE stresses the reason for this is a result of the vegetation management program having "a direct impact on property owners." [7] Therefore, BGE recommends timely and sufficient communication with property owners is a necessary commitment to maintain a positive relationship. To accomplish this, BGE has established processes and procedures to communicate vegetation related activities to the necessary parties

5 BGE, "Less Than 200kV Vegetation Management Program", May 28, 2012.
6 BGE, "Priority Trimming to Improve Reliability", http://www.ecosync.com/tdworld/PRIOTRIM03.pdf.
7 BGE, "Priority Trimming to Improve Reliability", http://www.ecosync.com/tdworld/PRIOTRIM03.pdf.

and also created outreach programs to educate its customers.[8] BGE addresses communication and notification objectives by focusing on providing notification to property owners and to the local county and local municipality, as well as providing outreach programs, such as an annual public education program and its company website.[9]

Cumberland Electric Membership Cooperative

Cumberland Electric Membership Cooperative utilizes laptops in the field. Cumberland's lineman and crew no longer rely on map books that are usually stored in their trucks. The company now provides their lineman with a vehicle mounted convertible-tablet, the Panasonic Toughbook 19, which is a 'ruggedized computer' that is able to withstand a 6-foot drop, includes a spill proof keyboard and can handle 220 pounds of pressure.[10]

The company also installed new mapping software from *PartnerSoft* to improve its vegetation management program. Previously, the company relied upon the linemen's experience to know the utility system, however, the company now relies upon the GIS mapping system that the company converted to after performing a system wide inventory of service territory. [11] The tablets installed in the vehicles allow the linemen to use the map viewer to: trace out a circuit and easily identify the number of customers affected by an outage; look at the lines, parcels and electric model of the utility's system and also study the distribution from the meter to the substation; access the time sheet program; connect to Wi-Fi within their truck bays.[12]

Great River Energy

A critical component of Great River Energy's (GRE) mission is managing the vegetation along its rights-of way. GRE uses regular aerial patrols to manage its vegetation and other rights-of-way issues. By implementing its aerial patrol program, GRE has reduced the risk of vegetation contacts on bulk electric transmission facilities and also on the lower-voltage sub-transmission load-serving system that directly serves its customers.[13] For instance, aerial patrols of transmission and lines rated 115 kV and above are performed on a monthly basis and on transmission and sub-transmission lines that are rated 69 kV and below are patrolled on a bi-monthly basis.[14] Essentially, the aerial patrols identify vegetation concerns and locate/identify any transmission / sub-transmission hardware issues and various ROW infringements.[15] As a result of using aerial patrols, the company has prevented outages from occurring which allowed GRE to manage its assets pro-actively and in a timely manner.[16]

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8 BGE, "Priority Trimming to Improve Reliability", http://www.ecosync.com/tdworld/PRIOTRIM03.pdf.
9 BGE, "Priority Trimming to Improve Reliability", http://www.ecosync.com/tdworld/PRIOTRIM03.pdf.
10 DataSource Mobility, "NIPSCO Streamlines Vegetation Management". http://datasourcemobility.com/photos/psc-tb-tdworldcoverage-3-1-11.pdf.
11 DataSource Mobility, "NIPSCO Streamlines Vegetation Management". http://datasourcemobility.com/photos/psc-tb-tdworldcoverage-3-1-11.pdf.
12 DataSource Mobility, "NIPSCO Streamlines Vegetation Management". http://datasourcemobility.com/photos/psc-tb-tdworldcoverage-3-1-11.pdf.
13 Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine*, June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.
14 Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine*, June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.
15 Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine*, June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.
16 Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine*, June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.

GRE also uses digital photographs, taken by the pilots during the aerial patrols, to assist in vegetation management. During the patrol, the pilots bring a digital camera along and take photographs that will provide field operation staff a bird's eye view of any equipment damage, ROW infringement and/or vegetation issues that pilot deems serious in nature.[17] Then the information from the patrols is entered into the company's central database on a weekly basis. GRE follows a process that promotes ownership. Structural issues are sent to area line personnel and ROW infringement issues are sent to the company's Land Rights department.

Additionally, each fall GRE has one-third of its corridor photographed.[18] The color photographs provide a more complete picture of the ROW corridors, including overall vegetation growth rates.[19] GRE uses the information from color surveys, as well as historical outage information, to prioritize and schedule corridors for ROW maintenance in the upcoming year.[20] The purpose of the survey is to assist in locating danger trees within the ROW corridor that may be hazardous during a storm. The survey also assists in defining access points for system restoration switching.

Overall, GRE finds that implementing this survey has produced positive results.[21] Using a survey as a practice to manage the vegetation, GRE indicates that this method saves time in vegetation and transmission line corridor surveying, provides early detection of potential ROW issues, and also allows the company to allocate available resources effectively.

Sumter Electric Cooperative

Sumter Electric Cooperative (SECO) uses a variety of vegetation management practices to continually improve its vegetation management program and customer satisfaction. For instance, the company utilizes line clearance contractors on unit-based pricing, paying the contractors only for work performed.[22] SECO pays the contractors based on set prices for the type of work performed such as side trims, overhang trims and 4-inch to 10-inch removals. Any work performed on emergency projects and/or reactive pruning is performed by separate crews paid on an hourly basis.[23]

To manage the pruning cycles, SECO provides notification to its customers. In terms of pruning and determining the correct pruning method, SECO uses a laser focus on selecting trees for removal with the scope of the vegetation management program's objectives.[24] A tree replacement program is also included in the program. By actively pursuing the practice of tree removal, SECO is making progress in long-term cost reduction and enhanced reliability.

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17 Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine*, June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.
18 Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine*, June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.
19 Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine*, June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.
20 Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine*, June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.
21 Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine*, June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.
22 Ken Lacasse, Sumter Electric Cooperative Inc., "SECO Clears the Way", *T&D World Magazine, September 1, 2012*, http://tdworld.com/vegetation-management/seco-clears-way.
23 Ken Lacasse, Sumter Electric Cooperative Inc., "SECO Clears the Way", *T&D World Magazine, September 1, 2012*, http://tdworld.com/vegetation-management/seco-clears-way.
24 Ken Lacasse, Sumter Electric Cooperative Inc., "SECO Clears the Way", *T&D World Magazine, September 1, 2012*, http://tdworld.com/vegetation-management/seco-clears-way.

Also, each planner and manager representing SECO in the field is a certified arborist. The company has aggressively been involved with tree removals that are voluntary. By using certified arborists in the field, the arborist is able to speak with customers about their concerns and also inform them about proper pruning methods, articulate the importance of tree removal and the trees' potential impact on electric reliability.[25] Using the certified arborists in the field, SECOs position is that this has improved customer satisfaction. Customers are able to speak one-one-one with the professionals, which SECO believes has influenced customers becoming more involved in the overall process and permitting trees to be removed.[26]

As part of the vegetation program, fully integrated herbicide program was implemented that is monitored by undergoing a post-application auditing process. This program also includes clearing 100% of brush and low-growing vegetation, as well as removing trees and other vegetation near switching and fusing points that might delay access during any storm restoration process.[27]

For the removal of hazard trees, SECO identifies trim-related and non-trim outages, outages caused by trees within the easement zone compared to outages caused by trees outside of the easement zone. Hazard trees are identified during routine work planning and then scheduled to be removed within 30 calendar days after being issued.[28]

SECO also addresses emergency weather situations. As soon as the first warning of major weather event is received, the company gathers the equipment and notifies the on-site crews. In preparation for the weather, SECO handles the logistics including food and staging locations for the crews. The storm crews set up in pre-established command centers and SECO possess the ability to use algorithms to help predict the extent of damage across the system after the storm has passed.[29]

Nashville Electric Service

During the fall of 2000, Nashville Electric Service (NES) had tree-related outages 10 times that of other utility companies that implemented vegetation management best practices. NES' system statistics showed that tree-related outages were 19% to 21% of the total outages.

At the time NES noticed the problem with its vegetation management program, its system had rear-lot lines that were grown up, tree line contact on both the distribution and transmission systems that was higher than best-practice utility standards, the brush component of the workload was higher than best-practices, and the crew productivity was below standard.

The statistics and vegetation problems motivated NES to move forward in developing a vegetation management program in order to improve its customer service reliability and also provide practices that would allow NES to maintain that reliability. NES began this process by

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25 Ken Lacasse, Sumter Electric Cooperative Inc., "SECO Clears the Way", *T&D World Magazine, September 1, 2012,* http://tdworld.com/vegetation-management/seco-clears-way.
26 Ken Lacasse, Sumter Electric Cooperative Inc., "SECO Clears the Way", *T&D World Magazine, September 1, 2012,* http://tdworld.com/vegetation-management/seco-clears-way.
27 Ken Lacasse, Sumter Electric Cooperative Inc., "SECO Clears the Way", *T&D World Magazine, September 1, 2012,* http://tdworld.com/vegetation-management/seco-clears-way.
28 Ken Lacasse, Sumter Electric Cooperative Inc., "SECO Clears the Way", *T&D World Magazine, September 1, 2012,* http://tdworld.com/vegetation-management/seco-clears-way.
29 Ken Lacasse, Sumter Electric Cooperative Inc., "SECO Clears the Way", *T&D World Magazine, September 1, 2012,* http://tdworld.com/vegetation-management/seco-clears-way.

evaluating the current conditions of its system, identified and determined the desired results of the program and then developed a timetable to accomplish this. In developing benchmarks and performance audit criteria, the company used GIS technologies, including a geo-database viewing application, aerial photos and ESRI's Arc 3GIS during the planning stages and used laptops in the field to further the program plan as the work moved forward.

The article published in *T&D World Magazine* highlighted some of the practices NES specifically focused on while developing this program. One of the practices NES focused on was communicating the plan with government officials and customers to educate them on why a more aggressive program involving tree-trimming was needed. The company also focused on its tree-trimming contracts. After determining that the productivity that was needed was not being accomplished using T&M contracts, NES preferred to use contracts with lump-sum trim with unit removal terms and drastically cut the number of T&M crews. In addition, NES implemented the program on a three-year trim cycle by concentrating on brush less than 4 inches in diameter, removing trees with a 5-inch diameter or greater, 20 feet (6cm) from the inside phase and average sized trees that averaged 85%, 12 inch (305mm) and smaller.[30]

Ten years later, NES had not only examined the factors contributed to such tree-related outages and developed a new vegetation management program, but had successfully implemented a vegetation management program for its electrical system. NES' tree-related outages dropped to 6%, with 3.5% of those outages caused by branch and tree failures.[31] After revamping its vegetation management program over the last three trim cycles, NES' current budget has been reduced 48%, retuning to that of the budget level when the project began. In the end, NES successfully accomplished its objective of implementing a vegetation management program that is reliable and changed its system to performing at a best-practice utility level.[32]

San Diego Gas and Electric

SDG&E's Vegetation Management (VM) program is responsible for the inspection and maintenance of approximately 400,000 trees that have the potential of growing or falling within the specified clearance area. This program defines two types of work; 1) routine work and 2) field memos and hazard tree work. To ensure the completion of these works according to the defined scope of work, SDG&E has a quality program that verifies the completion and certification of each work[33].

With regard to the inspection and management of hazard trees, SDG&E is developing additional training programs that are aimed at enhancing the skills of staff and contractors in identifying and managing hazard trees. In 2003, SDG&E implemented a three-phase approach to pole brushing that effectively manages poles prone to summer rains or leaf casting from surrounding

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30 Glenn Springer, Nashville Electric Service, "Trimming Your Way to a More Reliable Future, *T&D World Magazine*, May 1, 2012, http://tdworld.com/smart-energy-consumer/trimming-your-way-more-reliable-future.
31 Glenn Springer, Nashville Electric Service, "Trimming Your Way to a More Reliable Future, *T&D World Magazine*, May 1, 2012, http://tdworld.com/smart-energy-consumer/trimming-your-way-more-reliable-future.
32 Glenn Springer, Nashville Electric Service, "Trimming Your Way to a More Reliable Future, *T&D World Magazine*, May 1, 2012, http://tdworld.com/smart-energy-consumer/trimming-your-way-more-reliable-future.
33 "Prepared Direct Testimony of Scott P. Furgerson of Behalf of San Diego Gas & Electric Company: Exhibit No. SDG&E-05." Prepared by Scott P. Furgerson; https://www.sdge.com/sites/default/files/regulatory/Exhibit%20SDG&E-05R%20S_Furgerson_SDGE-R_Elec_Dist_O&M_Testimony.pdf

trees. This approach includes; chemical pole brushing using EPA approved herbicides, mechanical pole brushing and re-clear pole brushing which involves the removal of additional vegetation that has grown into the clearance area since the last maintenance. In addition, SDG&E is working towards implementing a second re-clear pole brushing cycle rather than a single cycle to maintain compliance with PRC 4292 and reduce fire risk.

Due to the increase in customer requests to remove all wood generated from pruning, SDG&E has been actively looking for alternative wood disposal methods due to high costs and resource requirements associated with the increased need to trim hazard trees. These alternative methods include composting, co-generation, and erosion control.

PEPCO

Pepco's Reliability Plan[34] outlines a six-point strategy including enhanced vegetation management in their Enhanced Integrated Vegetation Management (EIVM) Program, the largest of their preventative maintenance programs. In addition to a routine cyclical program of proactive trimming, this VM plan includes the following elements:

- Monitoring customer acceptance and cost effectiveness.
- More aggressive hazard tree and dead tree removal, ground-to-sky trimming and herbicide application, spending $3-5,000 per mile more than in past years.
- Inspecting all overhead feeder sections at least once every two years targeting areas of the electric system found to be most susceptible to damage from trees during storms. Based on this a prioritizing circuits to create a pre-scheduled plan, created on the basis of a prioritization based on the number of outages and reliability statistics of the circuit.
- Form public and private partnerships including a Pepco education campaign and coordination with local governments to ensure support.

Puget Sound Highlight

Serving over 1.2 million customers, Puget Sound Energy's rights of way and vegetation management activities are often in environmentally sensitive areas. To avoid impacting the wildlife and the surrounding ecological system, PSE implemented a Quality Vegetation Management (QVM) program that minimizes mowing through the use of selective herbicides that have minimal impact on the ecosystem. PSE personnel apply the herbicides via backpacks and eliminate the massive machinery that can affect the surrounding vegetation. Through the reduction of mowing, PSE has seen its vegetation management cost drop approximately $700 per mile.

Consolidated Edison of New York

In responses to a management audit conducted of Con Ed[35], the filing provides an update to the implementation of recommendations from the management audit. In particular, on page 146 of

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34 "Potomac Electric Power Company Comprehensive Reliability Plan for District of Columbia Including Distribution System Overview, Reliability Initiatives and Response to Public Service Commission of the District of Columbia Order No. 15568." Prepared by PEPCO; http://www.pepco.com/_res/documents/dccomprehensivereliabilityplan.pdf

35 "Audit Implementation Plan: Annual Report and Update." Prepared by Consolidated Edison Company of New York, Inc. Case 08-M-0152; http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7BF57D835F-2A9E-4C30-AFFD-F89DCD02D7FF%7D

the document, ***Recommendation #33: Strengthen the distribution vegetation management inspection program with accountability***, Con Ed describes their implemented Quality Assurance ("QA") program for all Electric Operations regions that was designed to ". . . . improve accountability in the line clearance function and ensure compliance with the current line clearance specification." This new QA program was outside the typical utility vegetation management programs. This additional process that is outside the normal vegetation management process provides a "second set of eyes" in the vegetation management area and has improved the reliability for Con Ed.

Xcel Energy

Vegetation Outage Assessment, Data Collection, and Reporting Programs - Documenting Vegetation Outages

The availability of accurate and detailed data with regard to tree-related outages, is highly dependent on the utility's outage reporting practices. While some utilities collect no data for the causes of outages, others enforce strict data collection and reporting practices in an attempt to improve vegetation management programs. An example of a utility that does that is Xcel Energy, which uses a detailed data collection process that includes high level data collection, individual outage inspection by vegetation experts, and subsequent data analysis that focuses on vegetation management activity.

Technology Utilization

Many utility companies are investing in technology to improve their vegetation management programs. For instance, utilities use technology to further objectives of managing vegetation by investing in tailor-made software programs/packages. The features included in the software appear to depend upon a utility's specific goals and methods of its vegetation management program. Utility companies have also started focusing on making field crews more comfortable with technology as well. Specific examples of utilities use of new forms of technology are described below.

Northern Indiana Public Service Company

Northern Indiana Public Service Company (NIPSCO) contracted with ArborMetrics Solutions to incorporate new vegetation management software into its vegetation management program. ArborMetrics software allowed NIPSCO to use its existing GIS data to digitally capture and overlay vegetation management data.[36] For example, the new software provides easy access to landowner's information, the ability to gather data on work specification and keep updated on the scope of projects, as well as capture customers' signatures digitally with the same ease as signing for a package delivery. The company also had printers mounted in the vehicles, so a document can be printed out in the field.

During the time NIPSCO incorporated its new software, the company also arranged for convertible laptops, the Panasonic ToughBook CF-19, to be installed in each of the arborist's vehicles. The laptops are used in the field to perform inspections, collect data and obtain

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36 DataSource Mobility, "NIPSCO Streamlines Vegetation Management". http://datasourcemobility.com/photos/psc-tb-tdworldcoverage-3-1-11.pdf.

permissions. After utilizing these laptops in the field, the company recognized that the new system eliminated some hassles relating to handwritten records that were difficult to read and the alleviated the problem of using a variety of terms to describe field work and tasks, which varied amongst the different field crews. Since each crew used their own terms to categorize and describe the work and tasks performed, the new laptops and software provided drop-down menus with specific descriptions which ensures that all of the crews and their records use the same language.[37]

Northpower, New Zealand Ground Fault Neutralizer and Tree Contact

Northpower, a New Zealand line company sponsored a project which follows the British grounding model of solid-grounding. In March 2010 Northpower commissioned a Ground Fault Neutralizer (GFN) in one of its substations as a pilot, in order to evaluate the deployment and benefits of this technology. The substation was chosen due to its presence of relatively long feeder and its location in rural areas where there is dense vegetation, causing faults frequently compared to other zone substations.

In Northpower, single phase to ground faults are the dominant type of fault on its electrical network, especially because of the tree density and resulting contacts. Therefore it is of utmost importance that these faults are handled in a satisfactory way. By injecting an anti-phase current into the neutral, the GFN effectively cancels out the fault current. This interception is exceptionally fast and has no impact on the conveyance of payload over the faulty feeder. Thus, ground faults can be handled without customer outage and thus the safety of the system is also improved.

As injury statistics clearly indicate, speed is the most essential aspect of protection. With a total response time of less than 60ms (three cycles) the GFN is substantially faster than traditional protection schemes, independent of the actual fault location. Instead of tripping the faulty feeder the GFN brings the fault current down to practically zero making it possible to maintain safe operation without disturbing power supply to customers. This unique feature can be guaranteed both during transient and sustained earth faults. Installed in the substation and connected to the transformer neutral, the GFN protects the entire network from one point.

Connecticut Light and Power

As a result of the extensive damage and work necessary to manage Superstorm Sandy, Connecticut Light and Power (CL&P) is currently launching a damage assessment tool that will make the process of surveying damage to the electric system following a storm more efficient, and provide real-time information about the materials and resources needed to make repairs. The tool was developed by CL&P and Clearion Software, LLC, a Georgia-based developer specializing in GPS-enabled technologies for utility vegetation[38]. It combines CL&P's

Geographic Information System (GIS) mapping data with information about the distribution system and GPS street location data.

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37 DataSource Mobility, "NIPSCO Streamlines Vegetation Management". http://datasourcemobility.com/photos/psc-tb-tdworldcoverage-3-1-11.pdf.
38 T&D World Magazine, "CL&P Implementing New Technology to Improve Storm Response"

Traditionally, damage assessment (DA) personnel took notes regarding damage and provided that information back to the planners in the office who would aggregate the information in an effort to understand the scope of the damage and prepare work packages with the necessary material and resources identified. With the new system, DA personnel utilize laptops that automatically display detailed information about the electrical equipment on the street, based on GPS locations. Thus, now when the DA personnel encounter damage, they click on the screen and indicate the specific problem – such as a broken pole, downed wires or a damaged transformer – and the system sends the information back to the office instantly. If the patrol team is in an area with no cellular service, the system stores the information and automatically uploads it when service is available again.

This technology drastically reduces the amount of time it takes to transmit information about damage and required repairs from the field to the planning and logistics teams in the office. Those teams can better plan the work and deploy crews more efficiently with the exact materials needed, and better estimates can be provided regarding the length of time to complete repairs.

Unitil

Unitil implemented GeoDigital Solutions' for the planning, reporting and analyzing vegetation maintenance. Unitil chose the package that included one of the mobile applications for its assessors and crews.[39] In determining the best software, Unitil focused on specific criteria that the software must address including the ability to: track and report on work based on feeder metrics, historic data, forecasts, work plans, unscheduled work and crew productivity; plan and forecast cycle work; store data in a database in a geographic format; provide quality assurance/quality control for the work and provide performance indicators; create work packets; and record and track customer restrictions.[40]

LiDAR

According to an article in *Electric Light & Power*, LiDAR, light detection and ranging, is used by many utilities in order to remain in compliance with FAC-003-1.[41] The article further stated that, 'lidar uses laser beams usually from a helicopter to measure distances accurately from wires to potential obstructions-primarily trees' and 'then creates a map that displays the relative heights and positions of towers, power lines and trees'.[42]

In 2010, LiDARs technology was improved and provided new applications for utilities to use for asset and risk management in connection with power line maintenance and applicable regulations.[43] In light of the numerous miles of transmission and sub-transmission lines, *T& D World Magazine* reports that, "LiDAR-based technology offers a more-standardized approach to

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39 T&D World Magazine, "Unitil to Boost Reliability with Mobile Vegetation Management Software", July 1, 2012. http://m.tdworld.com/smart-grid/unitil-boost-reliability-mobile-vegetation-management-software
40 T&D World Magazine, "Unitil to Boost Reliability with Mobile Vegetation Management Software", July 1, 2012. http://m.tdworld.com/smart-grid/unitil-boost-reliability-mobile-vegetation-management-software
41 William Atkinson, "Vegetation Management Takes to the Airwaves", *Electric Power & Light Magazine*, http://www.elp.com/articles/powergrid_international/print/volume-17/issue-5/features/vegetation-management-takes-to-the-airwaves.html
42 William Atkinson, "Vegetation Management Takes to the Airwaves", *Electric Power & Light Magazine*, http://www.elp.com/articles/powergrid_international/print/volume-17/issue-5/features/vegetation-management-takes-to-the-airwaves.html.
43 Gene Wolf, "LIDAR: Illuminating Hazardous Vegetation", *T&D World Magazine, February 1, 2010,* http://tdworld.com/overhead-distribution/lidar-illuminating-hazardous-vegetation.

manage vegetation in the utility's rights-of-way and improve[s] the maintenance cycle to identify hazardous vegetation before it causes problems for the grid."[44]

LiDAR technology is also used to record a transmission line's geometry and its placement in the ROW. The 3-D models from LiDAR technology provides 3-D imaging that shows trees and brush with vegetation encroachments, such as blow-in or grow-in violations.[45]

While initially designed to deal with the rigors associated with transmission vegetation maintenance, various discussions have been had amongst utility personnel regarding the use in sub-transmission and distribution applications.

Micro-weather Forecasting – IBM and Consolidated Edison of New York

As part of an effort to understand how weather was discretely impacting its overhead system, Con Edison in 2006 began working with IBM to develop a micro-weather prediction system, Deep Thunder, which provided visibility down to 1 square kilometer. While ultimately designed to provide better weather predictions at a local level, an unanticipated benefit was the identification of corridors that routinely were predicted to have extreme wind conditions. This information helped identify potential damage locations during severe events and opportunities to provide additional vegetation management focus.

GIS Databases

Utility vegetation management programs often include procedures in which vegetation management crews notify residents in order to clear the lines of overgrowth as needed.[46] As a result, many utilities utilize GIS databases for various things, including plotting surveys, sending out notifications and scheduling field crews' work.[47] Utilities may use mobile GIS equipment to accomplish this as, "all-in-one mobile GIS devices provide a unique, cost-saving alternative to traditional vegetation survey mapping".[48]

According to *T&D World Magazine*, *"[u]*sing a simple point-and-shoot procedure [that is] already being used to measure utility pole attachments, a vegetation management crew can quickly locate, measure and document sites where trees and other vegetation need to be trimmed".[49] Using GIS technology, data is able to be transferred digitally to a GIS mapping system, together with other details such as, photo documentation, addresses, descriptions and classifications.[50] Ultimately, this will assist a utility with further processing and scheduling equipment.[51]

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44 Gene Wolf, "LIDAR: Illuminating Hazardous Vegetation", *T&D World Magazine, February 1, 2010,* http://tdworld.com/overhead-distribution/lidar-illuminating-hazardous-vegetation.
45 Gene Wolf, "LIDAR: Illuminating Hazardous Vegetation", *T&D World Magazine, February 1, 2010,* http://tdworld.com/overhead-distribution/lidar-illuminating-hazardous-vegetation.
46 *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011,* http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management.
47 *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011,* http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management.
48 *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011,* http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management.
49 *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011,* http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management.
50 *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011,* http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management.
51 *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011,* http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management.

Mobile GIS/GPS Systems

Utilities also use mobile GIS/GPS systems, such as companies like ikeGPS mobile GIS systems, which provides hardware and software technology, to assist with utility operations. For instance, ikeGPS mobile GIS systems, provides utilities with the means for a one-man crew to be able to record not only specific site locations, data and photo documentation, but also create measurements from photographs.[52] This company provides utilities with the option to have an onboard vegetation management application that allows the operator to record a high resolution photograph, de-skew to create a TrueSize image, and also to make direct measurements of wire clearance and tree dimensions.[53] Using this type of technology allows utilities to document any violations of vegetation ordinances in a quick and simple manner, while also saving considerable time and expense in data acquisition and post-processing.

Tree Growth Regulators (Herbicides)

City of Glendora, California

The issue of tree canopy pruning is raised as a risk to infrastructure as a result of improper pruning. Regardless of the care taken, trees that have a canopy that if improperly pruned can result in failure. Tree growth retardants reduce the need for constant pruning and consequently reduce the risks and costs associated with pruning. In one example, the author illustrates a 200% improvement in required pruning moving from a twice a year trim cycle requires to a once every 2 years trim cycle. Using tree growth regulators has improved the city of Glendora, CA to manage trees in historically difficult areas, such as parking lots, and road medians[54].

Additionally, by managing tree growth on golf courses the city has reduced the spread of fungus pathogens on the course that would results from excess shade or wind movement associated with the unmanaged trees.

A second order effect of tree growth regulators is the deeper colors of the foliage. The tree growth regulator inhibits the growth of the leaves, but does not inhibit the chloroplast, or green pigment, in the leaf cells. Basically, while the leaves may be smaller, they still provide canopy coverage and the environmental benefits of trees.

Land Grant University - Purdue University research paper [55]

Dr. William Chaney provides insight into the tree growth regulators and the benefits of them. As a possible solution to reduce the costly and laborious method for mechanical trimming, utility arborists as far back as 1950 were looking for chemical methods to control tree growth. Solutions in the 1970's and 1908's had unintended and unacceptable consequences, so tree

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52 *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011,* http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management.
53 *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011,* http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management.
53 *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011,* http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management
54 Landscape Contractor National, "Cut Costs With Tree Growth Regulators" Mike Ventura, Landscape Maintenance Supervisor, City of Glendora, June 2009
55 *Purdue Extensions*, Purdue University "Growth Retardants: A Promising Tool for Managing Urban Trees", September 2005, https://www.extension.purdue.edu/extmedia/FNR/FNR-252-W.pdf

growth retardants use and preference declined. However, research continued and today paclobutrazol, formulated as Cambistat 2SC or Profile 2SC, is the preferred tree growth inhibitor. Paclobutrazol blocks gibberellin hormone production which is responsible for stimulating cell elongation. The result is the same number of leaves and connectors in a shorter length. This produces benefits that may have not been intended, but do add value to its application. The benefits include increased chlorophyll component phytol which is beneficial to tree growth and health. The average growth reduction using paclobutrazol is between 40 to 60%. Additionally, the leaves are greener and the leaves have a reduced water loss which enables them to do better in drought conditions. Finally, paclobutrazol also provides improved protection of trees from fungal attacks.

British Columbia Hydro

The British Columbia Hydro (BC Hydro) vegetation management program strives to use leading edge techniques and practices, minimize impact to the environment, and protect biodiversity[56].

To these ends, BC Hydro uses a very selective and focused application of low-toxicity herbicides away from recognized pesticide-free zones. BC Hydro also controls noxious or invasive plant species as part of the corporate commitment to the Provincial Invasive Plant Strategy, and to meet the requirements of regional weed control committees and the Weed Control Act (though BC Hydro is not subject to the Weed Control Act). BC Hydro supports research into new control methods, such as the use of insects for biological control.

In one of their more proactive technological practices, BC Hydro established a biophysical inventory project to collect, record, analyze, and monitor the current state of the ROW vegetation. All data collected is entered into a GIS database that allows aerial or ground patrols to monitor vegetation inventory and evaluate the efficacy of treatments. After vegetation management work has been completed at a site, BC Hydro collects qualitative and quantitative data to evaluate the effectiveness of the vegetation management program and measure the results against the site objectives.

Noteworthy Efforts

Connecticut proceeding 11-09-09

In Connecticut docket 11-09-09, Mike Townsley and John Goodfellow testifying on behalf of the Office of Consumer Counsel highlight in their April 17th 2012 testimony that telecommunication operators, especially those with custodial pole ownership rights should contribute to the cost of reducing the risk of tree failure. They highlight, that to not do so establishes a subsidy to the telecommunications company by the electric ratepayer. Vegetation management activities undertaken by electric utilities today reduce the risk of tree failures, which in turn reduces the potential for damage to supporting structures, such as poles and telecommunications equipment itself. They assert and seek telecommunications customers to contribute to these costs.

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56 “Integrated Vegetation Management Plan: For Transmission Rights-of-Way.” Prepared by BC Hydro; https://www.bchydro.com/content/dam/hydro/medialib/internet/documents/safety/bctc_pdf/integrated_vegetation.pdf

Florida Municipal Electric Association Workshop Highlights

In April, 2006, the Florida Public Service Commission directed each investor-owned electric utility in Florida to establish a plan to increase research in electricity infrastructure hardening. In response to this mandate, the Florida Municipal Electric Association conducted a workshop to review and benchmark best practices in Florida utility line clearance and vegetation management and to identify the highest priority areas for improvement[57]. Over 30 agencies participated.

To coordinate this effort, the attendees were divided into seven groups, focusing on overall trimming strategies, trimming around distribution facilities, proactive strategies for hazardous trees and damage reduction, strategies for working with the public and government, strategies for working with the public, operations and management, and relations and operations management. While the results of the workshop were not a collection of best practices currently being performed by individual utilities, key areas that the workshop attendees considered to be the most vital for future improvement were: coordination between utilities and government, communication with the public, adequate and consistent financial resources for vegetation management programs, better training and retention of crews, and a need for better storm preparation and restoration logistics.

Action Plans to deal with insect infestations creating high mortality rates

Several utilities throughout the nation are dealing with high mortality rates of certain species of trees due to disease and infestation of certain insects. Accordingly, utilities including Arizona Public Service and National Grid have developed processes working with other government agencies to address the debris created as a result of the vegetation management. The concern is the uncontrolled spread of the disease which is devastating hundreds of miles of utility right-of-way locations.

57 "Report on the Workshop for Best Practices in Vegetation Management." Prepared by Florida's Electric Utilities, Florida Municipal Electric Association, and Public Utility Research Center – University of Florida; http://www.floridapsc.com/utilities/electricgas/EIProject/docs/VegetationManagementWorkshopReport.pdf

5 HIGHLIGHTS FROM PARTICIPATING UTILITY SPONSOR INTERVIEWS

To be completed and integrated once completed.

Appendix C

6 REFERENCES

The references provided include cited and uncited material from the body of the report. They are provided as a compendium of sources from the vegetation management research. Readers can easily access copies of the references through hyperlinked text, if desired.

[1] "Resilience in the Context of the Management of Vegetation Near Overhead Electric Lines." Prepared by the Arboricultural Association Utility Arboriculture Group

This paper was written by the Arboricultural Association and discusses a risk-averse and a risk-based approach to vegetation management. While the Association understands the need for tree trimming this document tries to also encourage companies to take a look at the processes and practice of tree trimming.

To acquire this resource, visit http://www.trees.org.uk/aa/documents/uag-resilience-definition-210311.pdf

[2] "Five Year Vegetation Management Plan." Prepared by Unitil Corporation.

This document is Unitil Corporation's Vegetation Management Plan for the years 2014-2018. It details their plan to be compliant with Massachusetts's regulations on everything from identifying target vegetation to methods and cycles to ensure proper compliance.

To acquire this resource, visit http://www.unitil.com/sites/default/files/pdfs/UnitilVMPMay-1-2013.pdf

[3] "Audit Implementation Plan: Annual Report and Update." Prepared by Consolidated Edison Company of New York, Inc. Case 08-M-0152

This is the annual audit report that Consolidated Edison writes to determine where they stand on the improvement implementation. The report includes the basic plans for implementation and the actions that have already taken place.

To acquire this resource, visit http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7BF57D835F-2A9E-4C30-AFFD-F89DCD02D7FF%7D

[4] "Electric System Long Range Plan: 2010-2030." Prepared by Consolidated Edison Company of New York, Inc.

This plan covers what Consolidated Edison believes will be the issues in the next 20 years and their plan on dealing with each. It includes a look at the effect of items such as electric cars, metering advancements, new transmission facilities, and increased demand on the system.

To acquire this resource, visit http://www.coned.com/publicissues/PDF/Electric%20System%20Long%20Range%20Plan%20December%202010%20Final.pdf

[5] "Integrated Vegetation Management Plan: For Transmission Rights-of-Way." Prepared by BC Hydro.

This document is an Integrated Vegetation Management Plan (IVMP) for the management of vegetation on transmission line rights-of-way (ROWs) operated by British Columbia Hydro (BCH). The IVMP describes the program for controlling vegetation along transmission rights-of-way (ROWs), using the principles of integrated vegetation management, the process for planning, selecting, using, and evaluating control methods within that program, the methods for handling, preparing, mixing, applying, and otherwise using herbicides within that program

To acquire this resource, visit https://www.bchydro.com/content/dam/hydro/medialib/internet/documents/safety/bctc_pdf/integrated_vegetation.pdf

[6] "Report on the Workshop for Best Practices in Vegetation Management." Prepared by Florida's Electric Utilities, Florida Municipal Electric Association, and Public Utility Research Center – University of Florida.

This report on the workshop for Best Practices in Vegetation Management is a summarizing record of the events and results of the workshop. It includes a record of the agenda, the participants, notes on the discussions, results of the breakaway group sessions and the reconvened group discussion. It also documents the groups identified best practices and areas of improvement.

To acquire this resource, visit http://www.floridapsc.com/utilities/electricgas/EIProject/docs/VegetationManagementWorkshopReport.pdf

[7] "NSTAR Electric Integrated Vegetation Management Right-of-Way Program Overview." Prepared by NSTAR Electric.

This presentation discusses the transmission vegetation program at NSTAR. It discusses the basics of the program and the components of chemical control, mechanical control and natural control. It also touches upon the different state and federal laws that are in place to ensure compliance to a higher reliability standard.

To acquire this resource, visit http://www.wellfleetma.org/public_documents/WellfleetMA_Pesticide/NSTAR.pdf

[8] "NSTAR Electric and Gas Five Year Vegetation Management Plan 2008-2012." Prepared by NSTAR Electric.

NSTAR's VMP outlines and explains the standards of vegetation control from their Integrated Vegetation Management (IVM) program. The document describes the practices and procedures NSTAR uses to control vegetation in its ROWs, as well as the efforts to reduce the impact of vegetation management on the health of the environment, animals, and humans.

To acquire this resource, visit http://www.kenersongroup.com/VMP.pdf

[9] "Vegetation Management: Clearing a Path to Reliable Service." Prepared by SMUD.

This document highlights SMUD's commitment to effective vegetation management practices and principals. It provides a detailed overview of the types of pruning techniques employed and illustrates its current vegetation management practice with informational graphics.

To acquire this resource, visit https://www.smud.org/en/residential/customer-service/support-and-services/vegetation-management/

[10] "Integrated Vegetation Management." Prepared by EPRI.

This document is a plan forward for key research in the integrated vegetation management arena. It discusses the drivers for the research and the key areas that need to be focused on to ensure it is useful in the industry.

To acquire this resource, visit http://mydocs.epri.com/docs/Portfolio/P2014/Roadmaps/ENV-F-T&D-04.pdf

[11] "Potomac Electric Power Company Comprehensive Reliability Plan for District of Columbia Including Distribution System Overview, Reliability Initiatives and Response to Public Service Commission of the District of Columbia Order No. 15568." Prepared by PEPCO.

In this document Pepco has committed to providing safe and reliable electric service to all customers at a reasonable cost. They plan to work with communities, political officials and the Commission to implement a robust reliability plan that balances the cost and benefits to customers.

This plan includes six reliability initiatives:
• Enhanced Vegetation Management
• Priority Feeders
• Load Growth
• Distribution Automation
• Feeder Improvement
• Selective Undergrounding
To acquire this resource, visit
http://www.pepco.com/_res/documents/dccomprehensivereliabilityplan.pdf

[12] "Pacific Gas and Electric Company: 2014 General Rate Case Prepared Testimony Exhibit (PG&E-4) Electric Distribution" Prepared by PG&E.

This document is the testimony of the 2014 PG&E Rate Case. This document explains the forecast of PG&E's Electric Distribution Operations line of business expenditures for 2014-2016. In addition to information on its vegetation management practices, it also includes sections about plans for emergency recovery, pole replacement, electric operations technology, underground asset management and many other topics.

To acquire this resource, visit https://www.pge.com/regulation/GRC2014-Ph-I/Testimony/PGE/2012/GRC2014-Ph-I_Test_PGE_20121115_254321.pdf

[13] "Vegetation Management Plan" Prepared by Essential Electric.

This document outlined the various methods which Essential Electric in Australia utilizes to ensure compliance to standards and to ensure reliability of the system. It discusses the actual methods of clearing vegetation and includes a planting guide to be used by the landowners to help eliminate future costs in vegetation management.

To acquire this resource, visit http://www.essentialenergy.com.au/asset/cms/pdf/aasp/ce_vmp.pdf

[14] "Five Year Vegetation Management Plan 2014-2018." Prepared by National Grid.

The Five Year Vegetation Management Plan details National Grid's plan for managing vegetation in ROWs. The plan discusses integrated vegetation management, various vegetation management

control methods, a discussion of the selective herbicide applications, and an overview of National Grid's treatment of "Sensitive Areas".

To acquire this resource, visit
http://www.nationalgridus.com/non_html/National%20Grid%20VMP%202014%20-%202018.pdf

[15] "Best Practices in Vegetation Management for Enhancing Electric Services in Texas" Prepared by Texas Engineering Experiment Station for Public Utility Commission of Texas.

The report documents known common practices in vegetation management in the state of Texas and recommends a framework for "best practices" in vegetation management.

To acquire this resource, visit
http://www.puc.texas.gov/industry/projects/electric/38257/Russell_Report.pdf

[16] "LIPA Vegetation Management Program." Prepared by Long Island Power Authority.

This document is a set of slides that provide an overview of LIPA's vegetation management program. In addition to discussing basic information about its vegetation management program, it also notes the standards that LIPA complies with, challenges that it faces, results of its vegetation management program, lessons learned and opportunities for future improvement.

To acquire this resource, visit http://www.lipower.org/pdfs/company/papers/board/062713-op-veg.pdf

[17] "Regulatory Change for Utility Management in the US." Prepared by Will Porter of CN Utility Consulting.

This document is a set of slides that provide an overview of how regulatory commissions in different states are evolving as new practices in vegetation management evolve.

To acquire this resource, visit
http://www.isatexas.com/images/Conference/13/13_Presentations/Regulatory%20Change%20for%20Utility%20Vegetation%20Management%20in%20the%20US10%203%2013%20ISAT%20William%20Porter%20[Read-Only].pdf

[18] "Prepared Direct Testimony of Scott P. Furgerson of Behalf of San Diego Gas & Electric Company: Exhibit No. SDG&E-05." Prepared by Scott P. Furgerson.

A testimony on behalf of San Diego Gas and Electric Company in the matter of requesting to update its gas and electric revenue requirements and base rates effective on January 1, 2012. It includes detailed expenditures on the company's programs, including its vegetation management program.

To acquire this resource, visit
https://www.sdge.com/sites/default/files/regulatory/Exhibit%20SDG&E-05R%20S_Furgerson_SDGE-R_Elec_Dist_O&M_Testimony.pdf

[19] "Weather-Related Power Outages and Electric System Resiliency." Prepared by Richard J. Campbell of Congressional Research Service.

This congressional report discusses suggested solutions for reducing impacts from weather-related outages, including improved tree trimming schedules to keep rights-of-way clear, placing distribution and some transmission lines underground, implementing Smart Grid improvements to enhance power system operations and control, inclusion of more distributed generation, and changing utility maintenance practices and metrics to focus on power system reliability.

To acquire this resource, visit http://www.fas.org/sgp/crs/misc/R42696.pdf

[20] "Laws and Regulations." Prepared by PG&E.

This website is a general summary of the rules and regulations which Pacific Gas and Electric is required to follow in the State of California. It gives clear guidance on the minimal clearance provisions for each size of electrical line.

To acquire this resource, visit http://www.pge.com/en/mybusiness/services/maint/vegman/laws.page?%20-%204292

[21] "General Order 95: Rules for Overhead Electric Line Construction." Prepared by the State of California.

General Order 95 is the California regulation on construction of overhead electrical lines. Section 35 includes the detailed rules for vegetation management in the area of the lines that needs to be met

To acquire this resource, visit http://www.cpuc.ca.gov/gos/GO95/go_95_rule_35.html

[22] "Vegetation-Related Transmission Outage Report: First Quarter 2013." Prepared by North American Electric Reliability Corporation.

This paper is a review of the transmission outages from across the country that occurred due to vegetation issues. It discusses the three distinct categories of vegetation outages and concludes that all three of the outages that occurred during the first quarter of 2013 were from vegetation falling on the lines from outside of the ROW. It also mentions that this is down from nine outages that took place during the first quarter of 2012.

To acquire this resource, visit http://www.nerc.com/pa/comp/Reports%20DL/Vegetation-Related%20Transmission%20Outages%20-%20First%20Quarter%202013.pdf

[23] "Chapter 25: Iowa Electrical Safety Code." Prepared by the State of Iowa.

This document is the exact regulations in Iowa required for utility companies. It discusses the need for a vegetation management plan which includes both a schedule for tree trimming as well as written procedures to follow.

To acquire this resource, visit https://www.legis.iowa.gov/DOCS/ACO/IAC/LINC/11-27-2013.Chapter.199.25.pdf

[24] "Vegetation Management." Prepared by Raymond Fugere of the California Public Utilities Commission – Safety and Enforcement Division.

This presentation reviews the roles and regulations in place in California and federally. It also discusses how many outages occur due to trees across the three major utility companies in California and how many trees each has to maintain. It wraps up by discussing the issues customers have with tree trimming and how this can affect safety.

To acquire this resource, visit http://www.cpuc.ca.gov/NR/rdonlyres/16A369A5-A7B9-423A-9D07-72E7E24F9532/0/PowerPointforthe5913Meeting.pdf

[25] "Vegetation Management by Electric Utilities: Use of Herbicides and Other Methods." Prepared by Environmental Management Services for EPRI.

This report summarizes the essential elements and principles comprising electric utility vegetation management programs, defines management problems, and discusses possible research on vegetation management issues. The report particularly focuses on the use of herbicides and their effects on wildlife and human health. Legal and regulatory aspects and cost control issues are also covered.

To acquire this resource, visit http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=TR-104935

[26] "Integrated Vegetation Management: A System, a Process, a Framework." Prepared by SUNY – College of Environmental Science and Forestry.

This presentation is a comprehensive guide to integrated vegetation management. It focuses on the key steps in the process and how to achieve each.

To acquire this resource, visit http://www.esf.edu/ivm/PDFs/IVM%20System-Process-Framework.pdf

[27] "Utility Vegetation Management Final Report." Prepared by the Federal Energy Regulatory Commission.

This report was written as a result of the Northeast Blackout in 2003. It provides a detailed overview of utility vegetation management in the United States, major findings of the investigation and recommendations to prevent another such blackout in the future.

To acquire this resource, visit http://www.ferc.gov/industries/electric/indus-act/reliability/blackout/uvm-final-report.pdf

[28] "List of Covered Electric Utilities under the Public Utility Regulatory Policies Act of 1978 (PURPA)." Prepared by the Department of Energy.

This document is published by the Department of Energy and contains a list of all utilities throughout the United States which Title I of the Public Utilities Regulatory Act of 1978 (PURPA) applies to.

To acquire this resource, visit http://energy.gov/oe/downloads/list-covered-electric-utilities-under-public-utility-regulatory-policies-act-1978-purpa

[29] "A Review of Canadian Forest Vegetation Management Research and Practice." Prepared by Dean G. Thompson and Douglas G. Pitt for

This article covers the different research and practices used for vegetation management in Canada from 1990-2003. While not directly tied to overhead utility line work it provides insight into the research being done and the results of the practices

To acquire this resource, visit http://hal.inria.fr/docs/00/88/37/40/PDF/hal-00883740.pdf

[30] "The State of the Utility Vegetation Management (UVM) Industry." Prepared by Stephen R. Cieslewicz for Electric Energy Online.

This article is an overview of the rules and regulations which came from the Northeast Blackout in 2003. It also discusses how these standards are expected and have impacted the utility industry.

To acquire this resource, visit http://www.electricenergyonline.com/?page=show_article&article=244

[31] "UAA Best Management Practices Funding." Prepared by Lynn Grayson for Utility Arborist Association.

This paper discusses the best practices used in the utility industry for vegetation management with both reliability and funding in mind. It was written using information from surveys and the Final Blackout Report in conjunction with the Utility Arborist Association

To acquire this resource, visit http://www.utilityarborist.org/research/resources/fundingwp.pdf

[32] "Regulatory Requirements 2006-2009." Prepared by CN Utility Consulting.

This study breaks down the rules and regulations on vegetation management by state. It not only contains information about current law, but discusses the regulations view on future law as well.

To acquire this resource, visit http://www.cnutility.com/wp-content/uploads/2013/10/UVM-Regulatory-Requirements-2006-2009.pdf

[33] "Utilities Uncover Success in Vegetation Management." Prepared by Doug Haller and John Smith.

This article discusses the positive sides of herbicides and how the long term effect can be much greater then with traditional mechanical methods, such as mowing. It also discusses how in the long term the use of herbicides is more cost efficient.

To acquire this resource, visit http://www.irwaonline.org/eweb/upload/ROW%20Archives%207-05%20thru%207-06/706/VEGE.pdf

[34] "Utility Vegetation Management and Bulk Electric Reliability Report from the Federal Energy Regulatory Commission." Prepared by the Federal Energy Regulatory Commission.

This is the results of a study that was conducted in the early-summer of 2004 by the Federal Energy Regulatory Commission. It was in response to the Commission's Final Blackout Report which was released in April 2004 and asked the utilities specifically about their progress on the recommendations by the report.

To acquire this resource, visit http://www.ferc.gov/industries/electric/indus-act/reliability/veg-mgmt-rpt-final.pdf

[35] "ANSI A300: Part 7 Integrated Vegetation Management." Prepared by ANSI.

The American National Standards Institute has written ANSI A300. "ANSI A300 Standards are divided into multiple parts, each focusing on a specific aspect of woody plant management." Part

7 focuses on integrated vegetation management and provides an overview of methods for evaluating sites, management control methods and ensuring quality control.

To purchase this document visit: http://www.isa-arbor.com/store/

[36] "Best Management Practices: Integrated Vegetation Management." Prepared by ANSI.

This is a companion publication to ANSI A300: Part 7 Integrated Vegetation Management. It is intended to be a compilation of the best practices in vegetation management in the utility industry. The major topics it covers are: communication, evaluation of sites, selecting control methods, implementation, quality assurance and environmental concerns.

To purchase this document visit: http://www.isa-arbor.com/store/

[37] "ANSI A300: Part 9 Tree Risk Assessment." Prepared by ANSI.

The American National Standards Institute has written ANSI A300. "ANSI A300 Standards are divided into multiple parts, each focusing on a specific aspect of woody plant management." Part 9 covers tree risk assessment. This part of the specification breaks down the tree assessments into three specific levels and what techniques should be used in each. It also discusses what needs to be included in the risk assessment reports.

To purchase this document visit: http://www.isa-arbor.com/store/

[38] "Best Management Practices: Tree Risk Assessment." Prepared by ANSI.

This is a companion publication to ANSI A300: Part 9 Tree Risk Assessment. This manual goes into a more in-depth look at how to perform a vegetation risk assessment. It covers everything from how to choose the level of analysis to how to perform the actual assessment to reporting practices.

To purchase this document visit: http://www.isa-arbor.com/store/

[39] "Growth Strategies: Best Management Practice for Integrated Utility Vegetation Management." Prepared by Randall H. Miller for PacifiCorp.

This articles summarized the process of integrated utility vegetation management and discusses the best practices in the industry.

To acquire this resource, visit http://www.energydimensions.net/growth-strategies-best-management-practice-for-integrated-utility-vegetation-management/

[40] "Fact Sheet: Integrated Vegetation Management." Prepared by the Environmental Protection Agency.

This pamphlet was put together by the EPA and discusses basic integrated vegetation management and the steps one would take to control growth.

To acquire this resource, visit http://www.epa.gov/pestwise/publications/landscaping/ivm_fact_sheet.pdf

[41] "Utilities Using Mobile GIS for Vegetation Management." Prepared for T&D World Magazine.

This is a short article that introduces the reader to the use of handheld GIS units to locate, measure and document areas where vegetation management needs to take place and the benefits which can be gained.

To acquire this resource, visit http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management

[42] "Vegetation Management Takes to the Airwaves." Prepared by William Atkinson for Electric Power & Light Magazine.

This article focuses on PPL Electric and Northeast Electric's use of lidar (light detection and ranging) equipment to stay in compliance with federal standards. It discusses the issues with implementation and the improvements it has made in the field.

To acquire this resource, visit http://www.elp.com/articles/powergrid_international/print/volume-17/issue-5/features/vegetation-management-takes-to-the-airwaves.html

[43] "LIDAR: Illuminating Hazardous Vegetation." Prepared by Gene Wolf for T&D World Magazine.

This article discusses the difficulties faced by utilities when it comes to vegetation management and how LiDAR equipment can help when used properly.

To acquire this resource, visit http://tdworld.com/overhead-distribution/lidar-illuminating-hazardous-vegetation

[44] "NIPSCO Streamlines Vegetation Management." Prepared by Jason Lietz and Amy Fischbach.

This article focuses on Northern Indiana Public Service Company's transition to the digital age of recordkeeping and improve communications using ArborMetrics software. It concludes with a discussion of the advantages which have been seen by putting this software in place.

To acquire this resource, visit http://datasourcemobility.com/photos/psc-tb-tdworldcoverage-3-1-11.pdf

[45] "Monthly Aerial Patrols Promote Reliability." Prepared by Dick Pursley and Byron Johnson for T&D World Magazine.

This article discusses Great River Energy's success at using aerial patrols to monitor vegetation growth and other ROW issues. It covers the different methods, such as cyclical color surveys, as well as how the information on issues is relayed to the line crews and what affect this has had on the reliability of their service.

To acquire this resource, visit http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability

[46] "Met-Ed Conducts Vegetation Management Work to Enhance Electrical Reliability." Prepared for Electric Power & Light Magazine.

This article is an update on Metropolitan Edison Company's vegetation management plan and where they stood when the article was written as well as next steps.

To acquire this resource, visit http://www.elp.com/articles/2013/05/met-ed-conducts-vegetation-management-work-to-enhance-electric-r.html

[47] "SECO Clears the Way." Prepared by Ken Lacasse for T&D World Magazine.

Following the storm season of 2004 SECO in Florida realized it was spending more on vegetation management and getting a lower reliability. This article addresses SECO's use of the consulting firm ACRT and the changes implemented to improve reliability and decrease cost.

To acquire this resource, visit http://tdworld.com/vegetation-management/seco-clears-way

[48] "Trimming Your Way to a More Reliable Future." Prepared by Glenn Springer for T&D World Magazine.

In 2000 Nashville Electric Service had 10 times the number of tree outages then the utilities following vegetation management best practices. This article discusses how they identified the issue, the corrective actions they took and the results they saw after three trimming cycles.

To acquire this resource, visit http://tdworld.com/smart-energy-consumer/trimming-your-way-more-reliable-future

[49] "Assessing Ground Fault Neutralizer (GFN) Deployment and Benefits in 11kV Electricity Network." Prepared by Phan Qixun.

This paper looks at the Ground Fault Neutralizer used at the Poroti zone substation in New Zealand. It examines the positive and negative affects it had on the system, including a cost benefit analysis. It concludes by comparing GFN to more traditional methods and discussing what the future holds for these systems

To acquire this resource, visit https://apps.foe.auckland.ac.nz/p4p/ece/downloads/Part4Reports2012/PowerSystems/project49_qpha006.pdf

[50] "Ground Fault Neutralizer." Prepared by Swedish Neutral.

This website features several documents on the ground fault neutralizers developed by Swedish Neutral. These documents cover how the neutralizer ground fault protection systems differ from typical protection systems, benefits of the system and basic implementation.

To acquire this resource, visit http://www.swedishneutral.se/main.php?name=gfn

[51] "CL&P Implementing New Technology to Improve Storm Response." Prepared for T&D World Magazine.

This article focuses on CL&P's new damage assessment tool. The tool allows the company to combine the GIS mapping data with information about the distribution system and GPS street location and allow it to be uploaded to the planning and logistics teams in real time. This data can then be used for more accurate ETRs and more efficient work plans

To acquire this resource, visit http://tdworld.com/news/clp-implementing-new-technology-improve-storm-response

[52] "Helicon, Alabama: Power Supply Improvement Project." Prepared by Tennessee Valley Authority.

This paper covers TVA's plan to improve reliability in Helicon, Alabama. It purposes multiple methods to do this and discusses the vegetation management process on this line

To acquire this resource, visit http://www.tva.gov/environment/reports/helicon/fea.pdf

[53] "Tree Healthcare Products Catalog, 2014." Prepared by Rainbow Treecare Scientific Advancements.

This presentation contains information on herbicides and how to use each one. It also contains a short history of vegetation management

To acquire this resource, visit http://www.treecarescience.com/pdf/RTSA-2014-catalog.pdf

[54] "Growth Retardants: A Promising Tool for Managing Urban Trees." Prepared by Purdue University.

This article discusses tree growth retardants. It starts out with a brief history of how they were invented and then discusses the advantages they can have on the trees, such as greener leaves, reduced water stress and a higher resistance to fungal disease.

To acquire this resource, visit https://www.extension.purdue.edu/extmedia/FNR/FNR-252-W.pdf

[55] "Report to the Maryland Public Service Commission on the Progress of the Maryland Electric Reliability Tree Trimming Council (MERTT) in Addressing Commission Order #79159 Regarding Recommendation for Specific Actions that Utilities Can Take to Best Manage Privately Owned Trees Adjacent to and within the Utility Right-of-Way." Prepared by Niles L. Primrose, Fred Kelly, and Charles Anderson.

This report is a study of the tree related outage data collected from six Maryland utility companies from 2006 to 2010

To acquire this resource, visit http://mocoalliance.org/wp-content/upload/pepco-tree-report.pdf

[56] "Evaluation of PG&E's 2014 Gas Distribution GRC Filing." Prepared by Cycla Corporation for Pacific Gas and Electric.

A report by Cycla Corporation that provides a detailed evaluation of PG&E's 2014 GRC filing as well as an evaluation of the company's practices including its vegetation management practices.

Appendix C

Export Control Restrictions
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Appendix D: Highlights from VM Practices Interviews (2014)

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EPRI Distribution Grid Resiliency:

Vegetation Management

Literature Review of Vegetation Management Concepts, Methods and Management in Support of Improved Distribution Grid Resiliency

And

Highlights of Participating Utility Interviews on Vegetation Management Practices

Technical Update, December 2014

EPRI Project Manager

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ABSTRACT

Vegetation management continues to be a significant challenge to providing safe and reliable and resilient service in overhead electric distribution systems throughout the US. This Vegetation Management (VM) literature review is being conducted by EPRI on behalf of its member utilities which desire a reference and understanding of new practices and standards in the VM industry, and are being applied by their peers. Accordingly, this review will not focus on traditional and widely used practices such as cycle based trimming or hazard tree removal, but instead, will identify less traditional strategies and efforts that are being undertaken to address the significant challenges posed by vegetation.

Due to the increased frequency and severity of recent major storms Distribution grid resiliency has become a critical issue surrounding society and modern life, due in large part to cultural dependency on electricity. The environment within which utility companies reside and operate in, continually challenge electric distribution systems throughout the United States especially in the area of vegetation and the management of its impact on system resiliency. Indeed, vegetation interference is one of the main contributors to outages on overhead distribution systems. Today, even short outages have a significant impact upon society's ability to function safely and efficiently. It is with this backdrop that EPRI has undertaken a review of significant efforts being used throughout the United States, seeking to identify opportunities that can be leveraged and replicated to help overcome the challenges posed by vegetation interference.

In support of the EPRI Distribution Grid Resiliency project, this document provides visibility on recent advances in vegetation management concepts and programs, and identifies approaches that may improve VM program effectiveness. This document also provides an overview of recently published American National Standard Institute's (ANSI) and the International Society of Arboriculture's (ISA) standards and guidelines; and a high level review of state requirements regarding utility vegetation management practices.

Keywords

Distribution Grid Resiliency
Integrated Vegetation Management
Risk Assessment
Vegetation Management

EXECUTIVE SUMMARY

Throughout the last decade, the impact of outages has become more severe as society has become more dependent upon electricity and advanced technologies that require electricity. The subsequent regulatory, customer and industry focus on electric grid resiliency has heightened the focus upon vegetation management because of its overall impact during adverse weather events. It is critical in grid resiliency strategy development that utility companies develop and implement an integrated vegetation management strategy. Each company should apply transparent, repeatable and consistent decision making processes to manage constrained budgets. In doing so, this ensures that a utility is achieving its strategic goals and objectives through informed investment decisions, of which, resilience of the electric system continues to grow in significance.

There are millions of miles of overhead distribution throughout the US and the vast majority share the right of way space with mother nature; most notably vegetation. While vegetation and the distribution system can co-exist, there are some significant challenges that are posed by vegetation. Complicating the management of vegetation is the vastness of many distribution systems, vegetation growth patterns which are substantially influenced by weather, multiple species of vegetation within any right of way, property owners who own the vegetation, funding and governmental requirements. In addition, many vegetation events that interfere with the integrity of the distribution system are caused by vegetation that resides outside of the right of way easement and therefore is legally outside the control of the utility. Furthermore, the various types of vegetation growth and right of way easements necessitate different strategies to effectively manage the potential interference. Each of these strategies requires different prioritizations, skill sets and management oversight.

Recently, the American National Standards Institute (ANSI) updated its Vegetation Management Standards and established an Integrated Vegetation Management (IVM) standard which incorporates asset management principles as they relate to risk management.

In 2006 Part 7 of the ANSI A300 introduced the concept of Integrated Vegetation Management (IVM); two years after the catastrophic blackout of 2004. In 2012, this section was updated to incorporate some of the risk concepts published in ANSI A300 part 9 which was first published in 2011. The IVM differs from previous vegetation management strategies in that it necessitates more sophistication and more comprehensive management oversight. Outlined in six steps, ANSI A300, Part 7, is a methodology for continuous improvement which begins by establishing succinct objectives and involves; information gathering and evaluation, planning, optimally selecting compatible treatments based upon pertinent factors, executing the plan and ultimately evaluating the plan against the objective(s) based upon results.

In 2011 Part 9 of the ANSI A300 introduced the general concept of Risk Management as part of the IVM concept. Fundamentally, this section introduces the concept of treating the system's infrastructure as assets and the corresponding vegetation as a risk element that needs to be managed. It proposes concepts that are well accepted and utilized in the utility industry as it relates to the overabundance of infrastructure that utilities are responsible for and the asset management processes that have been utilized for decades. This section has taken the natural next step of correlating the two components that are generally occurring in the utilities right-of-

ways; vegetation and infrastructure. This standard incorporates advanced understanding of the science and practice of vegetation risk assessment.

The stated purpose for the tree risk assessment is "to provide guidelines for the practice of tree assessment and standards for writing specifications". The reason for the tree risk assessment standard is "to assess structural integrity and other factors that affect the level of risk to people or property and to provide information for mitigating risk". The ISA best management practices associated with the ANSI A300 Part 9 standard outline a systematic process that treats trees and coincident trees as assets. This facilitates the use of a tree risk assessment process which is a familiar process to utilities by virtue of the millions of infrastructure assets that require significant oversight and management. This process ultimately helps to ensure that the investments made in managing vegetation are efficient and effective.

Throughout the research undertaken by this literature research it is evident that a significant number of utilities are addressing vegetation management in traditional and similar ways. These traditional methods and philosophies include: trimming practices focused on eliminating opportunities for vegetation to adversely impact utility infrastructure, targeted cycle trimming with average cycle periods where certain critical facilities, based generally upon condition surveys, are trimmed more often and often include mainline or high impact feeders, and reliability centered programs based upon feeder inspections or hot spot inspections as realized through reliability performance.

There are a number of initiatives that are being utilized within the industry that are notable and include new strategies or different approaches to addressing vegetation management. They are grouped in the general categories of Process Enhancements, Technology Utilization, and Tree Growth Regulators (Herbicides). These sections identify various initiatives that are being undertaken in each category.

Specifically, as it relates to Process Enhancements; several utilities have embraced the updated ANSI standards and ISA best management practices. Other utilities have continued to advance their programs by conducting detailed analysis regarding underlying causes for tree related outages. Specifically as it relates to Technology Utilization, several utilities have begun to take advantage of the opportunities that are provided by technologies like GIS and computer-based management tools. Lastly, as it relates to Tree Growth Regulators (Herbicides), significant research has been done that provides utilities opportunities to capitalize on another tool to address, what is to many utilities the leading cause of outages during adverse weather events.

In summary, while traditional methods to manage vegetation management remain the mainstay of utilities efforts throughout the industry, changes in expectations, standards and technologies will continue to drive improvements that will alter the landscape for utility vegetation management programs.

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Appendix D

1
INTRODUCTION

The purpose of this report is to document and highlight modern practices used by utilities to manage vegetation. It is generally understood that throughout the majority of the US, tree related outages, whether falling limbs or entire trees, are the largest contributor to the overall damage realized by the electric system during adverse weather events; especially considering the last few years, which have seen increased frequency and severity of major storms.

As a result of the significant impact created by these power outages it is important that utilities develop vegetation management programs that appropriately address the risks associated with the results of tree related outages. Although trees are not generally owned by utilities, an effective vegetation management program is integral to meeting the regulatory obligation of the utility to provide safe and reliable power. Each utility has its unique challenges based upon, among other things, geography, topography and arboricultural attributes, regulatory environment, budget constraints, environmental sensitivities and weather.

Throughout the last decade, the impact of outages has become more severe as society has become more dependent upon electricity. Thus, the focus on electric grid resiliency has heightened the focus upon vegetation management because of its overall impact during adverse weather events. Each company should apply transparent, repeatable and consistent decision making processes to manage constrained budgets within and across competing priorities that grid resiliency investments typically reside. In doing so, this ensures that a utility is achieving its strategic goals and objectives through informed investment decisions, of which, resilience of the electric system continues to grow in significance.

The purpose of this report is to provide a document review of current leading practices specific to integrated vegetation management initiatives that ultimately support Distribution Grid Resiliency (DGR).

This document is a reference for readers to use as a tool as they develop an integrated vegetation management program. The document highlights applicable standards and integrates risk mitigation and vegetation leading management practice concepts.

In addition this report provides the Distribution Grid Resiliency (DGR) project participants with an understanding of integrated vegetation management and its leading practice application. This document can serve as a guide for utilities seeking to align its internal prioritization methodologies against an industry framework through the development of processes, procedures and methodologies that allow the utility to evaluate distribution grid resiliency options, and select a collection of options (portfolio) that produces the optimized business value for the utility particularly when dealing with a constrained budget.

Some specific objectives of this phase of the project are:

- Identify integrated vegetation management initiatives that can be utilized by other utilities;

- Identify where principles of risk management are incorporated into integrated vegetation management;
- Identify where asset management processes and modern technologies are being utilized as part of integrated vegetation management programs; and,
- Identify where initiative that are being used to address distribution grid resiliency are incorporated into integrated vegetation management programs.

2
OVERVIEW OF US ELECTRIC DISTRIBUTION SYSTEMS

Generally, in the United States the distribution system begins with a primary alternating current circuit or feeder which emanates from a substation and terminates at an end user or customer. Effectively, distribution circuits are the bridge between the transmission systems which are used to broadly disseminate power at high voltages (138kV, 345kV, 500kV etc.) over great distances and the end user or customer. Distribution circuits are fed from a power transformer located at a distribution substation which "transforms" the transmission level voltage to distribution level. On the distribution system, the voltage used is lower because there is usually less distance to transport the power and thus there are many distribution substations throughout the US. Typical voltages range from 2kV to about 35kV depending on utility standard design, distance to load, and the amount of load to be served.

Feeders generally consist of three single conductors which are utilized to transport or conduct the three phases that are generated at the generation station. Usually there is an additional conductor used as a ground reference which very broadly is designed to minimize electric shock during abnormal conditions. Distribution systems utilize overhead pole lines, or in densely populated areas, underground conduit systems, to transport power to end use customers.

While three phase power is utilized in densely populated areas, single phase distribution is often provided in less densely populated areas. Residential, commercial, and industrial loads are addressed via both of these means and the use of three-phase or single-phase service is usually determined by the amount of load needed to be served. Further, while very large loads may be provided service at distribution voltages, most utility customers are provided service at secondary voltages (120V/208V, 120V/240V, 277V/480V) through the use of a distribution transformer which converts the distribution voltage to secondary voltage. Throughout the US, the majority of these transformers are pole-mounted or pad-mounted and are supplied by overhead distribution systems. However, in very dense areas, like most of the major cities throughout the US, secondary networks are created where the transformer which converts distribution voltage to secondary voltage is placed in a conduit system underground.

Consequently, across the nearly 4 million square miles of land in the United States are millions of miles of overhead distribution wire owned by many utilities used to distribute ubiquitous electric service throughout the United States. These distribution systems supply power to hundreds of millions of residential, commercial and industrial customers and as such are an integral part of the infrastructure necessary to ensure that the United States remains, among other things, economically, and financially viable. In order to build the overhead electric system tens of millions of poles are installed along roadways or through land through the use of Right-of-Way (RoW) access easements. As one might expect, because of the nature of the locations where poles are placed there are challenges that interfere with the use of the RoW; most notably vegetation.

Vegetation and its Impact on Distribution Systems

There are millions of miles of overhead distribution throughout the US and the vast majority share the RoW space with Mother Nature; most notably vegetation. While vegetation and the distribution system can co-exist, there are some significant challenges that are posed by vegetation. As noted earlier, distribution systems distribute power along conductors. As part of the design and electrical requirements, these conductors are electrically isolated to avoid the uncontrolled flow of power. Generally, at each pole, the conductor is electrically isolated through the use of insulators which isolate the conductor from the pole; which is considered grounded via its placement in the ground. Additionally, each phase of the conductor is electrically isolated from the other phases to eliminate the uncontrolled flow of power due to the potential across phases. Notwithstanding the isolation efforts, vegetation may interfere in a variety of ways with the design efforts utilized by utilities to ensure the distribution of safe and reliable power.

The two primary interferences caused by vegetation are normal growth that encroaches on the primary voltage conductor(s) and limbs or trees that fall on the conductor(s). Either of these scenarios can create situations where there is uncontrolled power flow, by acting as a ground path, establishing a conductive path between otherwise electrically isolated phases; or damaging the equipment that normally provides the necessary electric isolation. In any of these events, the safety and reliability of the overhead distribution system may be compromised.

Challenges Associated with Managing Vegetation

There are several factors that influence a utility's ability to manage vegetation. It should be noted, utilities generally do not own the vegetation that often co-exists in its right of ways. However, by virtue of its RoW easement the utility generally has certain rights to manage and control those things that may reasonably interfere with its RoW rights. Managing this however is complicated by the vastness of many distribution systems, growth patterns which are substantially influenced by weather, multiple species of vegetation within any RoW, property owners who own the vegetation, funding and governmental requirements. In addition, many vegetation events that interfere with the integrity of the distribution system are caused by vegetation that resides outside of the RoW easement and therefore is legally outside the control of the utility. Furthermore, the various types of vegetation growth and RoW easements necessitate different strategies to effectively manage the potential interference. Each of these strategies requires different prioritizations, skill sets and management oversight.

History of Vegetation Management

Historically, vegetation has been a leading cause of outages in the US. Indeed, as a result of the Rural Electrification Act (REA) in the 1930s, overhead distribution systems throughout the US began to quickly expand, inadvertently increasing their exposure to the deleterious effects of vegetation. Utilities of all types; cooperatives, municipal and investor owned, began to realize that vegetation needed to be managed in order to provide the desired reliability contemplated by the REA.

For at least 50 years, many utilities throughout the US have focused on managing vegetation mainly through the establishment of RoWs during initial infrastructure installation, subsequent maintenance trimming programs and targeted removals. In addition herbicide application have also been widely used, often in conjunction with local municipal governments who have responsibility for managing roadside vegetation.

While these efforts have been highly successful, as evidenced by the reliability of the distribution system measured by overall availability of service, the negative impact of vegetation, particularly during severe weather events is notable and significant.

3
STANDARDS AND GUIDELINES FOR VEGETATION MANAGEMENT

Overview

Despite the importance of distribution vegetation management there has been, until recently with the 2012 publication of ANSI and ISA standards and guidelines, little guidance to the electric utility industry.

There are no federal standards set forth by the Federal Energy Regulatory Commission or the Department of Energy for distribution level voltages. However, as a result of the 2004 blackout, the North American Electric Reliability Corporation (NERC) standards, consistent with the provisions of section 1211 of the Energy Policy Act of 2005 (US Congress Public Law 109-58, enacted August 8, 2005), were established but only apply to transmission level voltages. Thus, distribution voltage vegetation management requirements are the jurisdiction of state regulatory agencies.

Not surprisingly, the Occupational Safety and Health Administration also does not provide any specific guidance as it relates to vegetation management; but, does address the safety of workers who work in the proximity of hazards. Though not specific to vegetation management, the only real guidance provided by OSHA involves the safe work practices necessary to work near energized conductors.

The National Electric Safety Code (NESC) by contrast does generally establish the requirement for vegetation management practices to be determined by each utility, and it does establish guidelines for line maintenance and worker safety. The NESC is not prescriptive regarding the frequency or determination for vegetation management nor does it establish clearance standards. Rather, it provides general guidance that acknowledges that vegetation may interfere with the safe operation of overhead conductors and recommends that these situations be addressed according to the needs of the specific utility.

In jurisdictions that are concerned with wildfires requirements set forth in the *Wildland-Urban Interface Code* are often mandated. These regulations may be voluntarily adopted by any given governmental jurisdiction seeking to utilize the efforts of the International Code Council. This code seeks to establish minimum regulation for land use and infrastructure that exists where wild land abuts urban locations. There is minimal discussion regarding vegetation management and it is focused on site-specific locations. The intention of this code is to bridge the gap between applicable building and fire codes within a jurisdiction.

In the United States in 1991 a committee of arboricultural professionals organized and developed tree maintenance standards focusing on improving public safety and establishing uniform standards to be utilized in arboricultural operations. These efforts resulted in the development, recommendation and acceptance as a standard by the American National Standards Institute (ANSI) and have been used throughout the industry for the last twenty years. Fundamentally,

these standards address safety requirements for vegetation management and identify best practices for trimming and pruning practices.

Recently however, the ANSI standards were updated and establish an Integrated Vegetation Management standard which incorporates asset management principles as they relate to risk management. Below is a summary of the ANSI standards and the associated ISA best management practices.

American National Standard and International Society of Arboriculture

The American National Standards Institute is a private non-profit corporation that oversees the development of voluntary standards for products, services, processes, systems, and personnel in the United States and coordinates international standards to ensure worldwide inter-operability.

ANSI accredits standards that are developed by representatives with extensive knowledge in the specific fields where standards are being developed with the goal of ensuring that the characteristics and performance of products are consistent, that people use the same definitions and terms, and that products are tested the same way. ANSI also accredits organizations that carry out product or personnel certification in accordance with requirements defined in international standards.

Since 1991 the Tree Care Industry Association (TCIA) has, working as an accredited Standards Developing Organization for ANSI, been providing guidance to, among others, property managers and owners, government agencies and utilities.

In August of 2012, ANSI published a revised A300 with a mission "to develop consensus performance standards based on current research and sound practice for writing specifications to manage trees, shrubs and other woody plants".

Fundamentally, the ANSI standards indicate requirements, and the companion International Society of Arboriculture (ISA) best management practices provide a more detailed and practical discussion regarding how to accomplish the requirements set forth by the standards.

Tree, Shrub, and Other Woody Plant Management - Standard Practices (Integrated Vegetation Management, a. Utility Rights-of-Way)

In 2006 the section of the ANSI A300 that addresses Tree, Shrub, and Other Woody Plant Management - Standard Practices (Integrated Vegetation Management, a. Utility Rights-of-Way) introduced the concept of Integrated Vegetation Management (IVM) only a couple years after the catastrophic blackout of 2004. In 2012, this section was updated to incorporate some of the risk concepts published in ANSI A300 part 9 which was published in 2011. The IVM differs from previous vegetation management strategies in that it necessitates more sophistication and more comprehensive management oversight.

The stated purpose for the IVM is "to provide standards for developing specifications to implement an integrated approach to management of vegetation on utility right-of-ways". The reason for the IVM "is to create, promote, and conserve sustainable plant communities that are compatible with the intended use of the site and discourage incompatible plants that may pose concerns, including safety, security, access, fire hazard, utility service reliability, emergency

restoration, visibility, line-of-sight requirements, regulatory compliance, and environmental or other specific concerns."

As defined, IVM is "a system of managing plant communities in which compatible and incompatible vegetation is identified, action thresholds are considered, control methods are evaluated, and selected control(s) are implemented to achieve a specific objective. Choice of control methods is based on effectiveness, environmental impact, site characteristics, safety, security and economics".

ANSI Best Management Practices

Not intended to supplant the expertise of a qualified vegetation manager, ISA intends to provide best management practices to guide arborists, and the people who employ them, toward the most appropriate arboricultural techniques. The repeatable steps outlined as part of the IVM offer a scientific basis for utility companies to manage vegetation.

ANSI A300, Part 7 offers a systematic way of planning and implementing a vegetation management program which consists of six steps:

1. Set Objective
2. Evaluate the site
3. Define action thresholds
4. Evaluate and select control methods
5. Implement IVM
6. Monitor treatment and quality assurance

The term integration as it relates to IVM is a recognition that each of the steps is integrated into the other and that the process is principled on continual improvement since each successive application will necessarily build upon the lessons learned from the previous application of the process.

Set Objectives

Objectives are set by each utility and may be utility specific or even project specific. The objective(s) is meant to establish the overall vision of the remaining steps and may be broad or narrow. Regardless, the results of the IVM must be evaluated to determine if the objective(s) has been met. It is important to establish appropriate metrics and the processes necessary to ensure the requisite data is available to evaluate whether the objective(s) has been met.

Evaluate the Site

Evaluating the site is fundamentally a planning function that recognizes the dynamic nature of areas where IVM programs will be employed. Site evaluations are utilized to identify risks and opportunities and may include, among other things; identifying safety concerns, identifying applicable regulations based upon location, political and budgetary concerns, the amount of work necessary to effectuate the plan, unique equipment or labor capabilities required by the site,

right-of-way conditions and constraints, adjacent land uses and constraints, the likelihood of fire risk, environmentally vulnerable or protected areas, access restrictions, and weather or time or year restraints. This information is useful for constructively challenging the objective(s) and defining future steps.

Define Action Thresholds

Action thresholds are determined by the results of the site evaluation and establish vegetation height and density targets that trigger specific control measures necessary to meet the objective(s).

Evaluate and Select Control Methods

A variety of control measures may be necessary to achieve the overall objective(s) set forth for the site or project, but each control method should optimally be chosen to suitably meet the objectives. There are a variety of control methods available to vegetation managers, including; manual, mechanical, biological, tree growth regulators, and a variety of herbicide applications, including individual stem treatment, broadcast treatment, and aerial treatment.

Each of these control methods are designed for specific applications and must be chosen to optimally meet the objectives and take into consideration needs identified during the site evaluation.

Implement IVM

This step highlights the integration of the previous steps and re-emphasizes the need to ensure systematic work scheduling using pre-determined control methods which considers relevant factors to inform the execution of the IVM, including workloads, accessibility, and importance of infrastructure and growth rates. It also superficially addresses, initial clearing and reclamation considerations, clearances following work completed predominantly focused on transmission level voltages and debris removal – most relevantly, as it relates to disease or insect infected debris.

Monitor Treatment and Quality Assurance

Consistent with good asset management practices, evaluating the results of decisions made and actions taken is critical for improving the plan. An important aspect related to evaluating the results is ensuring that the work defined to meet the objectives was executed as planned. As noted in the best management practices, “utility vegetation management programs should have systems and procedures in place for documenting and verifying that vegetation management work was completed to specification”. The management of vegetation is data intensive and thus it is important that appropriate processes are established early in the IVM process (ideally when establishing objectives) to ensure that pertinent data is defined and appropriately captured – this information is critical for further developing future IVM strategies.

Outlined in six steps, ANSI A300, Part 7, is a methodology for continuous improvement which begins with establishing succinct objectives and involves information gathering and evaluation, planning, optimally selecting compatible treatments based upon pertinent factors, executing the plan and ultimately evaluating the plan against the objective(s) based upon results.

Tree, Shrub, and Other Woody Plant Management - Standard Practices (Tree Risk Assessment, a. Tree Structure Assessment)

In 2011 this section, ANSI A300 Part 9 introduced the general concept of Risk Management as part of the IVM concept. Fundamentally, this section introduces the concept of treating the system's infrastructure as assets and the coincident vegetation as a risk. It proposes concepts that are well accepted and utilized in the utility industry as it relates to the plethora of infrastructure that utilities are responsible for and the asset management processes that have been utilized for decades. This section has taken the natural next step of correlating the two components that are generally occurring in the utilities right-of-ways, vegetation and infrastructure. This standard incorporates advanced understanding of the science and practice of vegetation risk assessment.

The stated purpose for the tree risk assessment is "to provide guidelines for the practice of tree assessment and standards for writing specifications". The reason for the tree risk assessment standard is "to assess structural integrity and other factors that affect the level of risk to people or property and to provide information for mitigating risk".

ANSI Best Management Practices

The best management practices promulgated by the ISA were developed consistent with, among other International Standards Organization (ISO) standards, ISO 31000:2009 Risk Management – Principles and Guidelines. Thus, it is not surprising that the information contained in this publication are remarkably similar to guidelines set forth in traditional risk management processes. As noted in the publication, this standard, like the ANSI standard, different from other standards, focuses solely on tree risk assessment and not the overarching goals and issues of tree risk management; and thus, it is geared toward guiding the arborist.

The purpose of the publication is "guide arborist to assess tree risk as accurately and consistently as possible, to evaluate that risk, and understand which treatments can achieve an acceptable level of risk". Similar to traditional risk management principles, risk is the combination of likelihood of an event and the severity of the potential consequences of that event. Thus, unlike the traditional and loosely applied terms, a tree is only considered "hazardous" when it has been appropriately assessed, found likely to fail and whose consequences of failure create an unacceptable degree of consequence.

Tree risk assessment is the systematic process to identify, analyze, and evaluate tree risk. The manner in which this process is applied depends on the context. The parameters of the risk assessment which may include objectives, applicable policies and legal requirements or communication flow, and the methods used to carry out the risk assessment. Generally, there are two approaches to undertaking risk assessment; quantitative and qualitative. While each has its limitations there are, depending on the objectives, requirements, resources and uncertainties, advantages and limitation to each. Regardless of the approach taken it must be understood that there are limitations inherent in the process due to the nature of the unknowns that are inextricably tied into the process of managing trees; weather, traffic issues, and rates of progression of decay. And, it should be noted, that there are generally two general types of risk

associated with trees: conflicts and failures. Conflicts are the result of a mismatch between a trees natural tendencies and its societal impact and function – these are not often the concern of utilities. Failures however, are the cause of much utility consternation and involves, as one might expect, mechanical failure of trees and tree parts.

Level and Scope of Tree Risk Assessment

The best management practices define three levels of risk assessment which should be specified in the scope-of-work and should be appropriate for the assignment. There are three levels of assessment.

Level 1 – Limited Visual Assessment

Level 1 assessment is a visual assessment from a specified perspective focused on identifying obvious defects or specific conditions. Because of the limited nature of some level 1 assessments, they may not even qualify as a "risk assessment" because of the lack of analysis or evaluation of individual trees. Level 1 assessments, though limited in value, do have important uses by a utility such as post-storm assessments or quick evaluations of a large population of trees.

Level 2 – Basic Assessment

Level 2 assessment is a detailed visual inspection of a tree and its surrounding site and a synthesis of the information collected. This level of assessment is the standard performed by the arborist in response to a request for a tree risk assessment. It should be noted, however that this level of assessment includes only conditions that are detected from a ground based inspection and thus many risks may go undetected.

Level 3 – Advanced Assessment

Advanced assessments provide detailed information about specific tree parts, defects, targets or site conditions. Specialized equipment, data collection and analysis, and expertise are usually required for advanced assessments. Advanced assessments may include a variety of techniques such as: aerial inspection and evaluation of structural defects in branches, using load and decay testing; detailed target analysis identifying use and occupancy of surrounding areas, taking into consideration the potential disruption of activities; detailed site evaluation including a soil profile inspection to determine root depth; decay testing including single path sonic stress testing and electrical impedance tomography; heath evaluation involving starch assessment and shoot length measurements; root inspection using ground penetrating radar; and wind load analysis using computer based estimations against engineering standards. Accordingly, prior to undertaking a advanced assessment the tree or area to be evaluated should be defined, the level and detail of the assessment should be established, the methods to report findings should be defined including the timeframe and the risk rating methodology and mitigation limitations and expectations should be discussed.

Assessing and Evaluating Risk from Tree Failures

This section of the publication outlines the basic expectations that are consistent with typical risk assessments utilized in traditional asset management processes, a likelihood versus consequence analysis. In this instance, the arborist defines the target(s) that are to be evaluated from a consequence perspective. Targets relevant to this discussion mainly involves utility infrastructure, vehicles and buildings, though targets may also include people, activities or other property. Once targets are defined, a risk assessment of nearby trees is undertaken to evaluate the likelihood of failure and the likelihood of the tree impacting a target. Obviously, the determination of the likelihood of a tree failure is very challenging; and consequently guidance is provided within the publication which focuses on the physics associated with environmental forces like wind and stresses within the structure of the tree itself, including compression, tension, shear and torsion. Similarly, understanding the potential impact of the tree failure is equally challenging because it may be dependent on the time of day of the tree failure, electrical loading needs of customers and weather conditions. As might be expected, various factors may influence either the likelihood or consequence of a tree failure, including site conditions and factors, potential wind excursions based upon things like topography or removal of other surrounding trees and tree species and their respective failure profiles.

Tree Risk Categorization

The tree risk categorization is similar to the categorization of risk used as part of traditional asset management programs. It relies on developing a matrix which estimates the likelihood of the combined events of a tree failure occurring and the tree impacting a specific target against the consequence of the resulting event.

The likelihood of an event taking place may consider, to varying degrees, the health of the tree, site conditions, species failure profiles, susceptibility to weather events and the experience of the assessor. The likelihood of failure is classified into four basic categories: improbable, possible, probable and imminent. Similarly, the likelihood of impacting the specified target considers various factors and is categorized into four levels: very low, low, medium and high. Thus the matrix using these four categories for each results in a 4-by-4 matrix which helps illustrate the likelihood of a tree failure impacting a specified target. The four levels used for populating this matrix are: very likely, likely, somewhat likely and unlikely.

This likelihood of failure and impact is then contrasted with the consequence of the resulting event to ultimately develop a risk rating matrix which demonstrates the level of risk as the combination of likelihood of a tree falling and impacting a specific target, and the severity of the associated consequence. Again, determining the consequence of an event occurring can be challenging because of the variety of factors to be considered. The consequences of an event are evaluated in four categories: negligible, minor, significant and severe. The four terms used to define the levels of risk in the resulting matrix are: extreme, high, moderate and low.

Similar to asset management risk profiles the risk matrix outlined in this publication appears in Table 1, below:

Table 1 - Risk rating matrix showing the level of risk as the combination of likelihood of a tree failing and impacting a specified target, and severity of the associated consequences.

		Consequence			
		Negligible	**Minor**	**Significant**	**Severe**
Likelihood of Failure and Impact	***Very Likely***	Low	Moderate	High	Extreme
	Likely	Low	Moderate	High	High
	Somewhat Likely	Low	Low	Moderate	Moderate
	Unlikely	Low	Low	Low	Low

It should be noted that the use of this matrix has limitations due to the subjectivity associated with the selection of both the likelihood and consequence factors, and the lack of comparability to other types of risk assessed using other means. Likewise, there are a variety of other limitation that are inherent in the process of risk assessment: tree assessment considers known targets and detectable tree conditions, the condition assessment is a snap-shot in time, and the scope of the risk assessment is defined early in the process.

Risk Mitigation: Preventative and Remedial Actions

Once the risk is understood, mitigation efforts can be developed. These mitigation efforts may address the likelihood of the failure, the likelihood of impact or the consequence of the failure. Mitigation efforts may be quite varied and may include: target management, which focuses on evaluating options for doing something to the target to mitigate the risk; pruning, installing structural support systems; adding lightning protection to trees, modifying the site; and using tree growth regulators. As might be expected the immediacy and type of response to developing mitigation plans is guided by the severity of the risk associated with the situations. For example, extreme risk situations necessitate immediate response, while low risk trees may be retained and monitored, if deemed necessary. It is important to note, that not all mitigation efforts completely eliminate the risk and thus it is important to be aware of and prepare for any residual risk that may remain, if necessary.

Risk Reporting

As noted in the publication the information, conclusions, recommendations and mitigation efforts should be appropriately documented. This documentation is necessary to help inform future decisions as well as ensure that communications with stakeholders are effective. Incidentally, in the wake of severe weather events, documented risk assessments and mitigation

efforts are valuable to convey the due diligence expected of utilities to meet the delivery of safe and reliable power.

Summary of Best Management Practices Associated with ANSI A300 Part 9

The ISA best management practices associated with the ANSI A300 Part 9 standard outline a systematic process that treats trees and coincident trees as assets. This facilitates the use of a tree risk assessment process which is a familiar process to utilities by virtue of the millions of infrastructure assets that require significant oversight and management. This process ultimately helps to ensure that the investments made in managing vegetation are efficient and effective.

4
UTILITY INDUSTRY HIGHLIGHTS

Throughout the research of this literature review, it is evident that a significant number of utilities are addressing vegetation management in traditional and similar ways. These traditional methods and philosophies include: trimming practices focused on eliminating opportunities for vegetation to adversely impact utility infrastructure; targeted cycle trimming with average cycle periods, where certain critical facilities, often prioritized by condition assessments, are trimmed more often and generally focus on mainline or high impact feeders; and reliability centered programs based upon feeder inspections or hot spot inspections as realized through reliability performance.

There are a number of initiatives that were evident throughout the review. They include the establishment of reliability indices and vegetation management metrics within utilities that have VM programs that focus on understanding the SAIFI impact of tree related outages. Also, most utilities focus on targeting mainline distribution because of the potential SAIFI impact of those type of outages as compared to fused laterals. Most VM programs have used cycle-based trimming for long enough periods that the adverse impact of outages caused by tree growth is minimal as compared to limbs, branches and trees; thus, most programs focus on addressing these types of issues. Similarly, maintaining mandated minimum clearances does not seem to be generally acknowledged as being useful and instead targeted trimming for identified risks seems more utilized.

Many utilities have hazard or danger tree identification and removal / mitigation strategies. During adverse weather events, trees and tree limbs are generally the major contributor to outages. Accordingly, many utilities have developed programs to identify these hazards and on a prioritized basis remove or mitigate the risk associated with these trees. The processes in these programs vary but generally the process is reasonably dovetailed into the cycle-based trimming, at least from an identification methodology. Generally, removal of these hazard tree locations is prioritized by its ability to adversely impact the reliability of service, thus mainline distribution often is the target. This is also reinforced because of the expense associated with full removals where necessary and the financial challenges realized by this Operations and Maintenance (O&M) expense.

An area where there was reasonable consensus is regarding public education. Generally, most utilities provide vegetation management education awareness. As part of this program, nearly all utilities provide some information regarding safety especially during storms and highlight the risk of downed wires. Many utilities are now using arborists to interact with stakeholders and work with property owners to facilitate the vegetation management process. Most utilities who utilize this process believe that the efforts of the arborist are important to stave the negative reaction that many property owners have to vegetation management initiatives, especially where their tree is being impacted.

There are a number of initiatives that are being utilized within the industry that are notable and are included below in the general categories of Process, Technology, Tree Growth Regulators and Noteworthy Efforts.

Process Enhancements

Unitil Corporation – (Fitchburg Gas and Electric Company, a subsidiary of Unitil Corporation)

In May of 2013 Unitil developed and submitted to the Department of Public Utilities in Massachusetts a five-year vegetation management plan[1]. This plan embraces the standards set forth in the ANSI A300, Part 7 standard.

The plan incorporates, consistent with the ANSI standards and ISA best management practice, various sections with significant relevant detail. Sections included in the plan are; The Primary Goals and Objectives of the VMP, Right-of-Way Vegetation and Identification of Target Vegetation, Integrated Vegetation Management Methods, Integrated Vegetation Management and Justification for Herbicide Use, Identification and Vegetation Management Methods in Sensitive Areas, Operational Guidelines for Applicators of Herbicides, Identification and Qualification of Individuals Preparing and Submitting this VMP and Supervision of the IVM Program, Description of Alternative Land Uses of Right-of-Way, and Remedial Spill and Emergency Plan.

The Primary Goals and Objectives section of the VMP defines eight objectives that guide the development and execution of the Integrated Vegetation Management Plan.

The Right-of Way Vegetation and Identification of Target Vegetation section acknowledges that a successful IVM approach to vegetation management leads to establishment of vegetative communities that are compatible with the electric facility. This section further defines target vegetation, as envisioned by the ISA VMPs, both for potential interference with electric infrastructure and plant species that present an environmental or safety problem especially where humans are the impacted target.

The Integrated Vegetation Management Method section outlines the expected methods that will be utilized to address the target vegetation and provides a detailed assessment of how each of the methods will be utilized.

The Integrated Vegetation Management and Justification for Herbicide Use section outlines its regulatory compliance strategy relating to application of herbicides and contemplates the transition from a historic use of mechanical methods to one that incorporates the use of herbicides.

The Identification and Vegetation Management Methods in Sensitive Areas defines sensitive areas, including; water supplies, surface waters, cultural sites, and wildlife areas and addresses restrictions in these areas, specifically as they relate toe herbicides.

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[1] "Five Year Vegetation Management Plan." Prepared by Unitil Corporation; http://www.unitil.com/sites/default/files/pdfs/UnitilVMPMay-1-2013.pdf

The Operational Guidelines for Applicators of Herbicides section fundamentally establishes the Vegetation Management Guidelines for the application of herbicides as part of the IVM. It is primarily focused on providing information to a third-party service provider.

The Identification and Qualification of Individuals Preparing and Submitting this VMP and Supervision of the IVM Program simply outlines who has overall responsibility for the development and implementation of the VMP. It notes, that this responsible person has ultimate responsibility for the preparation, implementation and compliance with all aspects of the VMP.

The Description of Alternative Land Uses of Right-of-Ways section addresses the concept of using right-of-way land differently as a cultural control method. Specifically, this aspect of the plan contemplates using right-of-way property for alternative uses which may include, farming, pasture land, orchards, golf course and paved roads, all which reduce the need to address target vegetation.

The Remedial Spill and Emergency Plan proactively anticipates hazards associated with the use of chemicals and other hazardous materials. It includes reference material, outlines notification contact information and establishes an herbicide spill checklist.

In all, the IVM set forth by Unitil provides tremendous insight to the objectives of the plan and the actions necessary to achieve these objectives. It is aligned with the anticipated format included in the ANSI and ISA documentation.

Northeast Utilities System

Similar to Unitil, Northeast Utilities outlines, in its 2014-2018 IVM plan, efforts consistent with the requirements of the ANSI A300 standard. One notable difference between the plans involves the alternate use of right-of-ways. At Northeast, the IVM establishes a process whereby a party may contract with the company to use the land for certain purposes which ultimately precludes the company from having to maintain vegetation management in that area.

Specifically, as set forth in the IVM, this is an agreement between the Company and another party (an individual, state or local government agency, or corporation), regarding property owned by the Company. A party may enter into an agreement with the Company (through a Company Representative) which allows them to use Company owned land for their purpose (e.g., commercial or agricultural use) in exchange for some agreed to compensation. Certain land uses preclude or reduce the need for brush control. License agreements are negotiated on a case-by-case basis via the Company's Real Estate Department.

Long Island Power Authority

LIPA has a high tree density per circuit mile which is one of the several challenges that it faces with regard to vegetation management[2]. As of June 2013, LIPA's VM program identified 1,600 circuit miles on its distribution trim list and 200 circuit miles on its transmission trim list. In the process of identifying the vegetation management and the acquisition of contracts, LIPA's

[2] "LIPA Vegetation Management Program." Prepared by Long Island Power Authority; http://www.lipower.org/pdfs/company/papers/board/062713-op-veg.pdf

reliability engineers perform an analysis of tree caused interruptions and consult with vegetation management supervisors with regard to the field conditions.

With regard to vegetation management related to storm hardening, LIPA's reliability management provides analysis on where entire trees and large limbs impact the system. Moreover, LIPA's vegetation management supervisors work with contractors and municipalities to identify hazard trees. Following a more innovative approach, LIPA is currently experimenting with a pilot iPad Application that can improve monitoring and efficiency of hazard tree management.

LIPA's right of way and substation maintenance activities include grounds maintenance and selective herbicide spraying in substations in addition to developing plans and monitoring field crews on a daily basis. In addition to utilizing "directional pruning", LIPA's tree trimming activities are performed in compliance with ANSI A300. Moreover, LIPA holds an annual contractor workshop to review all trim specifications. Furthermore, LIPA's Line Clearance Supervisor monitors field work during trimming jobs, performs a full inspection at the end of jobs and electronically files Contractor Evaluation assessments upon the completion of each circuit.

Orange and Rockland Utilities

Orange and Rockland has had an aggressive Distribution vegetation management program in active practice for over twenty years. Beginning about 1991, Orange and Rockland committed to a consistent cycle-based approach to Distribution vegetation management of its primary electric facilities. Since making this commitment, Orange and Rockland has employed a distribution clearance specification of (10') under, (10') to the side, and (15') feet over top of all primary facilities of all construction types. This specification has been implemented over a consistent cycle length of four-years and slightly quicker in more customer-dense areas. This standard pruning specification and commitment to maintaining the cycle length has led to a more reliable electrical infrastructure and quicker repairs when tree-related incidents do occur. When Orange and Rockland first began to introduce the new distribution vegetation management concept and pruning standards, it was not received well by all customer or municipalities within its service territory. Through a consistent message, outreach, education, and informational meetings, Orange and Rockland has made tremendous strides forward and currently both customers and municipalities view Orange and Rockland as a partner and an asset in terms of maintenance of the shared community forest.

In June 2013, Orange and Rockland enhanced its long standing Distribution vegetation maintenance program with advancements that are designed to further improve the program. These enhancements include a larger pruning specification for selected areas of the overhead system. The first area that will receive additional treatment is the primary conductor from the substation out to the first set of protection. The philosophy is that from the substation exit to the first protective device the entire customer base on the circuit has exposure to a tree-caused event. To mitigate that risk, Orange and Rockland has introduced an expanded pruning specification 33% larger than the standard pruning specifications. Orange and Rockland now achieves clearance specification of (15') under, (15') to the side, and (20') feet over top from the substation out to the first protective device, or a mile should no protective device be present. After the protective device (or the mile), the pruning clearance reverts back to the standard

clearance specification of (10') under, (10') to the side, and (15') feet over top. This expanded pruning clearance is also now applied to entire length of the 34.5kV distribution system.

Following the major storm events that Orange and Rockland endured, another vegetation management program enhancement in terms of pruning techniques called Branch Reduction has been developed. Over the successive maintenance cycles since 1991, Orange and Rockland has done a very good job of first establishing and then maintaining the aerial space through and near adjacent tree canopies. Limbs, especially over top of the conductor that are outside of the normal maintenance zone, have continued lateral growth over the conductors. Orange and Rockland participated in a study following the 2011 storms evaluating these long, extended limbs and their potential to break under snow, ice, or wind loading. Among the conclusions of this study is to look at these long limbs as levers, and by shortening these extended limbs (reducing the lever), targeted pruning can stiffen and make the remaining limb less prone to breakage thereby lessening potential damage in a loading situation like a storm event. Accordingly, Orange and Rockland is undertaking worker training to assist its vegetation contract workers in identifying these potential limbs and reduce their length through appropriate branch reduction pruning.

Another program Orange and Rockland has instituted following the 2011 and 2012 storm events is the Hazards Tree Program. Evaluating tree failures following the storm events led to the assumption that a significant portion of the tree-related damage was not caused by vegetation immediately alongside the conductors, but by trees rooted well back from the conductors and outside the normal maintenance zone. When these larger, well out of the maintenance zone trees fail, the resulting outages likely included greater infrastructure damage including broken poles. To address this issue, Orange and Rockland instituted a modified Hazard Tree Program. This program entails looking at and evaluating identified Hazard Trees rooted well back from the conductors. A Hazard Tree is a tree that has the ability to contact an energized conductor combined with a defect of some type, such as being a dead or declining tree, rot, upheaving or unstable soils, root decay, cavities, or other condition contributing to potential tree failure. These trees are identified and the municipality or property owner is attempted to be contacted by a door hanger requesting contact to discuss the identified hazard tree. The objective is to continually cull out identified Hazard Trees during the scheduled maintenance cycles and remove these trees to harden the overhead electrical system and make it more resilient in storm conditions.

One other initiative Orange and Rockland is undertaking is a comprehensive evaluation of the health of the urban forest. Orange and Rockland is currently involved with this study to evaluate several parameters of the urban forest in which their service area exits, including stocking densities of tree species, sizes and heights, overall health condition, and potential to contact the electrical system. The objective of this evaluation is to get a better knowledge basis of the local urban forest and use this information to assure the Orange and Rockland vegetation program has the ability to address emerging issues be they cultural or environmental. The results of this study will be delivered to Orange and Rockland early in 2014.

Pacific Gas and Electric

As part of their tree trimming program, PG&E inspects five million trees over 113,500 miles of distribution lines and takes action on over one million trees per year in addition to clearing vegetation around 120,000 utility poles. Hazard trees are identified during annual inspections,

they are pruned or removed to prevent contact with power lines[3]. With a tree related customer outage SAIFI at 0.087, their efforts are noteworthy.

The activities of the VM Program that were once viewed as incidental, and therefore not having significant impact on the environment, are increasingly being viewed as having a significant impact. PG&E now works closely with the US Forest Service and Fish and Wildlife Service in areas where endangered species are known to live, and to limit work at certain times of year to minimize the disturbance on wildlife. An environmental specialist was added to assist VM contractors and PG&E personnel in evaluating and addressing environmental sites. They also use techniques recommended by International Society of Arboriculture in order to prune responsibly. Contractor personnel must attend training to be able to identify when they are working in environmentally sensitive areas, and be familiar with the expectations for protective practices associated with sensitive habitats and species. However, overall cost for the VM program are increasing as new environmental permits are becoming required.

Wildfires have been recognized as a risk to the system; vegetation management can mitigate the risk. This has entailed hiring a consultant that specializes in fire risk modeling who has created a modeling tool to predict the most at risk areas in the PG&E service territory for wildfires. This allows the VM program to focus efforts on maintaining facilities within these high priority areas.

PG&E maintains an annual trim and patrol program which can be described as "just in time" trimming. Its operations group is in charge of field management and is organized into eight areas, each with two designated foresters. The state of California has a number of different fire areas, each with different minimum trim standards and regulations. PG&E's trimming activities are in compliance with all the regulations in all the areas and no area is allowed to drop below the standard. PG&E's trimming process includes an annual pre-inspection of all overhead power lines utilizing handheld devices for trim data collection and performing trims within four to six weeks from the pre-inspection. They input information on trees that need to be pruned or removed in the current year. This information includes tree species, tree size, trim type, clearance required, permission from the property owner for a removal, and location of the tree.

Moreover, PG&E has a quality control sampling process as well as a quality assurance audit process to provide details on the work review. In addition, PG&E investigates every vegetation related outage on its system.

Lastly, public education is an integral part of PG&E's VM Program and includes: communication materials, outreach efforts, and tree planting events. Randomly selected customers who recently had tree work done on their property are sent the "VM Customer Satisfaction Survey." More than 75 percent of responding customers rated the work as either excellent, very good, or good.

[3] "Pacific Gas and Electric Company: 2014 General Rate Case Prepared Testimony Exhibit (PG&E-4) Electric Distribution" Prepared by PG&E; https://www.pge.com/regulation/GRC2014-Ph-I/Testimony/PGE/2012/GRC2014-Ph-I_Test_PGE_20121115_254321.pdf

National Grid

Like Unitil and Northeast Utilities, National Grid has a formalized IVM plan which mirrors the requirements outlined in the ANSI standard and ISA best management practices[4]. From steep mountainous topography to rolling hills and level lowlands, and from remote, relatively inaccessible locations right through high density population centers, National Grid manages a diverse terrain in its 20,000 acres and 1,500 miles of rights of way within the Commonwealth of Massachusetts. Their integrated vegetation management (IVM) approach relies on reducing the amount of herbicides used, using selective herbicides/application techniques, timing applications for maximum effect, avoiding fixed application schedules, using mechanical control techniques where appropriate, encouraging low growing plant communities, and encouraging wildlife destruction and other ecosystem processes to reduce the overall dependence on chemical and mechanical controls. This multi-faceted approach minimizes the disadvantages and maximizes the benefits of each IVM component, thereby reducing the environmental impact and the financial cost of vegetation management while simultaneously increasing the overall effectiveness of the program.

Essential Energy, Australia

Essential Energy is a government-owned corporation, with responsibility for building, operating and maintaining Australia's largest electricity network - delivering essential network services to more than 800,000 homes and businesses across 95 per cent of parts of southern Queensland and northern Victoria. One of the major focuses of their vegetation management is brush fires and in high risk areas of their territory they require much larger right of ways in order to ensure the lines themselves do not spark any fires. Another unique feature of their process is to involve the landowners in risk reduction. **The landowners are responsible for reporting any clearance issues to Essential Energy who will then ensure trimming to the proper distances.** The landowner can also be responsible for the cost of trimming if they planted the plants after the utility lines were installed and did not follow proper guidelines on location and species of plants to use.

NSTAR

The use of mechanical and chemical controls in vegetation management of right of way corridors along transmission and sub-transmission lines can be an environmentally damaging and costly process. NSTAR recognizes the importance of the Massachusetts Endangered Species Act, ROW wetlands impact studies, and the Rights of Way Management Regulations set forth in 333 CMR 11.00. In so-called "Sensitive Areas," NSTAR tailors its use of mechanical controls and herbicides to have minimal impact on the health of the environment and safety of the local area residents. NSTAR only uses Sensitive Area approved herbicides for its integrated vegetation management (IVM) program. To help ensure the protection of endangered wildlife, NSTAR uses GIS data to identify Priority Habitats and Sensitive Areas and trains its crews and contractors in the use of GPS equipment and GIS systems so that they are able to recognize these areas in the field. NSTAR also uses the GIS data to identify public water supplies and private wells.

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[4] "Five Year Vegetation Management Plan 2014-2018." Prepared by National Grid; http://www.nationalgridus.com/non_html/National%20Grid%20VMP%202014%20-%202018.pdf

Sacramento Municipal Utility District

Known as the "City of Trees," Sacramento Municipal Utility District (SMUD) services nearly a quarter million trees across a services territory of 900 square miles. Rigorous adherence to guidelines and tree pruning practices set forth by the American National Standards Institute (ANSI), International Society of Arboriculture (ISA), and the National Arbor Day Foundation has earned SMUD the Tree Line USA award for its vegetation management practices by the National Arbor Day Foundation each year since 2001. While their standard inspection schedule requires each tree be inspected once every three years, for fast growing trees, inspectors make it a point to return every year and a half. To ensure a knowledgeable workforce, all SMUD employees are required to complete a certified course of study to become a member of the ISA. In addition, all SMUD arborists are members of both the ISA and the Utility Arborist Association.

Baltimore Gas and Electric Company

Baltimore Gas and Electric Company (BGE) developed a "Less Than 200kV Vegetation Management Program", which was effective in May, 2012. This plan includes a variety of practices to manage vegetation adjacent to its electric facilities, including: inspections, tree pruning, tree removal, mowing, and herbicide or other cultural control practices." [5] Inspections for BGE target the vegetation on and in proximity to the utility easement or free-owned land, tree pruning and removal, mowing, herbicide application and interim tree work. Tree pruning and removal is performed based upon various operational and environmental characteristics of the ROW. BGE operates a practice to leave as much of the remaining tree crown as possible to help maintain the health of the tree. If a large amount is recommended to be removed, the entire tree may be removed instead. Machine mowing is a maintenance practice used to maintain woody vegetation and other unwanted vegetation along the electric facility's rights-of-way and is usually performed on an annual basis. As an alternative, BGE may hand-cut and/or apply herbicides to control growth of all brush, grasses, vines and other unwanted vegetation. Cultural control practices involve management of vegetation through the establishment of compatible stable plant communities or the use of crops, pastures, mulching, or other managed landscapes. Finally, debris removal of all wood pieces less than eight inches in diameter and brush are typically chipped, lopped, or disposed of, unless requested or approved by the property owner or occupant. [6]

BGEs plan does not address the program or method it uses to maintain its record keeping or technology specifically utilized to accomplish and meet the objectives of the vegetation management plan.

However, the plan emphasizes the importance of communication and notification with implementing its program. BGE stresses the reason for this is a result of the vegetation management program having "a direct impact on property owners." [7] Therefore, BGE recommends timely and sufficient communication with property owners is a necessary commitment to maintain a positive relationship. To accomplish this, BGE has established processes and procedures to communicate vegetation related activities to the necessary parties

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[5] BGE, "Less Than 200kV Vegetation Management Program", May 28, 2012.

[6] BGE, "Priority Trimming to Improve Reliability", http://www.ecosync.com/tdworld/PRIOTRIM03.pdf.

[7] BGE, "Priority Trimming to Improve Reliability", http://www.ecosync.com/tdworld/PRIOTRIM03.pdf.

and also created outreach programs to educate its customers.[8] BGE addresses communication and notification objectives by focusing on providing notification to property owners and to the local county and local municipality, as well as providing outreach programs, such as an annual public education program and its company website.[9]

Cumberland Electric Membership Cooperative

Cumberland Electric Membership Cooperative utilizes laptops in the field. Cumberland's lineman and crew no longer rely on map books that are usually stored in their trucks. The company now provides their lineman with a vehicle mounted convertible-tablet, the Panasonic Toughbook 19, which is a 'ruggedized computer' that is able to withstand a 6-foot drop, includes a spill proof keyboard and can handle 220 pounds of pressure.[10]

The company also installed new mapping software from *PartnerSoft* to improve its vegetation management program. Previously, the company relied upon the linemen's experience to know the utility system, however, the company now relies upon the GIS mapping system that the company converted to after performing a system wide inventory of service territory. [11] The tablets installed in the vehicles allow the linemen to use the map viewer to: trace out a circuit and easily identify the number of customers affected by an outage; look at the lines, parcels and electric model of the utility's system and also study the distribution from the meter to the substation; access the time sheet program; connect to Wi-Fi within their truck bays.[12]

Great River Energy

A critical component of Great River Energy's (GRE) mission is managing the vegetation along its rights-of way. GRE uses regular aerial patrols to manage its vegetation and other rights-of-way issues. By implementing its aerial patrol program, GRE has reduced the risk of vegetation contacts on bulk electric transmission facilities and also on the lower-voltage sub-transmission load-serving system that directly serves its customers.[13] For instance, aerial patrols of transmission and lines rated 115 kV and above are performed on a monthly basis and on transmission and sub-transmission lines that are rated 69 kV and below are patrolled on a bi-monthly basis.[14] Essentially, the aerial patrols identify vegetation concerns and locate/identify any transmission / sub-transmission hardware issues and various ROW infringements.[15] As a result of using aerial patrols, the company has prevented outages from occurring which allowed GRE to manage its assets pro-actively and in a timely manner.[16]

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[8] BGE, "Priority Trimming to Improve Reliability", http://www.ecosync.com/tdworld/PRIOTRIM03.pdf.

[9] BGE, "Priority Trimming to Improve Reliability", http://www.ecosync.com/tdworld/PRIOTRIM03.pdf.

[10] DataSource Mobility, "NIPSCO Streamlines Vegetation Management". http://datasourcemobility.com/photos/psc-tb-tdworldcoverage-3-1-11.pdf.

[11] DataSource Mobility, "NIPSCO Streamlines Vegetation Management". http://datasourcemobility.com/photos/psc-tb-tdworldcoverage-3-1-11.pdf.

[12] DataSource Mobility, "NIPSCO Streamlines Vegetation Management". http://datasourcemobility.com/photos/psc-tb-tdworldcoverage-3-1-11.pdf.

[13] Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine,* June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.

[14] Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine,* June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.

[15] Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine,* June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.

[16] Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine,* June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.

GRE also uses digital photographs, taken by the pilots during the aerial patrols, to assist in vegetation management. During the patrol, the pilots bring a digital camera along and take photographs that will provide field operation staff a bird's eye view of any equipment damage, ROW infringement and/or vegetation issues that pilot deems serious in nature.[17] Then the information from the patrols is entered into the company's central database on a weekly basis. GRE follows a process that promotes ownership. Structural issues are sent to area line personnel and ROW infringement issues are sent to the company's Land Rights department.

Additionally, each fall GRE has one-third of its corridor photographed.[18] The color photographs provide a more complete picture of the ROW corridors, including overall vegetation growth rates.[19] GRE uses the information from color surveys, as well as historical outage information, to prioritize and schedule corridors for ROW maintenance in the upcoming year.[20] The purpose of the survey is to assist in locating danger trees within the ROW corridor that may be hazardous during a storm. The survey also assists in defining access points for system restoration switching.

Overall, GRE finds that implementing this survey has produced positive results.[21] Using a survey as a practice to manage the vegetation, GRE indicates that this method saves time in vegetation and transmission line corridor surveying, provides early detection of potential ROW issues, and also allows the company to allocate available resources effectively.

Sumter Electric Cooperative

Sumter Electric Cooperative (SECO) uses a variety of vegetation management practices to continually improve its vegetation management program and customer satisfaction. For instance, the company utilizes line clearance contractors on unit-based pricing, paying the contractors only for work performed.[22] SECO pays the contractors based on set prices for the type of work performed such as side trims, overhang trims and 4-inch to 10-inch removals. Any work performed on emergency projects and/or reactive pruning is performed by separate crews paid on an hourly basis.[23]

To manage the pruning cycles, SECO provides notification to its customers. In terms of pruning and determining the correct pruning method, SECO uses a laser focus on selecting trees for removal with the scope of the vegetation management program's objectives.[24] A tree replacement program is also included in the program. By actively pursuing the practice of tree removal, SECO is making progress in long-term cost reduction and enhanced reliability.

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[17] Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine*, June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.

[18] Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine*, June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.

[19] Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine*, June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.

[20] Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine*, June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.

[21] Dick Pursley and Byron Johnson, Great River Energy, "Monthly Aerial Patrols Promote Reliability", *T&D World Magazine*, June 1, 2007, http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability.

[22] Ken Lacasse, Sumter Electric Cooperative Inc., "SECO Clears the Way", *T&D World Magazine, September 1, 2012,* http://tdworld.com/vegetation-management/seco-clears-way.

[23] Ken Lacasse, Sumter Electric Cooperative Inc., "SECO Clears the Way", *T&D World Magazine, September 1, 2012,* http://tdworld.com/vegetation-management/seco-clears-way.

[24] Ken Lacasse, Sumter Electric Cooperative Inc., "SECO Clears the Way", *T&D World Magazine, September 1, 2012,* http://tdworld.com/vegetation-management/seco-clears-way.

Also, each planner and manager representing SECO in the field is a certified arborist. The company has aggressively been involved with tree removals that are voluntary. By using certified arborists in the field, the arborist is able to speak with customers about their concerns and also inform them about proper pruning methods, articulate the importance of tree removal and the trees' potential impact on electric reliability.[25] Using the certified arborists in the field, SECOs position is that this has improved customer satisfaction. Customers are able to speak one-one-one with the professionals, which SECO believes has influenced customers becoming more involved in the overall process and permitting trees to be removed.[26]

As part of the vegetation program, fully integrated herbicide program was implemented that is monitored by undergoing a post-application auditing process. This program also includes clearing 100% of brush and low-growing vegetation, as well as removing trees and other vegetation near switching and fusing points that might delay access during any storm restoration process.[27]

For the removal of hazard trees, SECO identifies trim-related and non-trim outages, outages caused by trees within the easement zone compared to outages caused by trees outside of the easement zone. Hazard trees are identified during routine work planning and then scheduled to be removed within 30 calendar days after being issued.[28]

SECO also addresses emergency weather situations. As soon as the first warning of major weather event is received, the company gathers the equipment and notifies the on-site crews. In preparation for the weather, SECO handles the logistics including food and staging locations for the crews. The storm crews set up in pre-established command centers and SECO possess the ability to use algorithms to help predict the extent of damage across the system after the storm has passed.[29]

Nashville Electric Service

During the fall of 2000, Nashville Electric Service (NES) had tree-related outages 10 times that of other utility companies that implemented vegetation management best practices. NES' system statistics showed that tree-related outages were 19% to 21% of the total outages.

At the time NES noticed the problem with its vegetation management program, its system had rear-lot lines that were grown up, tree line contact on both the distribution and transmission systems that was higher than best-practice utility standards, the brush component of the workload was higher than best-practices, and the crew productivity was below standard.

The statistics and vegetation problems motivated NES to move forward in developing a vegetation management program in order to improve its customer service reliability and also provide practices that would allow NES to maintain that reliability. NES began this process by

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[25] Ken Lacasse, Sumter Electric Cooperative Inc., "SECO Clears the Way", *T&D World Magazine, September 1, 2012,* http://tdworld.com/vegetation-management/seco-clears-way.

[26] Ken Lacasse, Sumter Electric Cooperative Inc., "SECO Clears the Way", *T&D World Magazine, September 1, 2012,* http://tdworld.com/vegetation-management/seco-clears-way.

[27] Ken Lacasse, Sumter Electric Cooperative Inc., "SECO Clears the Way", *T&D World Magazine, September 1, 2012,* http://tdworld.com/vegetation-management/seco-clears-way.

[28] Ken Lacasse, Sumter Electric Cooperative Inc., "SECO Clears the Way", *T&D World Magazine, September 1, 2012,* http://tdworld.com/vegetation-management/seco-clears-way.

[29] Ken Lacasse, Sumter Electric Cooperative Inc., "SECO Clears the Way", *T&D World Magazine, September 1, 2012,* http://tdworld.com/vegetation-management/seco-clears-way.

evaluating the current conditions of its system, identified and determined the desired results of the program and then developed a timetable to accomplish this. In developing benchmarks and performance audit criteria, the company used GIS technologies, including a geo-database viewing application, aerial photos and ESRI's Arc 3GIS during the planning stages and used laptops in the field to further the program plan as the work moved forward.

The article published in *T&D World Magazine* highlighted some of the practices NES specifically focused on while developing this program. One of the practices NES focused on was communicating the plan with government officials and customers to educate them on why a more aggressive program involving tree-trimming was needed. The company also focused on its tree-trimming contracts. After determining that the productivity that was needed was not being accomplished using T&M contracts, NES preferred to use contracts with lump-sum trim with unit removal terms and drastically cut the number of T&M crews. In addition, NES implemented the program on a three-year trim cycle by concentrating on brush less than 4 inches in diameter, removing trees with a 5-inch diameter or greater, 20 feet (6cm) from the inside phase and average sized trees that averaged 85%, 12 inch (305mm) and smaller.[30]

Ten years later, NES had not only examined the factors contributed to such tree-related outages and developed a new vegetation management program, but had successfully implemented a vegetation management program for its electrical system. NES' tree-related outages dropped to 6%, with 3.5% of those outages caused by branch and tree failures.[31] After revamping its vegetation management program over the last three trim cycles, NES' current budget has been reduced 48%, retuning to that of the budget level when the project began. In the end, NES successfully accomplished its objective of implementing a vegetation management program that is reliable and changed its system to performing at a best-practice utility level.[32]

San Diego Gas and Electric

SDG&E's Vegetation Management (VM) program is responsible for the inspection and maintenance of approximately 400,000 trees that have the potential of growing or falling within the specified clearance area. This program defines two types of work; 1) routine work and 2) field memos and hazard tree work. To ensure the completion of these works according to the defined scope of work, SDG&E has a quality program that verifies the completion and certification of each work[33].

With regard to the inspection and management of hazard trees, SDG&E is developing additional training programs that are aimed at enhancing the skills of staff and contractors in identifying and managing hazard trees. In 2003, SDG&E implemented a three-phase approach to pole brushing that effectively manages poles prone to summer rains or leaf casting from surrounding

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[30] Glenn Springer, Nashville Electric Service, "Trimming Your Way to a More Reliable Future, *T&D World Magazine*, May 1, 2012, http://tdworld.com/smart-energy-consumer/trimming-your-way-more-reliable-future.

[31] Glenn Springer, Nashville Electric Service, "Trimming Your Way to a More Reliable Future, *T&D World Magazine*, May 1, 2012, http://tdworld.com/smart-energy-consumer/trimming-your-way-more-reliable-future.

[32] Glenn Springer, Nashville Electric Service, "Trimming Your Way to a More Reliable Future, *T&D World Magazine*, May 1, 2012, http://tdworld.com/smart-energy-consumer/trimming-your-way-more-reliable-future.

[33] "Prepared Direct Testimony of Scott P. Furgerson of Behalf of San Diego Gas & Electric Company: Exhibit No. SDG&E-05." Prepared by Scott P. Furgerson; https://www.sdge.com/sites/default/files/regulatory/Exhibit%20SDG&E-05R%20S_Furgerson_SDGE-R_Elec_Dist_O&M_Testimony.pdf

trees. This approach includes; chemical pole brushing using EPA approved herbicides, mechanical pole brushing and re-clear pole brushing which involves the removal of additional vegetation that has grown into the clearance area since the last maintenance. In addition, SDG&E is working towards implementing a second re-clear pole brushing cycle rather than a single cycle to maintain compliance with PRC 4292 and reduce fire risk.

Due to the increase in customer requests to remove all wood generated from pruning, SDG&E has been actively looking for alternative wood disposal methods due to high costs and resource requirements associated with the increased need to trim hazard trees. These alternative methods include composting, co-generation, and erosion control.

PEPCO

Pepco's Reliability Plan[34] outlines a six-point strategy including enhanced vegetation management in their Enhanced Integrated Vegetation Management (EIVM) Program, the largest of their preventative maintenance programs. In addition to a routine cyclical program of proactive trimming, this VM plan includes the following elements:

- Monitoring customer acceptance and cost effectiveness.
- More aggressive hazard tree and dead tree removal, ground-to-sky trimming and herbicide application, spending $3-5,000 per mile more than in past years.
- Inspecting all overhead feeder sections at least once every two years targeting areas of the electric system found to be most susceptible to damage from trees during storms. Based on this a prioritizing circuits to create a pre-scheduled plan, created on the basis of a prioritization based on the number of outages and reliability statistics of the circuit.
- Form public and private partnerships including a Pepco education campaign and coordination with local governments to ensure support.

Puget Sound Highlight

Serving over 1.2 million customers, Puget Sound Energy's rights of way and vegetation management activities are often in environmentally sensitive areas. To avoid impacting the wildlife and the surrounding ecological system, PSE implemented a Quality Vegetation Management (QVM) program that minimizes mowing through the use of selective herbicides that have minimal impact on the ecosystem. PSE personnel apply the herbicides via backpacks and eliminate the massive machinery that can affect the surrounding vegetation. Through the reduction of mowing, PSE has seen its vegetation management cost drop approximately $700 per mile.

Consolidated Edison of New York

In responses to a management audit conducted of Con Ed[35], the filing provides an update to the implementation of recommendations from the management audit. In particular, on page 146 of the document, ***Recommendation #33: Strengthen the distribution vegetation management***

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[34] "Potomac Electric Power Company Comprehensive Reliability Plan for District of Columbia Including Distribution System Overview, Reliability Initiatives and Response to Public Service Commission of the District of Columbia Order No. 15568." Prepared by PEPCO; http://www.pepco.com/_res/documents/dccomprehensivereliabilityplan.pdf

[35] "Audit Implementation Plan: Annual Report and Update." Prepared by Consolidated Edison Company of New York, Inc. Case 08-M-0152; http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7BF57D835F-2A9E-4C30-AFFD-F89DCD02D7FF%7D

inspection program with accountability, Con Ed describes their implemented Quality Assurance ("QA") program for all Electric Operations regions that was designed to ". . . . improve accountability in the line clearance function and ensure compliance with the current line clearance specification." This new QA program was outside the typical utility vegetation management programs. This additional process that is outside the normal vegetation management process provides a "second set of eyes" in the vegetation management area and has improved the reliability for Con Ed.

Xcel Energy

Vegetation Outage Assessment, Data Collection, and Reporting Programs - Documenting Vegetation Outages

The availability of accurate and detailed data with regard to tree-related outages, is highly dependent on the utility's outage reporting practices. While some utilities collect no data for the causes of outages, others enforce strict data collection and reporting practices in an attempt to improve vegetation management programs. An example of a utility that does that is Xcel Energy, which uses a detailed data collection process that includes high level data collection, individual outage inspection by vegetation experts, and subsequent data analysis that focuses on vegetation management activity.

Technology Utilization

Many utility companies are investing in technology to improve their vegetation management programs. For instance, utilities use technology to further objectives of managing vegetation by investing in tailor-made software programs/packages. The features included in the software appear to depend upon a utility's specific goals and methods of its vegetation management program. Utility companies have also started focusing on making field crews more comfortable with technology as well. Specific examples of utilities use of new forms of technology are described below.

Northern Indiana Public Service Company

Northern Indiana Public Service Company (NIPSCO) contracted with ArborMetrics Solutions to incorporate new vegetation management software into its vegetation management program. ArborMetrics software allowed NIPSCO to use its existing GIS data to digitally capture and overlay vegetation management data.[36] For example, the new software provides easy access to landowner's information, the ability to gather data on work specification and keep updated on the scope of projects, as well as capture customers' signatures digitally with the same ease as signing for a package delivery. The company also had printers mounted in the vehicles, so a document can be printed out in the field.

During the time NIPSCO incorporated its new software, the company also arranged for convertible laptops, the Panasonic ToughBook CF-19, to be installed in each of the arborist's vehicles. The laptops are used in the field to perform inspections, collect data and obtain permissions. After utilizing these laptops in the field, the company recognized that the new system eliminated some hassles relating to handwritten records that were difficult to read and the

[36] DataSource Mobility, "NIPSCO Streamlines Vegetation Management". http://datasourcemobility.com/photos/psc-tb-tdworldcoverage-3-1-11.pdf.

alleviated the problem of using a variety of terms to describe field work and tasks, which varied amongst the different field crews. Since each crew used their own terms to categorize and describe the work and tasks performed, the new laptops and software provided drop-down menus with specific descriptions which ensures that all of the crews and their records use the same language.[37]

Northpower, New Zealand Ground Fault Neutralizer and Tree Contact

Northpower, a New Zealand line company sponsored a project which follows the British grounding model of solid-grounding. In March 2010 Northpower commissioned a Ground Fault Neutralizer (GFN) in one of its substations as a pilot, in order to evaluate the deployment and benefits of this technology. The substation was chosen due to its presence of relatively long feeder and its location in rural areas where there is dense vegetation, causing faults frequently compared to other zone substations.

In Northpower, single phase to ground faults are the dominant type of fault on its electrical network, especially because of the tree density and resulting contacts. Therefore it is of utmost importance that these faults are handled in a satisfactory way. By injecting an anti-phase current into the neutral, the GFN effectively cancels out the fault current. This interception is exceptionally fast and has no impact on the conveyance of payload over the faulty feeder. Thus, ground faults can be handled without customer outage and thus the safety of the system is also improved.

As injury statistics clearly indicate, speed is the most essential aspect of protection. With a total response time of less than 60ms (three cycles) the GFN is substantially faster than traditional protection schemes, independent of the actual fault location. Instead of tripping the faulty feeder the GFN brings the fault current down to practically zero making it possible to maintain safe operation without disturbing power supply to customers. This unique feature can be guaranteed both during transient and sustained earth faults. Installed in the substation and connected to the transformer neutral, the GFN protects the entire network from one point.

Connecticut Light and Power

As a result of the extensive damage and work necessary to manage Superstorm Sandy, Connecticut Light and Power (CL&P) is currently launching a damage assessment tool that will make the process of surveying damage to the electric system following a storm more efficient, and provide real-time information about the materials and resources needed to make repairs. The tool was developed by CL&P and Clearion Software, LLC, a Georgia-based developer specializing in GPS-enabled technologies for utility vegetation[38]. It combines CL&P's

Geographic Information System (GIS) mapping data with information about the distribution system and GPS street location data.

Traditionally, damage assessment (DA) personnel took notes regarding damage and provided that information back to the planners in the office who would aggregate the information in an effort to understand the scope of the damage and prepare work packages with the necessary

[37] DataSource Mobility, "NIPSCO Streamlines Vegetation Management". http://datasourcemobility.com/photos/psc-tb-tdworldcoverage-3-1-11.pdf.

[38] T&D World Magazine, "CL&P Implementing New Technology to Improve Storm Response"

material and resources identified. With the new system, DA personnel utilize laptops that automatically display detailed information about the electrical equipment on the street, based on GPS locations. Thus, now when the DA personnel encounter damage, they click on the screen and indicate the specific problem – such as a broken pole, downed wires or a damaged transformer – and the system sends the information back to the office instantly. If the patrol team is in an area with no cellular service, the system stores the information and automatically uploads it when service is available again.

This technology drastically reduces the amount of time it takes to transmit information about damage and required repairs from the field to the planning and logistics teams in the office. Those teams can better plan the work and deploy crews more efficiently with the exact materials needed, and better estimates can be provided regarding the length of time to complete repairs.

Unitil

Unitil implemented GeoDigital Solutions' for the planning, reporting and analyzing vegetation maintenance. Unitil chose the package that included one of the mobile applications for its assessors and crews.[39] In determining the best software, Unitil focused on specific criteria that the software must address including the ability to: track and report on work based on feeder metrics, historic data, forecasts, work plans, unscheduled work and crew productivity; plan and forecast cycle work; store data in a database in a geographic format; provide quality assurance/quality control for the work and provide performance indicators; create work packets; and record and track customer restrictions.[40]

LiDAR

According to an article in *Electric Light & Power*, LiDAR, light detection and ranging, is used by many utilities in order to remain in compliance with FAC-003-1.[41] The article further stated that, 'lidar uses laser beams usually from a helicopter to measure distances accurately from wires to potential obstructions-primarily trees' and 'then creates a map that displays the relative heights and positions of towers, power lines and trees'.[42]

In 2010, LiDARs technology was improved and provided new applications for utilities to use for asset and risk management in connection with power line maintenance and applicable regulations.[43] In light of the numerous miles of transmission and sub-transmission lines, *T& D World Magazine* reports that, "LiDAR-based technology offers a more-standardized approach to

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39 T&D World Magazine, "Unitil to Boost Reliability with Mobile Vegetation Management Software", July 1, 2012. http://m.tdworld.com/smart-grid/unitil-boost-reliability-mobile-vegetation-management-software

40 T&D World Magazine, "Unitil to Boost Reliability with Mobile Vegetation Management Software", July 1, 2012. http://m.tdworld.com/smart-grid/unitil-boost-reliability-mobile-vegetation-management-software

41 William Atkinson, "Vegetation Management Takes to the Airwaves", *Electric Power & Light Magazine*, http://www.elp.com/articles/powergrid_international/print/volume-17/issue-5/features/vegetation-management-takes-to-the-airwaves.html

42 William Atkinson, "Vegetation Management Takes to the Airwaves", *Electric Power & Light Magazine*, http://www.elp.com/articles/powergrid_international/print/volume-17/issue-5/features/vegetation-management-takes-to-the-airwaves.html.

43 Gene Wolf, "LIDAR: Illuminating Hazardous Vegetation", *T&D World Magazine, February 1, 2010,* http://tdworld.com/overhead-distribution/lidar-illuminating-hazardous-vegetation.

manage vegetation in the utility's rights-of-way and improve[s] the maintenance cycle to identify hazardous vegetation before it causes problems for the grid."[44]

LiDAR technology is also used to record a transmission line's geometry and its placement in the ROW. The 3-D models from LiDAR technology provides 3-D imaging that shows trees and brush with vegetation encroachments, such as blow-in or grow-in violations.[45]

While initially designed to deal with the rigors associated with transmission vegetation maintenance, various discussions have been had amongst utility personnel regarding the use in sub-transmission and distribution applications.

Micro-weather Forecasting – IBM and Consolidated Edison of New York

As part of an effort to understand how weather was discretely impacting its overhead system, Con Edison in 2006 began working with IBM to develop a micro-weather prediction system, Deep Thunder, which provided visibility down to 1 square kilometer. While ultimately designed to provide better weather predictions at a local level, an unanticipated benefit was the identification of corridors that routinely were predicted to have extreme wind conditions. This information helped identify potential damage locations during severe events and opportunities to provide additional vegetation management focus.

GIS Databases

Utility vegetation management programs often include procedures in which vegetation management crews notify residents in order to clear the lines of overgrowth as needed.[46] As a result, many utilities utilize GIS databases for various things, including plotting surveys, sending out notifications and scheduling field crews' work.[47] Utilities may use mobile GIS equipment to accomplish this as, "all-in-one mobile GIS devices provide a unique, cost-saving alternative to traditional vegetation survey mapping".[48]

According to *T&D World Magazine*, *"[u]*sing a simple point-and-shoot procedure [that is] already being used to measure utility pole attachments, a vegetation management crew can quickly locate, measure and document sites where trees and other vegetation need to be trimmed".[49] Using GIS technology, data is able to be transferred digitally to a GIS mapping system, together with other details such as, photo documentation, addresses, descriptions and

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[44] Gene Wolf, "LIDAR: Illuminating Hazardous Vegetation", *T&D World Magazine, February 1, 2010*, http://tdworld.com/overhead-distribution/lidar-illuminating-hazardous-vegetation.

[45] Gene Wolf, "LIDAR: Illuminating Hazardous Vegetation", *T&D World Magazine, February 1, 2010*, http://tdworld.com/overhead-distribution/lidar-illuminating-hazardous-vegetation.

[46] *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011*, http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management.

[47] *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011*, http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management.

[48] *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011*, http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management.

[49] *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011*, http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management.

classifications.[50] Ultimately, this will assist a utility with further processing and scheduling equipment.[51]

Mobile GIS/GPS Systems

Utilities also use mobile GIS/GPS systems, such as companies like ikeGPS mobile GIS systems, which provides hardware and software technology, to assist with utility operations. For instance, ikeGPS mobile GIS systems, provides utilities with the means for a one-man crew to be able to record not only specific site locations, data and photo documentation, but also create measurements from photographs.[52] This company provides utilities with the option to have an onboard vegetation management application that allows the operator to record a high resolution photograph, de-skew to create a TrueSize image, and also to make direct measurements of wire clearance and tree dimensions.[53] Using this type of technology allows utilities to document any violations of vegetation ordinances in a quick and simple manner, while also saving considerable time and expense in data acquisition and post-processing.

Tree Growth Regulators (Herbicides)

City of Glendora, California

The issue of tree canopy pruning is raised as a risk to infrastructure as a result of improper pruning. Regardless of the care taken, trees that have a canopy that if improperly pruned can result in failure. Tree growth retardants reduce the need for constant pruning and consequently reduce the risks and costs associated with pruning. In one example, the author illustrates a 200% improvement in required pruning moving from a twice a year trim cycle requires to a once every 2 years trim cycle. Using tree growth regulators has improved the city of Glendora, CA to manage trees in historically difficult areas, such as parking lots, and road medians[54].

Additionally, by managing tree growth on golf courses the city has reduced the spread of fungus pathogens on the course that would results from excess shade or wind movement associated with the unmanaged trees.

A second order effect of tree growth regulators is the deeper colors of the foliage. The tree growth regulator inhibits the growth of the leaves, but does not inhibit the chloroplast, or green pigment, in the leaf cells. Basically, while the leaves may be smaller, they still provide canopy coverage and the environmental benefits of trees.

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[50] *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011*, http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management.

[51] *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011*, http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management.

[52] *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011*, http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management.

[53] *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011*, http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management.

[53] *T&D World Magazine, "Utilities Using Mobile GIS for Vegetation Management", July 12, 2011*, http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management

[54] Landscape Contractor National, "Cut Costs With Tree Growth Regulators" Mike Ventura, Landscape Maintenance Supervisor, City of Glendora, June 2009

Land Grant University - Purdue University research paper [55]

Dr. William Chaney provides insight into the tree growth regulators and the benefits of them. As a possible solution to reduce the costly and laborious method for mechanical trimming, utility arborists as far back as 1950 were looking for chemical methods to control tree growth. Solutions in the 1970's and 1908's had unintended and unacceptable consequences, so tree growth retardants use and preference declined. However, research continued and today paclobutrazol, formulated as Cambistat 2SC or Profile 2SC, is the preferred tree growth inhibitor. Paclobutrazol blocks gibberellin hormone production which is responsible for stimulating cell elongation. The result is the same number of leaves and connectors in a shorter length. This produces benefits that may have not been intended, but do add value to its application. The benefits include increased chlorophyll component phytol which is beneficial to tree growth and health. The average growth reduction using paclobutrazol is between 40 to 60%. Additionally, the leaves are greener and the leaves have a reduced water loss which enables them to do better in drought conditions. Finally, paclobutrazol also provides improved protection of trees from fungal attacks.

British Columbia Hydro

The British Columbia Hydro (BC Hydro) vegetation management program strives to use leading edge techniques and practices, minimize impact to the environment, and protect biodiversity[56].

To these ends, BC Hydro uses a very selective and focused application of low-toxicity herbicides away from recognized pesticide-free zones. BC Hydro also controls noxious or invasive plant species as part of the corporate commitment to the Provincial Invasive Plant Strategy, and to meet the requirements of regional weed control committees and the Weed Control Act (though BC Hydro is not subject to the Weed Control Act). BC Hydro supports research into new control methods, such as the use of insects for biological control.

In one of their more proactive technological practices, BC Hydro established a biophysical inventory project to collect, record, analyze, and monitor the current state of the ROW vegetation. All data collected is entered into a GIS database that allows aerial or ground patrols to monitor vegetation inventory and evaluate the efficacy of treatments. After vegetation management work has been completed at a site, BC Hydro collects qualitative and quantitative data to evaluate the effectiveness of the vegetation management program and measure the results against the site objectives.

Noteworthy Efforts

Connecticut proceeding 11-09-09

In Connecticut docket 11-09-09, Mike Townsley and John Goodfellow testifying on behalf of the Office of Consumer Counsel highlight in their April 17th 2012 testimony that telecommunication operators, especially those with custodial pole ownership rights should contribute to the cost of

[55] *Purdue Extensions*, Purdue University "Growth Retardants: A Promising Tool for Managing Urban Trees", September 2005, https://www.extension.purdue.edu/extmedia/FNR/FNR-252-W.pdf

[56] "Integrated Vegetation Management Plan: For Transmission Rights-of-Way." Prepared by BC Hydro; https://www.bchydro.com/content/dam/hydro/medialib/internet/documents/safety/bctc_pdf/integrated_vegetation.pdf

reducing the risk of tree failure. They highlight, that to not do so establishes a subsidy to the telecommunications company by the electric ratepayer. Vegetation management activities undertaken by electric utilities today reduce the risk of tree failures, which in turn reduces the potential for damage to supporting structures, such as poles and telecommunications equipment itself. They assert and seek telecommunications customers to contribute to these costs.

Florida Municipal Electric Association Workshop Highlights

In April, 2006, the Florida Public Service Commission directed each investor-owned electric utility in Florida to establish a plan to increase research in electricity infrastructure hardening. In response to this mandate, the Florida Municipal Electric Association conducted a workshop to review and benchmark best practices in Florida utility line clearance and vegetation management and to identify the highest priority areas for improvement[57]. Over 30 agencies participated.

To coordinate this effort, the attendees were divided into seven groups, focusing on overall trimming strategies, trimming around distribution facilities, proactive strategies for hazardous trees and damage reduction, strategies for working with the public and government, strategies for working with the public, operations and management, and relations and operations management. While the results of the workshop were not a collection of best practices currently being performed by individual utilities, key areas that the workshop attendees considered to be the most vital for future improvement were: coordination between utilities and government, communication with the public, adequate and consistent financial resources for vegetation management programs, better training and retention of crews, and a need for better storm preparation and restoration logistics.

Action Plans to deal with insect infestations creating high mortality rates

Several utilities throughout the nation are dealing with high mortality rates of certain species of trees due to disease and infestation of certain insects. Accordingly, utilities including Arizona Public Service and National Grid have developed processes working with other government agencies to address the debris created as a result of the vegetation management. The concern is the uncontrolled spread of the disease which is devastating hundreds of miles of utility right-of-way locations.

[57] "Report on the Workshop for Best Practices in Vegetation Management." Prepared by Florida's Electric Utilities, Florida Municipal Electric Association, and Public Utility Research Center – University of Florida; http://www.floridapsc.com/utilities/electricgas/EIProject/docs/VegetationManagementWorkshopReport.pdf

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HIGHLIGHTS OF PARTICIPATING UTILITY INTERVIEWS ON VEGETATION MANAGEMENT PRACTICES

One objective of the Distribution Grid Resilience (DGR) initiative is to develop a set of metrics that surrounds each DGR task's contribution to system resilience and provide that information to participating utilities. To that end, utility practices, industry norms and industry standards must be reviewed. In previous sections of this document, information concerning standards and industry requirements is provided. The Standards and Guidelines for Vegetation Management (Section 3), provides a detailed review of the new ANSI Standard and new ISA Guideline for managing vegetation; and the implementation of these references, along with application of asset management techniques to vegetation management strategies are beginning to emerge as leading practices within the industry. In the initial phase of identifying leading VM practices that impact distribution grid resiliency (and valid at aspects of the companion literature search), a survey was developed and the analysis was documented in the EPRI document "Summary of 2013 Vegetation Management Practices Survey." Following reviewing the survey results, it was clear that a more in depth assessment of leading VM practices was needed. To facilitate this assessment, EPRI collaborated with the participating utilities (via the Task 2 Task Force) to develop an interview guide (Appendix A) to identify VM activities, attributes, and processes being implemented (or considered) to mitigate distribution system damage caused by vegetation during major storm events; as well as to understand the metrics used to determine the value vegetation management provides for a utility. This section provides insights from these interviews.

The interviews focused on nine key areas related to VM practices:

1. Organization
2. Roles and Responsibilities
3. Program Budget
4. Program Scope
5. Line Clearance Specifications
6. Metrics and Tree Damage Data
7. Program Management
8. Contractor & Contract Management
9. Use of Technology.

While arguably the vast majority of a VM program contributes to grid resiliency, the practices identified during the survey and interviews were focused on changes that have been made by participants to address improving the resilience of the distribution system during extreme events. One of the general themes that resonated throughout the investigation is that programs were migrating toward a more risk-based approach as envisioned by the ANSI/ISA standards, especially from the perspective of optimizing the utilization of resources to address the most critical infrastructure.

Vegetation Management Interviews Metrics Summary:

Through the interview process, the value of VM programs to participating utilities was justified by a consistent set of predominantly reliability-driven metrics. The table below summarizes the metrics identified during the interview process.

Table 2
Metrics Used to Justify Vegetation Management Investment

VM Resilience Investment Justification Metrics
Tree SAIFI
Tree SAIDI
Tree CAIDI
Number of Customers Affected
Type of Customers Affected
Customers Experiencing Multiple Outages
$/Customer Interruption
Likelihood and Consequence of VM Outage
Critical Infrastructure Feeder Priority
Trim Cycle
Cost

Vegetation Management Utilizing an Asset Management Approach:

Placing responsibility for VM strategy within an Asset Management organization seems to provide a more comprehensive and informed approach to developing a VM strategy. Currently, only 12% of participants place their VM responsibility within the asset management group.

This is not to say VM programs were not effective in those instances where the VM responsibility was not in an Asset Management organization; however it was apparent throughout the interviews that the strategies developed by Asset Management organizations were more thorough and based upon actual analysis, and linked to asset management and system performance goals and objectives, rather than simply optimizing traditional VM specific practices. One area this was readily apparent was the evaluations utility Asset Management organizations performed to assess the impact of the VM programs, which was focused on the value of VM investments as compared to other reliability efforts. For instance, neglecting the differences between capital and O&M investments as it relates to the utility's bottom line, hazard tree removal was identified as the best reliability dollar spent on a dollar / customer interrupted basis. Also, the Asset Management-centered VM programs generally relied upon specific metrics which were geared to determine the value of previous and on-going investment; specifically tree SAIFI, tree CAIDI and tree SAIDI. Of those companies using metrics, Tree SAIFI was the most commonly used.

Additionally, utilizing integrated asset management feeder-specific data which captured the underlying root causes informs the decision regarding where to invest in vegetation management. Those companies that tracked one or more of these indices were able to best describe the value of each of the aspects of their respective programs. Interestingly, tracking these indices and

associating the holistic decision making process with asset management objectives helps justify certain traditional VM programs. The actual data has provided additional information which has compelled companies to modify aspects of their program (e.g. determining the maintenance trimming cycle or the investment in Hazard Tree / Risk Tree programs).

A leading practice utilized by several companies (to differing degrees) involved identifying customers who were impacted by outages more frequently than the norm. For instance, one company noted a program which employed an approach that targeted customers who had experienced 4 or more outages, of which 2 or more were tree related. As a result of this program the same company was developing a tree CAIDI and analysis tools to identify the outlier customers who were experiencing significantly more outages than the system average. This information was being used to inform the utilization of tree patrol resources. Given that most customers do not tolerate frequent outages, targeted and cost-effective efforts that reduce the number of outages a customer experiences are generally good investments.

Hazard Tree / Risk Tree Programs:

The inclusion of Hazard Tree / Risk Tree programs is a leading practice as identified through the interviews. While this type of strategy is not new, the processes, analysis and rigor to develop the program has evolved; and there are notable practices that have been identified. There are several companies that are incorporating the guidelines set forth in ANSI 300 Part 9, relating to evaluating the risk associated with the identified hazard tree population. This naturally incorporates the *likelihood and impact* of the failure of the identified tree. To this end, there are leading practice efforts regarding determining the likelihood aspect which is incorporated in the overall risk analysis. Specifically, when determining the likelihood of an event, in what inevitably is an overwhelming population of "at risk" trees, companies are prioritizing areas and trees based upon the empirical strength of the species of tree and whether the tree is in a blighted or epidemic area. Similarly, there are leading practice efforts regarding determination of the impact of a failed hazard tree which is incorporated in the overall risk analysis. These proactive efforts include: hazard tree by hazard tree inspections where the number of potentially impacted customers is larger than 500 customers; prioritization of hazard tree investments based upon the prioritization of feeders, based upon the critical infrastructure and number and type of customer; the use of GIS handheld technology to rapidly determine the exact location and thus the potential system impact of identified hazard trees; and the use of sonic scans for off ROW trees to establish the health of the tree.

Another leading practice involving hazard trees is the collection of information regarding hazard tree locations. Knowing hazard tree locations, as well as customer information surrounding the hazard tree (e.g. number and types of customers) facilitated better vegetation management decisions. Additionally, the information allows a utility to develop customer relations strategies in dealing with hazard trees. Understanding the potential impact of hazard trees on the system, as well as knowing the customers in close proximity, provides an opportunity to communicate the reliability implications to the customers and collaboratively develop solutions for tree removal, such as possible replacement with a different species that more naturally coexists with utility infrastructure.

Although the removal of hazard trees (and other elements of the VM strategy) can be challenging to execute because of underlying customer concerns, notwithstanding some of the legal

requirements for specific jurisdictions, coordinating VM strategies with state, county and local municipal officials has proven to be an effective practice.

The removal of hazard trees is typically an expensive proposition. Approaches for mitigating cost include selling the wood that is being harvested, or utilizing loggers who remove the trees at their own cost in order to obtain the wood for milling. In some instances, utilities donate the harvest to businesses that may utilize the otherwise unused material, such as biomass energy facilities and zoos.

Obtaining property owner consent to remove hazard trees can pose a significant challenge for utilities. Some companies are aggressively pursuing legal remedies to encourage homeowner participation by notifying the homeowner of the tree, its risk and potential to interfere with the utility's easement. This is proving useful in encouraging homeowners to allow, without interference, the removal of hazard trees. Additionally, a notable practice which will likely produce significant resiliency results is identifying the trees that have the potential to continue to grow and become known as a "hazard" tree. These trees are being identified and removed during the cycle-based trim cycle. The philosophy of the program is to eliminate the tree before it can become a hazard tree. One company has increased its removal of these potential hazard trees from 2% in 2011 to 18% in 2013, with a goal of 30% for 2014.

Other Notable Initiatives:

In addition to the Hazard Tree / Risk Tree mitigation programs that are utilized by VM managers to improve distribution grid resiliency, there are other VM initiatives that have been identified through the survey including: reduced trim cycles; enhanced line clearance for circuit backbones; branch reduction strategies; proactive elimination of epidemic or insect prone species; and increased utilization of technology.

Reduced Trim Cycles

The use of reduced trim cycles is something that has always been considered in the industry. Finding the "right" trim cycle is not as easy as it seems because while vegetation growth is primarily determined by the growth zone that a service territory is in, it is highly dependent upon the actual weather that is experienced, especially the amount of rainfall. Several utilities have been working through the last five years to modify the trim cycle in an effort to improve storm resiliency. Furthermore, some utilities have introduced mid-cycle inspections as a resiliency initiative, to identify encroachment issues that left unaddressed until the next scheduled trimming, would adversely impact the system.

Clearance Specifications

Some utilities have been applying enhanced clearance for backbone infrastructure for many years. In the recent past, due to the increased frequency of storms, the clearance requirements for backbone have seemed to intensify. One utility indicated that it has recently modified the enhanced clearance specifications to provide ground-to-sky clearance from the substation to the first protective device on mainline construction. This is an aggressive initiative but has the effect of minimizing the likelihood of an event that will cause a breaker to lock out. Accordingly, this

type of approach provides resiliency benefits and helps optimize restoration by increasing the likelihood that the mainline distribution system will be available to restore laterals as they are repaired. Additionally, in some instances utilities are also intensifying the clearance specifications for laterals, which helps reduce the frequency of outages and shorten the restoration process.

During the interviews, it became apparent that utilities also vary trimming specifications based upon other characteristics of the system and relevant factors that implicitly include the risk associated with tree contact. Distinctions consider whether the feeder is urban or rural, and thus incorporates the density of customers served. Also, the types of customers served (including those categorized as "critical" customers) is considered, which involves evaluating the number of residential customers versus the commercial and industrial customers. This implicitly involves an evaluation of the criticality of the customer base served and naturally prioritizes critical infrastructure, which helps in maintaining some sense of "normalcy" for the community during significant weather events. Likewise, strategies are employed that recognize the type of construction being utilized (e.g., armless vs. crossarm) and the type of primary conductor (e.g., bare vs. covered).

Building upon understanding the risks associated with managing a VM strategy, a leading practice identified through the interviews is considering weather patterns for establishing mid-cycle "hot spot" programs. For example, it is import to recognize that excessive or abnormal rainfall may promote increased growth rates and necessitate mid-cycle trimming. Conversely, another example is responding to draught conditions where tree root balls contract, thereby reducing a tree's ability to sustain the same amount of strain with a normal size root ball without toppling, also helps identify susceptible areas that are prioritized for investigation.

Increased and aggressive clearances have traditionally been utilized by utilities, particularly in the wake of significant events. Recent leading practices have begun to focus on the physics associated with vegetation management specifically as it relates to entire trees toppling. The focus has been on opportunities to reduce the loading on the trees such that there is less strain or stress on the tree when there are ice / heavy snow events – effectively reducing the torque around the focal point or base of the tree. For instance, the interviews identified that there is the opportunity to reduce the strain on the entire tree by approximately 30% by increasing the elimination of branches by 50%. While this is not a remarkable insight, it has encouraged the removal of dead branches; and of healthy branches to reduce the strain on a tree that would not have been removed (because there was no risk of contact). The result is eliminating the removal of the tree, yet improving the resilience of the system through knowledgeable vegetation management. Additionally, the benefit in this instance is the reduced cost of not having to remove the tree while still reducing the risk of the tree failing. Because it is less obtrusive than the wholesale removal of trees, the public is likely to be more receptive to its continued and expanded use and ultimately increase the resiliency of the areas where it is applied.

Focused Training for Risk Based Asset Management - Vegetation Management

As the focus on grid resiliency has intensified over the last several years it has become apparent that there is a shift in the way utilities and other stakeholders are viewing vegetation. Indeed the recent ANSI / ISA publications have essentially incorporated traditional asset management

principles and philosophies into the development of VM guidelines, leading practices and strategies. Today, there is an expectation that the vegetation management programs being executed by utilities incorporate asset management principles – including the understanding of risk and its impact and likelihood of occurrence. As might be expected, the application of asset management principles to vegetation management is challenging because of the complexity introduced by millions of trees, tens of species and uncontrollable weather patterns. But, the development of asset management informed programs will improve the overall VM strategies.

As a result of evaluating opportunities to reduce the risk to the system as a grid resiliency improvement, companies are realizing the need for different skillsets, including ISA certified personnel who can identify and develop mitigation strategies for risk trees. As the industry transitions its VM programs to mimic asset management programs, the skillsets required to optimize tVM investments will also need to transition. The development and utilization of the recent ANSI / ISA standards is helping to facilitate this transition.

Elimination of Epidemic or Insect Prone Species:

Unfortunately, trees are susceptible to certain diseases which can cause premature death or cause inherent weakness. Similarly, insects and other parasites can also cause damage to trees. These susceptibilities create yet another challenge when attempting to manage a diverse population of trees. Accordingly, utilities have developed targeted strategies where there have been recent epidemics/insect intrusion which have adversely impacted certain species of trees. These proactive programs are designed to address the mass casualties that are caused and thus reduce the number of tree/limb failures experienced during storm events. In some instances, utilities have been able to convince regulators to approve a rare rider in order to fund these initiatives without adversely impacting the existing funding for routine vegetation management.

Utilization of Technology:

The use of advanced technology has improved the development and execution of VM programs. As a result of using advanced technology the overall effectiveness of the VM programs has increased, thereby improving grid resiliency. There are a number of uses of technology that have been identified as leading practices during the survey process, including the use of Geographic Information System technology, use of weather information to guide the VM program, and the utilization of smart phone and similar platform technology.

Geographic Information Systems (GIS):

Most companies are using GIS technology for various utility purposes, and most have established a VM-specific layer in their GIS platform enhance its ability to manage vegetation. There is an abundance of useful information that is being captured to help drive the development and execution of the VM programs. Information that is being captured in GIS systems include: the locations of poles, property owner information, information regarding risk analysis, trim dates, setback information, individual trees for removal, areas for mowing and herbicide application, property boundaries, archeological areas, tree species, customer issues, dead tree locations, vine locations, refusals for tree removals, actual tree removals and other relevant

structure information. As many noted through the interview process, there is virtually no limit to what information can be captured.

The GIS information can be coupled with the information being captured by OMS to permit engineers to evaluate system design as well as VM program opportunities.

In a similar regard one company has utilized pictometry in conjunction with GIS to help develop VM strategies. Pictometry is an aerial imaging process that produces imagery showing various perspectives of locations on the ground. Images are captured by low-flying helicopters that capture many oblique perspectives as well as an orthogonal view of every location flown. Using software these perspectives are used to create composite aerial maps that can seamlessly span many miles of terrain. This information can, among other things, be used to determine the health of various assets, including vegetation; and even provides enough granularity to enable tree risk analysis. Relying on similar technology, another company is using LIDAR technology to establish a tree growth calculator which will inform their VM strategy.

Weather Informed Vegetation Management Programs:

A leading practice identified was the use of weather related information to guide the development and execution of VM strategies. Specifically, analyzing weather information specific to certain areas, such as the magnitude and direction of the prevailing wind, and the amount of lightning due to elevation or rock bed is included when determining the strategies that are employed. Another company is working with a local university to develop correlation models to tie weather to the resulting damage on the system. The evaluation of weather information is another example of where a risk based approach is being incorporated into the development of VM strategies.

Smart Phone and Similar Platform Technology:

Recent improvements in technology have enabled devices like Smart Phones and similarly capable Tablet devices to become integral to establishing and improving grid resiliency and storm response. A few utilities are beginning to use this technology as part of their VM program. Among other things, this technology provides real-time two-way data flow regarding VM information; enables capturing relevant vegetation related data during storm patrols; and can link directly to the Control Center's OMS system via GIS coordinates, to provide photographs of damage and to provide information regarding various tree and system conditions. In addition, this technology enables the electronic execution of repair work by linking with the OMS and Work Management system.

In addition to the distribution grid resiliency focused practices discussed above there were several initiatives and practices identified during the utility interviews that were notable because of financial implications, and/or overall program value. These include: VM Program Management, Contractor and Contract Management, and Customer Satisfaction.

VM Program Management:

Planning and executing VM programs are challenging to manage because of the complexity of the various aspects of VM programs, especially during and after significant storm events. Major challenges associated with managing VM programs include: ensuring the work is done safely; work quality meets expectation and is completed on schedule; implementing a formal audit

process; and coordinating with state and local governments to clear roads blocked by downed trees.

Notable practices identified during the interviews regarding ensuring that work is performed safely include; safety audits where a certain number of safety observations are conducted per month on a per person basis; post job discussions and lessons learned reviews; behavior audits that identify good and poor work safety practices; and individual safety indices, and the use of safety key performance indicators, to alter the market share any one contractor can achieve.

Notable practices regarding work quality include: field arborists conducting 100% audits of trimmed circuits, and field arborists conducting quality assurance audits while separate auditing groups conduct quality control audits.

Notable practices ensuring work is being performed on schedule include: monthly reports which include planned completion status and budget versus actuals, on a per circuit basis; milestones identified in the contract for payments; and financial incentives for exceeding targets and penalties for failing to meet targets.

All of these aspects are managed through a formalized audit process. Notably, many companies utilize a formal audit process with an audit form. These forms capture various criteria including aspects which ensure safety, quality and timely work, as well as basic components geared to effectively manage the program. In some cases, there are multiple layers of review to ensure that the process is effectively driving the VM strategy in a cost effective and safe manner.

Additionally, with regards to vegetation management efforts to improve resiliency during and after extreme storm events, coordinating efforts with local municipal entities during the restoration of an event can significantly improve a utilities ability to restore power in a timely manner. This relies upon the collaboration and utilization of municipal resources to coordinate cleanup efforts. Specifically, local municipalities often have various highway personnel and equipment which can be effectively utilized to clear critical roadways much quicker than utility tree contractors can. This leverages the fact that many roads are owned by the municipalities and as such they can, while ensuring communication with the utility for safety reasons, clear the roads by disposing of entire trees without cutting them and placing them on the side of the road. It should be noted that the process and relationship with the underlying municipal personnel should be established before the onset of an event and should be captured in storm restoration plans.

Contractor and Contract Management:

The significant expense associated with executing VM strategies makes it imperative that excellent contract strategies are employed. The efficiencies of a well-constructed contract management facilitate achieving the desired reliability and system resilience objectives associated with a VM program. At issue is what defines the efficiencies. Most companies operate under the notion that bid awards will drive the performance of the contractor. While it may meet financial objectives of a utility, many companies discussed that the execution of the contracts were not as efficient as the biding and award process. There are some notable contractor and contract management practices that are more discretely designed to drive performance and efficiencies in the VM program. Specifically, some companies use a variety of performance indicators to drive the program, including: safety indices, customer surveys,

contractor caused interruptions indices, availability for call-outs on off-hours and storm emergency, evaluation of QA/QC results and the number of areas that require re-work. The focal point is ensuring that there is proper contractor oversight and that the legal contract that establishes the relationship with the contractor is appropriate given the financial risk and importance of the program.

As might be expected, throughout the industry the terms of the contract generally include the scope of work, methodology of payment and general oversight provisions. There are examples where the contract is awarded on an annual basis but the vast majority of contracts are awarded on a multiple-year basis. For those contracts awarded for multiple years there are generally accepted and utilized escalation costs contained in the contract; including, fuel, wages and equipment & material. Additionally, there is no consensus as to the method of payment used; the use of either time and material, lump sum or unit cost pricing is dependent upon the type of work being completed and the experience of the company. Although some companies have specific penalties for contractor caused outages, media events or damaged equipment, most companies do not delineate specific penalties or incentives in their contract. Rather, they rely upon the evaluation processes that award the contract, and therefore the on-going work for a contractor (or not) to be the incentive / disincentive mechanism that drives performance. This notwithstanding, the best practices in the industry invoke the use of a variety of performance indicators to drive the program, including: safety indices, customer surveys, contractor caused interruptions indices, availability for call-outs on off-hours and storm emergency, evaluation of QA/QC results and the number of areas that require re-work.

Managing the contractor on a day-to-day basis is also critically important to the overall success of a VM program. Nearly all companies have a process in place that provides oversight and evaluation of work performed with a feedback mechanism to the contractor. Most companies communicate with the management of the contract company and rely upon the organizational structure within that company to provide the feedback to the actual crews completing the work. Most companies are focused upon ensuring that the work being performed by the contractor is done safely, on-time and that the quality of work meets their specifications and needs. To ensure this there are rigorous processes that are set up that involve auditing of work site safety by independent organizations within the company and may involve an evaluation of OSHA Recordable performance. Additionally, to ensure that the work quality is satisfactory most companies conduct some level of Quality Assurance / Quality Control and provide feedback to the contractor. And finally, most companies track the work being completed to ensure that the needs of the program are satisfied. It was evident through the interview process that the vast majority of companies utilize a formalized audit process to continually monitor the contractors work and progress. This is not surprising given the large financial cost associated with VM programs and its overall impact on the safety and reliability of the system.

Customer Satisfaction:

To achieve the grid resilience objectives that are associate with VM, utilities consider the impacts on customers, their satisfaction with the reliability of service, and the utility's shared commitment to the environment and aesthetics surrounding the VM program. A utility customer's perception about a company's commitment to these factors can influence day-to-day VM activities significantly.

VM line clearance crews often meet with resistance from customers when trimming trees. In the interviews, several utilities discussed how important customer perception and satisfaction was to being able to get support for aggressive vegetation management and distribution grid resilience initiatives. When the weather is good and service is uninterrupted, customers are not in favor of aggressive trimming. However, when severe weather events affect service, customers are more understanding of the impact that vegetation has on the ability to keep power on to the customer, though they still are hesitant to have trees trimmed. This paradox requires a balanced and well-communicated VM strategy and effective execution of VM program requirements.

While the study participants analyze the reliability of the distribution system and use reliability as an indicator of customer satisfaction, only a few companies combine detailed system reliability analytics (e.g. feeder SAIFI/SAIDI, trim cycle analysis, etc.) with a customer outreach program in support of their VM (and other resiliency) initiatives. During the interviews a leading practice was identified, concerning a program designed to contact customers who have experienced long duration and multiple outages, or who have recently experienced trimming along their circuit. Every customer who has had their circuits trimmed is surveyed to ascertain whether they are satisfied with the reliability impact (if an improvement, so noted), as well as the effect on the aesthetics (was the trimming to obtrusive). Additionally, as a community relations and customer satisfaction initiative, tree crews have been given the leeway to provide gratis support to customers while on site (such as branch removal from a roof) that customers would not be able to perform safely on their own, or without costs to the customer. The investment in this customer satisfaction strategy that balances VM program execution with customer support has proven to be worth the expense for the utility implementing this approach (to facilitate achievement of resilience and reliability targets.

Conclusion:

The electric industry has continued to evolve VM Strategies to improve reliability and distribution grid resiliency through various initiatives. The most notable VM program enhancements include the use of risk-based asset management principles and best management practices as set forth in the most-recent ANSI / ISA guidelines. As the adoption and use of these guidelines become more widespread further improvements in VM strategies inevitably will be realized and costs could be more efficiently managed. Customer-centric communications and strategies surrounding the customer together with the use of technology provides opportunities to improve the development and execution of effective VM programs, and to achieve VM resilience objectives.

Lastly, the leading practices for improving distribution grid resiliency – increased line clearances, enhanced/blue-sky trimming of circuit backbones, and implementation/expansion of Hazard/Risk Tree programs – are not new VM practices. Although resiliency considerations may have increased the funding level, fundamentally these practices are elements of long-standing, reliability-driven VM programs; and benefit stakeholders whether the driver is traditional day-to-day system performance or resiliency during a major storm.

6
REFERENCES

The references provided include cited and uncited material from the body of the report. They are provided as a compendium of sources from the vegetation management research. Readers can easily access copies of the references through hyperlinked text, if desired.

[1] "Resilience in the Context of the Management of Vegetation Near Overhead Electric Lines." Prepared by the Arboricultural Association Utility Arboriculture Group

This paper was written by the Arboricultural Association and discusses a risk-averse and a risk-based approach to vegetation management. While the Association understands the need for tree trimming this document tries to also encourage companies to take a look at the processes and practice of tree trimming.

To acquire this resource, visit http://www.trees.org.uk/aa/documents/uag-resilience-definition-210311.pdf

[2] "Five Year Vegetation Management Plan." Prepared by Unitil Corporation.

This document is Unitil Corporation's Vegetation Management Plan for the years 2014-2018. It details their plan to be compliant with Massachusetts's regulations on everything from identifying target vegetation to methods and cycles to ensure proper compliance.

To acquire this resource, visit http://www.unitil.com/sites/default/files/pdfs/UnitilVMPMay-1-2013.pdf

[3] "Audit Implementation Plan: Annual Report and Update." Prepared by Consolidated Edison Company of New York, Inc. Case 08-M-0152

This is the annual audit report that Consolidated Edison writes to determine where they stand on the improvement implementation. The report includes the basic plans for implementation and the actions that have already taken place.

To acquire this resource, visit http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7BF57D835F-2A9E-4C30-AFFD-F89DCD02D7FF%7D

[4] "Electric System Long Range Plan: 2010-2030." Prepared by Consolidated Edison Company of New York, Inc.

This plan covers what Consolidated Edison believes will be the issues in the next 20 years and their plan on dealing with each. It includes a look at the effect of items such as electric cars, metering advancements, new transmission facilities, and increased demand on the system.

To acquire this resource, visit http://www.coned.com/publicissues/PDF/Electric%20System%20Long%20Range%20Plan%20December%202010%20Final.pdf

[5] "Integrated Vegetation Management Plan: For Transmission Rights-of-Way." Prepared by BC Hydro.

This document is an Integrated Vegetation Management Plan (IVMP) for the management of vegetation on transmission line rights-of-way (ROWs) operated by British Columbia Hydro (BCH). The IVMP describes the program for controlling vegetation along transmission rights-of-way (ROWs), using the principles of integrated vegetation management, the process for planning, selecting, using, and evaluating control methods within that program, the methods for handling, preparing, mixing, applying, and otherwise using herbicides within that program

To acquire this resource, visit https://www.bchydro.com/content/dam/hydro/medialib/internet/documents/safety/bctc_pdf/integrated_vegetation.pdf

[6] "Report on the Workshop for Best Practices in Vegetation Management." Prepared by Florida's Electric Utilities, Florida Municipal Electric Association, and Public Utility Research Center – University of Florida.

This report on the workshop for Best Practices in Vegetation Management is a summarizing record of the events and results of the workshop. It includes a record of the agenda, the participants, notes on the discussions, results of the breakaway group sessions and the reconvened group discussion. It also documents the groups identified best practices and areas of improvement.

To acquire this resource, visit http://www.floridapsc.com/utilities/electricgas/EIProject/docs/VegetationManagementWorkshopReport.pdf

[7] "NSTAR Electric Integrated Vegetation Management Right-of-Way Program Overview." Prepared by NSTAR Electric.

This presentation discusses the transmission vegetation program at NSTAR. It discusses the basics of the program and the components of chemical control, mechanical control and natural control. It also touches upon the different state and federal laws that are in place to ensure compliance to a higher reliability standard.

To acquire this resource, visit http://www.wellfleetma.org/public_documents/WellfleetMA_Pesticide/NSTAR.pdf

[8] "NSTAR Electric and Gas Five Year Vegetation Management Plan 2008-2012." Prepared by NSTAR Electric.

NSTAR's VMP outlines and explains the standards of vegetation control from their Integrated Vegetation Management (IVM) program. The document describes the practices and procedures NSTAR uses to control vegetation in its ROWs, as well as the efforts to reduce the impact of vegetation management on the health of the environment, animals, and humans.

To acquire this resource, visit http://www.kenersongroup.com/VMP.pdf

[9] "Vegetation Management: Clearing a Path to Reliable Service." Prepared by SMUD.

This document highlights SMUD's commitment to effective vegetation management practices and principals. It provides a detailed overview of the types of pruning techniques employed and illustrates its current vegetation management practice with informational graphics.

To acquire this resource, visit https://www.smud.org/en/residential/customer-service/support-and-services/vegetation-management/

[10] "Integrated Vegetation Management." Prepared by EPRI.

This document is a plan forward for key research in the integrated vegetation management arena. It discusses the drivers for the research and the key areas that need to be focused on to ensure it is useful in the industry.

To acquire this resource, visit http://mydocs.epri.com/docs/Portfolio/P2014/Roadmaps/ENV-F-T&D-04.pdf

[11] "Potomac Electric Power Company Comprehensive Reliability Plan for District of Columbia Including Distribution System Overview, Reliability Initiatives and Response to Public Service Commission of the District of Columbia Order No. 15568." Prepared by PEPCO.

In this document Pepco has committed to providing safe and reliable electric service to all customers at a reasonable cost. They plan to work with communities, political officials and the Commission to implement a robust reliability plan that balances the cost and benefits to customers.

This plan includes six reliability initiatives:
• Enhanced Vegetation Management
• Priority Feeders
• Load Growth
• Distribution Automation
• Feeder Improvement
• Selective Undergrounding
To acquire this resource, visit
http://www.pepco.com/_res/documents/dccomprehensivereliabilityplan.pdf

[12] "Pacific Gas and Electric Company: 2014 General Rate Case Prepared Testimony Exhibit (PG&E-4) Electric Distribution" Prepared by PG&E.

This document is the testimony of the 2014 PG&E Rate Case. This document explains the forecast of PG&E's Electric Distribution Operations line of business expenditures for 2014-2016. In addition to information on its vegetation management practices, it also includes sections about plans for emergency recovery, pole replacement, electric operations technology, underground asset management and many other topics.

To acquire this resource, visit https://www.pge.com/regulation/GRC2014-Ph-I/Testimony/PGE/2012/GRC2014-Ph-I_Test_PGE_20121115_254321.pdf

[13] "Vegetation Management Plan" Prepared by Essential Electric.

This document outlined the various methods which Essential Electric in Australia utilizes to ensure compliance to standards and to ensure reliability of the system. It discusses the actual methods of clearing vegetation and includes a planting guide to be used by the landowners to help eliminate future costs in vegetation management.

To acquire this resource, visit http://www.essentialenergy.com.au/asset/cms/pdf/aasp/ce_vmp.pdf

[14] "Five Year Vegetation Management Plan 2014-2018." Prepared by National Grid.

The Five Year Vegetation Management Plan details National Grid's plan for managing vegetation in ROWs. The plan discusses integrated vegetation management, various vegetation management control methods, a discussion of the selective herbicide applications, and an overview of National Grid's treatment of "Sensitive Areas".

To acquire this resource, visit
http://www.nationalgridus.com/non_html/National%20Grid%20VMP%202014%20-%202018.pdf

[15] "Best Practices in Vegetation Management for Enhancing Electric Services in Texas" Prepared by Texas Engineering Experiment Station for Public Utility Commission of Texas.

The report documents known common practices in vegetation management in the state of Texas and recommends a framework for "best practices" in vegetation management.

To acquire this resource, visit
http://www.puc.texas.gov/industry/projects/electric/38257/Russell_Report.pdf

[16] "LIPA Vegetation Management Program." Prepared by Long Island Power Authority.

This document is a set of slides that provide an overview of LIPA's vegetation management program. In addition to discussing basic information about its vegetation management program, it also notes the standards that LIPA complies with, challenges that it faces, results of its vegetation management program, lessons learned and opportunities for future improvement.

To acquire this resource, visit http://www.lipower.org/pdfs/company/papers/board/062713-op-veg.pdf

[17] "Regulatory Change for Utility Management in the US." Prepared by Will Porter of CN Utility Consulting.

This document is a set of slides that provide an overview of how regulatory commissions in different states are evolving as new practices in vegetation management evolve.

To acquire this resource, visit
http://www.isatexas.com/images/Conference/13/13_Presentations/Regulatory%20Change%20for%20Utility%20Vegetation%20Management%20in%20the%20US10%203%2013%20ISAT%20William%20Porter%20[Read-Only].pdf

[18] "Prepared Direct Testimony of Scott P. Furgerson of Behalf of San Diego Gas & Electric Company: Exhibit No. SDG&E-05." Prepared by Scott P. Furgerson.

A testimony on behalf of San Diego Gas and Electric Company in the matter of requesting to update its gas and electric revenue requirements and base rates effective on January 1, 2012. It includes detailed expenditures on the company's programs, including its vegetation management program.

To acquire this resource, visit
https://www.sdge.com/sites/default/files/regulatory/Exhibit%20SDG&E-05R%20S_Furgerson_SDGE-R_Elec_Dist_O&M_Testimony.pdf

[19] "Weather-Related Power Outages and Electric System Resiliency." Prepared by Richard J. Campbell of Congressional Research Service.

This congressional report discusses suggested solutions for reducing impacts from weather-related outages, including improved tree trimming schedules to keep rights-of-way clear, placing distribution and some transmission lines underground, implementing Smart Grid improvements to enhance power system operations and control, inclusion of more distributed generation, and changing utility maintenance practices and metrics to focus on power system reliability.

To acquire this resource, visit http://www.fas.org/sgp/crs/misc/R42696.pdf

[20] "Laws and Regulations." Prepared by PG&E.

This website is a general summary of the rules and regulations which Pacific Gas and Electric is required to follow in the State of California. It gives clear guidance on the minimal clearance provisions for each size of electrical line.

To acquire this resource, visit http://www.pge.com/en/mybusiness/services/maint/vegman/laws.page?%20-%204292

[21] "General Order 95: Rules for Overhead Electric Line Construction." Prepared by the State of California.

General Order 95 is the California regulation on construction of overhead electrical lines. Section 35 includes the detailed rules for vegetation management in the area of the lines that needs to be met

To acquire this resource, visit http://www.cpuc.ca.gov/gos/GO95/go_95_rule_35.html

[22] "Vegetation-Related Transmission Outage Report: First Quarter 2013." Prepared by North American Electric Reliability Corporation.

This paper is a review of the transmission outages from across the country that occurred due to vegetation issues. It discusses the three distinct categories of vegetation outages and concludes that all three of the outages that occurred during the first quarter of 2013 were from vegetation falling on the lines from outside of the ROW. It also mentions that this is down from nine outages that took place during the first quarter of 2012.

To acquire this resource, visit http://www.nerc.com/pa/comp/Reports%20DL/Vegetation-Related%20Transmission%20Outages%20-%20First%20Quarter%202013.pdf

[23] "Chapter 25: Iowa Electrical Safety Code." Prepared by the State of Iowa.

This document is the exact regulations in Iowa required for utility companies. It discusses the need for a vegetation management plan which includes both a schedule for tree trimming as well as written procedures to follow.

To acquire this resource, visit https://www.legis.iowa.gov/DOCS/ACO/IAC/LINC/11-27-2013.Chapter.199.25.pdf

[24] "Vegetation Management." Prepared by Raymond Fugere of the California Public Utilities Commission – Safety and Enforcement Division.

This presentation reviews the roles and regulations in place in California and federally. It also discusses how many outages occur due to trees across the three major utility companies in California and how many trees each has to maintain. It wraps up by discussing the issues customers have with tree trimming and how this can affect safety.

To acquire this resource, visit http://www.cpuc.ca.gov/NR/rdonlyres/16A369A5-A7B9-423A-9D07-72E7E24F9532/0/PowerPointforthe5913Meeting.pdf

[25] "Vegetation Management by Electric Utilities: Use of Herbicides and Other Methods." Prepared by Environmental Management Services for EPRI.

This report summarizes the essential elements and principles comprising electric utility vegetation management programs, defines management problems, and discusses possible research on vegetation management issues. The report particularly focuses on the use of herbicides and their effects on wildlife and human health. Legal and regulatory aspects and cost control issues are also covered.

To acquire this resource, visit http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=TR-104935

[26] "Integrated Vegetation Management: A System, a Process, a Framework." Prepared by SUNY – College of Environmental Science and Forestry.

This presentation is a comprehensive guide to integrated vegetation management. It focuses on the key steps in the process and how to achieve each.

To acquire this resource, visit http://www.esf.edu/ivm/PDFs/IVM%20System-Process-Framework.pdf

[27] "Utility Vegetation Management Final Report." Prepared by the Federal Energy Regulatory Commission.

This report was written as a result of the Northeast Blackout in 2003. It provides a detailed overview of utility vegetation management in the United States, major findings of the investigation and recommendations to prevent another such blackout in the future.

To acquire this resource, visit http://www.ferc.gov/industries/electric/indus-act/reliability/blackout/uvm-final-report.pdf

[28] "List of Covered Electric Utilities under the Public Utility Regulatory Policies Act of 1978 (PURPA)." Prepared by the Department of Energy.

This document is published by the Department of Energy and contains a list of all utilities throughout the United States which Title I of the Public Utilities Regulatory Act of 1978 (PURPA) applies to.

To acquire this resource, visit http://energy.gov/oe/downloads/list-covered-electric-utilities-under-public-utility-regulatory-policies-act-1978-purpa

[29] "A Review of Canadian Forest Vegetation Management Research and Practice." Prepared by Dean G. Thompson and Douglas G. Pitt for

This article covers the different research and practices used for vegetation management in Canada from 1990-2003. While not directly tied to overhead utility line work it provides insight into the research being done and the results of the practices

To acquire this resource, visit http://hal.inria.fr/docs/00/88/37/40/PDF/hal-00883740.pdf

[30] "The State of the Utility Vegetation Management (UVM) Industry." Prepared by Stephen R. Cieslewicz for Electric Energy Online.

This article is an overview of the rules and regulations which came from the Northeast Blackout in 2003. It also discusses how these standards are expected and have impacted the utility industry.

To acquire this resource, visit http://www.electricenergyonline.com/?page=show_article&article=244

[31] "UAA Best Management Practices Funding." Prepared by Lynn Grayson for Utility Arborist Association.

This paper discusses the best practices used in the utility industry for vegetation management with both reliability and funding in mind. It was written using information from surveys and the Final Blackout Report in conjunction with the Utility Arborist Association

To acquire this resource, visit http://www.utilityarborist.org/research/resources/fundingwp.pdf

[32] "Regulatory Requirements 2006-2009." Prepared by CN Utility Consulting.

This study breaks down the rules and regulations on vegetation management by state. It not only contains information about current law, but discusses the regulations view on future law as well.

To acquire this resource, visit http://www.cnutility.com/wp-content/uploads/2013/10/UVM-Regulatory-Requirements-2006-2009.pdf

[33] "Utilities Uncover Success in Vegetation Management." Prepared by Doug Haller and John Smith.

This article discusses the positive sides of herbicides and how the long term effect can be much greater then with traditional mechanical methods, such as mowing. It also discusses how in the long term the use of herbicides is more cost efficient.

To acquire this resource, visit http://www.irwaonline.org/eweb/upload/ROW%20Archives%207-05%20thru%207-06/706/VEGE.pdf

[34] "Utility Vegetation Management and Bulk Electric Reliability Report from the Federal Energy Regulatory Commission." Prepared by the Federal Energy Regulatory Commission.

This is the results of a study that was conducted in the early-summer of 2004 by the Federal Energy Regulatory Commission. It was in response to the Commission's Final Blackout Report which was released in April 2004 and asked the utilities specifically about their progress on the recommendations by the report.

To acquire this resource, visit http://www.ferc.gov/industries/electric/indus-act/reliability/veg-mgmt-rpt-final.pdf

[35] "ANSI A300: Part 7 Integrated Vegetation Management." Prepared by ANSI.

The American National Standards Institute has written ANSI A300. "ANSI A300 Standards are divided into multiple parts, each focusing on a specific aspect of woody plant management." Part

7 focuses on integrated vegetation management and provides an overview of methods for evaluating sites, management control methods and ensuring quality control.

To purchase this document visit: http://www.isa-arbor.com/store/

[36] "Best Management Practices: Integrated Vegetation Management." Prepared by ANSI.

This is a companion publication to ANSI A300: Part 7 Integrated Vegetation Management. It is intended to be a compilation of the best practices in vegetation management in the utility industry. The major topics it covers are: communication, evaluation of sites, selecting control methods, implementation, quality assurance and environmental concerns.

To purchase this document visit: http://www.isa-arbor.com/store/

[37] "ANSI A300: Part 9 Tree Risk Assessment." Prepared by ANSI.

The American National Standards Institute has written ANSI A300. "ANSI A300 Standards are divided into multiple parts, each focusing on a specific aspect of woody plant management." Part 9 covers tree risk assessment. This part of the specification breaks down the tree assessments into three specific levels and what techniques should be used in each. It also discusses what needs to be included in the risk assessment reports.

To purchase this document visit: http://www.isa-arbor.com/store/

[38] "Best Management Practices: Tree Risk Assessment." Prepared by ANSI.

This is a companion publication to ANSI A300: Part 9 Tree Risk Assessment. This manual goes into a more in-depth look at how to perform a vegetation risk assessment. It covers everything from how to choose the level of analysis to how to perform the actual assessment to reporting practices.

To purchase this document visit: http://www.isa-arbor.com/store/

[39] "Growth Strategies: Best Management Practice for Integrated Utility Vegetation Management." Prepared by Randall H. Miller for PacifiCorp.

This articles summarized the process of integrated utility vegetation management and discusses the best practices in the industry.

To acquire this resource, visit http://www.energydimensions.net/growth-strategies-best-management-practice-for-integrated-utility-vegetation-management/

[40] "Fact Sheet: Integrated Vegetation Management." Prepared by the Environmental Protection Agency.

This pamphlet was put together by the EPA and discusses basic integrated vegetation management and the steps one would take to control growth.

To acquire this resource, visit http://www.epa.gov/pestwise/publications/landscaping/ivm_fact_sheet.pdf

[41] "Utilities Using Mobile GIS for Vegetation Management." Prepared for T&D World Magazine.

This is a short article that introduces the reader to the use of handheld GIS units to locate, measure and document areas where vegetation management needs to take place and the benefits which can be gained.

To acquire this resource, visit http://tdworld.com/vegetation-management/utilities-using-mobile-gis-vegetation-management

[42] "Vegetation Management Takes to the Airwaves." Prepared by William Atkinson for Electric Power & Light Magazine.

This article focuses on PPL Electric and Northeast Electric's use of lidar (light detection and ranging) equipment to stay in compliance with federal standards. It discusses the issues with implementation and the improvements it has made in the field.

To acquire this resource, visit http://www.elp.com/articles/powergrid_international/print/volume-17/issue-5/features/vegetation-management-takes-to-the-airwaves.html

[43] "LIDAR: Illuminating Hazardous Vegetation." Prepared by Gene Wolf for T&D World Magazine.

This article discusses the difficulties faced by utilities when it comes to vegetation management and how LiDAR equipment can help when used properly.

To acquire this resource, visit http://tdworld.com/overhead-distribution/lidar-illuminating-hazardous-vegetation

[44] "NIPSCO Streamlines Vegetation Management." Prepared by Jason Lietz and Amy Fischbach.

This article focuses on Northern Indiana Public Service Company's transition to the digital age of recordkeeping and improve communications using ArborMetrics software. It concludes with a discussion of the advantages which have been seen by putting this software in place.

To acquire this resource, visit http://datasourcemobility.com/photos/psc-tb-tdworldcoverage-3-1-11.pdf

[45] "Monthly Aerial Patrols Promote Reliability." Prepared by Dick Pursley and Byron Johnson for T&D World Magazine.

This article discusses Great River Energy's success at using aerial patrols to monitor vegetation growth and other ROW issues. It covers the different methods, such as cyclical color surveys, as well as how the information on issues is relayed to the line crews and what affect this has had on the reliability of their service.

To acquire this resource, visit http://tdworld.com/overhead-transmission/monthly-aerial-patrols-promote-reliability

[46] "Met-Ed Conducts Vegetation Management Work to Enhance Electrical Reliability." Prepared for Electric Power & Light Magazine.

This article is an update on Metropolitan Edison Company's vegetation management plan and where they stood when the article was written as well as next steps.

To acquire this resource, visit http://www.elp.com/articles/2013/05/met-ed-conducts-vegetation-management-work-to-enhance-electric-r.html

[47] "SECO Clears the Way." Prepared by Ken Lacasse for T&D World Magazine.

Following the storm season of 2004 SECO in Florida realized it was spending more on vegetation management and getting a lower reliability. This article addresses SECO's use of the consulting firm ACRT and the changes implemented to improve reliability and decrease cost.

To acquire this resource, visit http://tdworld.com/vegetation-management/seco-clears-way

[48] "Trimming Your Way to a More Reliable Future." Prepared by Glenn Springer for T&D World Magazine.

In 2000 Nashville Electric Service had 10 times the number of tree outages then the utilities following vegetation management best practices. This article discusses how they identified the issue, the corrective actions they took and the results they saw after three trimming cycles.

To acquire this resource, visit http://tdworld.com/smart-energy-consumer/trimming-your-way-more-reliable-future

[49] "Assessing Ground Fault Neutralizer (GFN) Deployment and Benefits in 11kV Electricity Network." Prepared by Phan Qixun.

This paper looks at the Ground Fault Neutralizer used at the Poroti zone substation in New Zealand. It examines the positive and negative affects it had on the system, including a cost benefit analysis. It concludes by comparing GFN to more traditional methods and discussing what the future holds for these systems

To acquire this resource, visit https://apps.foe.auckland.ac.nz/p4p/ece/downloads/Part4Reports2012/PowerSystems/project49_qpha006.pdf

[50] "Ground Fault Neutralizer." Prepared by Swedish Neutral.

This website features several documents on the ground fault neutralizers developed by Swedish Neutral. These documents cover how the neutralizer ground fault protection systems differ from typical protection systems, benefits of the system and basic implementation.

To acquire this resource, visit http://www.swedishneutral.se/main.php?name=gfn

[51] "CL&P Implementing New Technology to Improve Storm Response." Prepared for T&D World Magazine.

This article focuses on CL&P's new damage assessment tool. The tool allows the company to combine the GIS mapping data with information about the distribution system and GPS street location and allow it to be uploaded to the planning and logistics teams in real time. This data can then be used for more accurate ETRs and more efficient work plans

To acquire this resource, visit http://tdworld.com/news/clp-implementing-new-technology-improve-storm-response

[52] "Helicon, Alabama: Power Supply Improvement Project." Prepared by Tennessee Valley Authority.

This paper covers TVA's plan to improve reliability in Helicon, Alabama. It purposes multiple methods to do this and discusses the vegetation management process on this line

To acquire this resource, visit http://www.tva.gov/environment/reports/helicon/fea.pdf

[53] "Tree Healthcare Products Catalog, 2014." Prepared by Rainbow Treecare Scientific Advancements.

This presentation contains information on herbicides and how to use each one. It also contains a short history of vegetation management

To acquire this resource, visit http://www.treecarescience.com/pdf/RTSA-2014-catalog.pdf

[54] "Growth Retardants: A Promising Tool for Managing Urban Trees." Prepared by Purdue University.

This article discusses tree growth retardants. It starts out with a brief history of how they were invented and then discusses the advantages they can have on the trees, such as greener leaves, reduced water stress and a higher resistance to fungal disease.

To acquire this resource, visit https://www.extension.purdue.edu/extmedia/FNR/FNR-252-W.pdf

[55] "Report to the Maryland Public Service Commission on the Progress of the Maryland Electric Reliability Tree Trimming Council (MERTT) in Addressing Commission Order #79159 Regarding Recommendation for Specific Actions that Utilities Can Take to Best Manage Privately Owned Trees Adjacent to and within the Utility Right-of-Way." Prepared by Niles L. Primrose, Fred Kelly, and Charles Anderson.

This report is a study of the tree related outage data collected from six Maryland utility companies from 2006 to 2010

To acquire this resource, visit http://mocoalliance.org/wp-content/upload/pepco-tree-report.pdf

[56] "Evaluation of PG&E's 2014 Gas Distribution GRC Filing." Prepared by Cycla Corporation for Pacific Gas and Electric.

A report by Cycla Corporation that provides a detailed evaluation of PG&E's 2014 GRC filing as well as an evaluation of the company's practices including its vegetation management practices.

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Appendix E: Force of Impact Associated with Tree Failures

Force of Impact Associated with Tree Failures

Characterizing Branch Failure Line Strikes

Technical Update, December 2013

EPRI Project Manager

J. Potvin

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This report describes research sponsored by EPRI.

BioCompliance Consulting, Inc. would like to acknowledge the support and involvement of several individuals that have been instrumental in the successful completion of this project.

Joe Potvin, an EPRI Distribution Senior Project Engineer/Scientist, participated directly in the field phase of this investigation and contributed to the data analysis. EPRI's Brian Green participated in the field experiment.

Andreas Detter, Brudi & Partner TreeConsult, Gauting, Germany, participated in project design, provided advisory support during field work, and assisted in the review of the literature and analysis of branch allometry data.

Ken James, Ph.D., Environmental Engineer, ENSPEC Pty Ltd, Victoria, Australia, provided advisory support during field work, and assisted in the data analysis.

Field work was carried out during International Society of Arboriculture's "Tree Biomechanics Week 2013". This event provided an opportunity for the exchange of experimental design ideas between researchers and leading scientists actively working in the emerging field of tree biomechanics. The project also benefited from the support of tree climbers, technicians, and volunteers.

Special recognition is given Mark Hoenigman for use of his crane and his participation as crane operator.

This publication is a corporate document that should be cited in the literature in the following manner:

Force of Impact Associated with Tree Failures: Characterizing Branch Failure Line Strikes
EPRI, Palo Alto, CA: 2013.

Appendix E

PRODUCT DESCRIPTION

This document reports on the findings from an investigation of the destructive potential of falling tree branches impacting overhead distribution lines. The results of this work include projections of the potential energy, kinetic energy, and momentum associated with falling branches. The force of impact on a rigid target is presented and considered a worst-case scenario. The force of impact due to branch strikes upon a span of distribution line would be smaller, due to the dynamic nature of the line.

Background

This project was undertaken as part of EPRI's Distribution Grid Resiliency efforts. That effort includes an assessment of the characteristic distribution system infrastructure, and an assessment of vegetation management practices. Any assessment of the risk of tree-caused damage due to line strikes must consider two factors: the likelihood that a tree fails and strikes the line, and consequences of that impact. Utility vegetation maintenance programs are intended to reduce the likelihood of tree failures causing damage. Considerable work has been done to develop condition assessment methods and hazard mitigation techniques. Less is known about the destructive potential of falling branches, which has been the focus of this project. The results of this investigation may be used by structural engineers in an assessment of the resiliency of energy delivery infrastructure.

Objectives

The objective of this research was to identify and quantify metrics that would be useful in describing the destructive potential of falling trees and branches. The intent was to provide distribution engineers with a tangible basis for assessing the durability of overhead distribution system infrastructure exposed to tree and branch failures.

Approach

Line strikes were simulated in a series of branch drop tests from a fixed height onto a rigid target. Data that describe the branch, its velocity, and acceleration of both the branch and target were recorded. Eighteen branch specimens in full leaf from two different tree species were dropped on a fixed target. As many as six replications were completed with each specimen. A subset of these replications was conducted with branches that had been stripped of leaves. Branch velocity was determined by interpretation of high speed video. Target acceleration and branch deceleration due to impact were recorded directly. These data, and the mass of the branch, were used to calculate the potential energy, kinetic energy, and momentum associated with falling branches as well as the force of impact on the target.

A review of the literature was conducted as part of this investigation. It revealed little in the way of studies quantifying the energy, momentum transfer, or impact forces associated with tree and branch failures.

Limitations in the data due to sampling frequency and precision were identified but not determined to be so great as to discount the findings of the investigation.

Results

The project was successful in providing quantitative evidence of the destructive potential of line strikes by branches. The metrics quantified include potential energy, kinetic energy, momentum, and resulting force of impact associated with falling branches.

Applications, Value, and Use

Findings from this investigation are intended for use by distribution engineers in conducting structural analysis of overhead distribution system infrastructure and its ability to survive a strike by a failed branch.

Keywords

Branch Failure
Distribution
Force of Impact
Kinetic Energy
Line Strike
Momentum
Risk
Tree Caused Outages
Tree Failure

ABSTRACT

An investigation of the destructive potential of falling tree branches impacting overhead distribution lines was completed. A series of branches were dropped from a fixed height onto a rigid target. The mass and velocity of the falling branches and the rate of acceleration of the target upon impact were determined. These variables were used to calculate the amount of energy and momentum available for transfer to the target upon impact, and the force experienced by the target due to impact of the falling branch.

The use of a rigid target provided a worst-case study. The force of impact on an overhead electric distribution line would be expected to be lower than those observed due to the dynamic nature of a span of conductor power line suspended between poles.

Keywords
Branch Failure
Distribution
Force of Impact
Kinetic Energy
Line Strike
Momentum
Risk
Tree Caused Outages
Tree Failure

Appendix E

EXECUTIVE SUMMARY

The potential for trees to severely damage an overhead electric distribution system was made abundantly clear in the aftermath of several recent severe storm events. High winds, ice, and accumulations of heavy wet snow can overload trees of the point of structural failure. Broken branches falling onto the overhead distribution lines have the potential to damage lines, conductors and supporting poles leading to interruptions and extended outages as repairs are made to the system.

An assessment of risk associated with tree failures requires consideration of both the likelihood that a branch failure will occur resulting in a line strike, and the magnitude of impact on the line. Utility vegetation management programs focus on the first consideration and are intended to reduce the likelihood of tree failures and line strikes. The second part of the risk equation is less well understood: the potential for structural damage if/when a line strike occurs.

Whole tree failures have the potential to create significant damage to an overhead distribution system particularity during periods of severe weather. Yet the incidence of branch failures is higher under most conditions. Some types of distribution line construction currently in service may be able to survive the force of impact of some branch impacts. It is also possible that more robust line designs can reduce the consequences of a line strike.

A series of branch drop tests from a fixed distance onto a target were conducted. Data acquired were used to calculate the potential energy, kinetic energy, and momentum associated with dropped branches as well as the force of impact on the targets. The focus of this project was to characterize and quantify the line strikes in a manner that would be useful to distribution engineers studying the question of infrastructure resiliency and survivability.

Analysis supports use of branch diameter as a reasonable surrogate for mass, allowing presentation of findings in an intuitive manner. Each metric used in quantifying the energy in a falling branch available to damage an overhead distribution line is presented as a function of branch diameter. The project was successful in providing quantitative evidence of the destructive potential of line strikes by branches. The metrics quantified included potential energy, kinetic energy, momentum, and resulting force of impact associated with falling branches.

This project focused on branches with a 3 - 8” (8 - 20 cm) diameter at the butt end. The focus on impact forces due to line strikes by smaller branches was consistent with the goal of providing supportive data for efforts to improve storm hardening of the distribution system infrastructure.

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1 PROJECT SCOPE AND BACKGROUND

There are two basic modes of failure associated with tree-initiated interruptions on the energy delivery system: electrical and mechanical. The electrical mode of failure occurs when tree or parts of trees provide a short circuit fault pathway between areas of unequal electrical potential. The mechanical mode of failure is caused by structural failure of the tree or parts of trees (branches) causing physical damage to energy delivery infrastructure. Mechanical damage results as a tree fails, taking down conductors, cross arms and poles as it falls. Mechanical damage can be extensive in major storm events.

The structural failure of trees adjacent to and sometimes well outside a maintained line clearance corridor has been recognized as a dominant cause of electric service interruptions on well-managed overhead electric distribution systems. This point was clearly demonstrated in the experience of several utilities following recent bouts of severe weather. As a result, the industry has been considering means of improving the resiliency of overhead electric distribution systems, sometimes referred to as “storm hardening”.

The basic risk assessment model considers two factors: probability and consequence of an adverse event. In the case of assessing the risk that trees pose to an overhead power line, the first consideration is determining the likelihood of failure of the tree. The second consideration is the consequence, which in this case is the potential damage to energy delivery infrastructure resulting in an interruption and, subsequently, customer outages. While the need to assess the potential for structural failure of trees is generally well understood, less consideration has been given to assessing the destructive potential of the impact on a target such as an overhead utility line.

Considerable work has been done throughout the industry to address the likelihood of tree failures. The industry continues to develop hazard tree risk assessment and mitigation techniques. Vegetation managers focus on identification of individual trees adjacent to the cleared corridor that demonstrate readily apparent characteristics that would predispose them to failure. Vegetation maintenance practices such as tree removal, enhanced clearances, and reduction pruning are all intended to reduce the likelihood of tree failures resulting in adverse consequences in terms of reliability.

The second factor in assessing risk is the consequence: in this case, the damage potential of a tree or branch striking a line. This has received little attention. There is an abundance of anecdotal evidence that the failure of large branches, as well as whole trees, can strike overhead lines with enough force to sever conductors and break cross arms and poles. The force of impact and amount of damage caused is a function of the mass of tree or branch, distance from the line, and the line characteristics.

The force of impact associated with line strikes by medium and smaller branches may not exceed reasonable structural design capacities and are an important factor in assessing changes to energy delivery infrastructure intended to mitigate risk and improve system performance during adverse

weather. This question is particularly relevant in any discussion of increasing the resiliency of the overhead distribution system through storm hardening of energy delivery infrastructure.



Figure 1-1
Damage to a single phase distribution line caused by impact of a branch from an American sycamore (Platanus occidentalis) tree.

This project focused on characterizing and quantifying the amount of energy available at the point of impact on a target due to the structural failure of medium sized tree branches, generally defined as being less than 8" (20 cm) in diameter at the point of attachment. Important factors considered in making such an assessment include the mass and position of the failed branch relative to the target, the velocity at which it was traveling when it struck the target, and rates of acceleration and deceleration.

2 LITERATURE REVIEW

The mass of entire trees, tree crowns and individual branches are important considerations in any effort to assess the destructive potential associated with structural failure of trees. To that end, a review of the literature including research papers, conference proceedings, magazine articles and books was completed with regard to data on mass of trees, tree sections and branches. Due to the limited nature of this body of work, the review was expanded to include works by the authors and others that have not been published in the public domain.

The search for references as to the mass of entire trees considered five broad areas:

1. Allometric studies
2. Structural stability studies that considered failures in the main stem/trunk and soil/root plate.
3. Carbon sequestration and storage within the biomass of trees
4. Arboricultural practices of rigging and dismantling operations
5. Forestry, harvesting, and wood production efficacy
6. Engineering implications

Allometric studies

Allometry, as applied to the structural integrity of trees, typically considers the basic architecture of a tree, and focuses on relationships between fundamental parts of the tree. In this case we were concerned with the characteristics of trunks, stems, and branches.

A very early work [1] reports on a study of 116 trees involving nine different species. The weights of whole trees of up to 23" (58cm) circumference (7" in diameter) and masses up to 55lbs (120kg) were determined. More detailed measurements of branches and twigs down to 0.1" (0.25cm) were then made. The work demonstrated a linear relationship between circumference of a tree, branch, or twig and mass. Error was shown to increase with smaller diameter pieces.

Three formulae were compared in [2] for assessing the weight of branches. In this study, measurements were made of both length and diameter of 116 main branches with laterals on Norway maple (*A. platanoides)*, horse chestnut (*A. hippocastaneum)* and a varietal of London planetree (*P. x hispanica*). Mass was normalized using a specific gravity of 0.84 for all species. Additionally, weights of 16 branches of horse chestnut and Norway maple with diameters of 1.5 - 6.5" (4 - 16cm) at the base of the branch were calculated. However, only three branches of 23 – 46lbs (50 - 100kg) mass were included in this study.

Several references proposed the use of geometry to address the question of estimating mass. A current representative reference [3] provides a method of determining mass based on the cubic volume of a simple cylinder calculated using branch diameters and length of branch sections. It uses the diameter at the large and small ends and the length of a branch. It then

uses specific factors for wood density and average moisture content of both sap and heart wood to predict mass. The article does not speak to the accuracy of the proposed formula.

Structural Stability

Tree and crown mass was found to typically be measured and incorporated in equations for assessing critical loads during the structural failure process, but was rarely explicitly included in any tables and graphs found in these references. In [4] a useful overview of literature in this area was provided. Mass distribution throughout the tree is typically described as a function of height (*e.g.,* [5]). An alternative approach attempts to correlate mass with stem and crown parameters [6]. In either case, data were acquired by cutting entire trees, stems or crowns into sections and weighing them separately.

Good estimates of the distribution of mass throughout entire trees, crowns and branches are required in order to model the behavior of trees as they respond to dynamic loads. In a study on the effect of branches on sway parameters, crown mass was derived from weighing branches of nine Douglas fir trees [7]. The mass of branches high in the upper crown of the trees was determined and used to model sway. In another study [8], Douglas fir trees were modeled in a simulation of sway parameters and used correlations for stem and branch mass from measurements of dry density, moisture content and geometry.

Carbon sequestration

Carbon storage in tree biomass has been an international field of study for several years (*e.g.*, [9]). In an attempt to study the amount of carbon stored in urban trees, nine trees were harvested and weighed in a study conducted in the city of Karlsruhe, Germany [10]. The majority of references that related to mass and carbon sequestration focused on quantifying the mass of carbon at the timber stand and forest level of detail, and were not particularly helpful in describing the mass of individual medium-sized branches.

Arboricultural practices

Anecdotal data collected from crane tree-felling operations are reported for 16 trees from 10 different species [11]. The mass of five beech trees (*F. sylvatica*) was recorded during a crane-felling operation in Braunschweig, Germany [12]. Data were provided on diameters and heights of the trees, as well as the weight of 10 tree sections (five crown sections, four trunks and one entire tree).

Methods for mass estimations of logs without branches and parts of the crown (with branches) are described in the HSE Rigging Report. Data on branches of Poplar *(Populus canadensis)* were measured by V. Genenz for his 1998 paper [13]. The masses for branches correlate very closely with branch diameter measured at the base. Analysis in the HSE Rigging Report revealed that a suitable form factor for branches of this species would have ranged from 0.35 to 0.40. A prototype of a worksheet was also developed and included in the HSE Rigging Report that is intended to enable arborists to estimate the mass of logs and crown sections.

Wessolly [14] used estimated branch masses to justify the recommendations for the strength of crown support systems in the German technical standard (FLL 2006). His estimations were based on several studies that measured length and diameter of broad-leafed trees in Germany. Data reported included stem diameter, tree height and crown dimensions. Log weight charts are commonly published in books, magazine articles and product catalogues (*e.g.* [15]).

Forestry

The relationship between standing tree diameter, height, and various wood products are in common use in the forestry industry. However, these relationships are typically too coarse to be particularly useful as an indication of the mass of tree parts. A summary of published relationships used in forestry is available from [16].

Seventy-five Scots pine trees (*Pinus sylvestris*) were harvested and removed from the site by helicopter. The masses of up to three sections of each tree were recorded and plotted against tree data. The mass of the crown section was estimated best from the stem diameter at the cut. Variability in the mass estimate did not correlate well with the length of the crown section. Simple models were derived to predict entire tree mass from tree diameter and the volume of a cylinder with the stem's diameter and the tree's height. Data were provided by Michael Moosbauer [17], courtesy of the German cooperative for helicopter felling "Arge Helikopterfällung" (www.helikopterfaellung.de).

Engineering references

This report focuses on characterizing the destructive potential of line strikes from the frame of reference of the tree failure that transfers momentum to the target. As such, the literature review did not consider references related to the structural engineering aspects of the dynamic response of an overhead distribution system to a line strike by tree or branch. However, an investigation [18] related to the performance of a span of overhead line following impact. This investigation was undertaken following the aftermath of major storms in the northeastern US. It concluded that trees are the largest risk factor for overhead electric distribution system infrastructure. The investigation used simulation modeling to assess impacts and to determine the ability of overhead lines to withstand falling tree limbs. The forces generated by medium-to-large limbs falling from 15 feet above a power line were shown to be sufficient to break various components including conductors, cross arms, and poles. The engineering analysis determined that relatively light masses (21-26 lbs) dropped from a height of 15 feet (< 5 m) would exceed 100% of the system's designed mechanical load capacity in 200ft spans of overhead conductor (#6 CU-336 AAC).

The simulation analysis predicted that conductor size was the most significant attribute to be considered when evaluating resiliency. If the conductor survives the impact, the next point of failure is the attachment of conductor to the pole. Appendix E of that report describes an approach to analysis and methods used in modeling an overhead line strike by a branch. The basic method begins with a static load and approximates dynamic loading on the conductor from a falling object, such as a tree limb, using an energy balance equation.

3 EXPERIMENTAL DESIGN

The field work for this investigation involved dropping branches on a target and gathering data on mass, velocity, and acceleration. The intended focus was on branches considered large enough to cause damage to a typical overhead distribution line, but not large enough to automatically destroy poles or conductors.

Prior work by team members on the structural integrity of trees and branches under static and dynamic loads aided the development of experimental methods, data acquisition techniques, and application of test instrumentation. Field work was completed during the week of August 12-16, 2013, as part of the International Society of Arboriculture's Tree Biomechanics Week 2013. The event was a week-long scientific endeavor intended to provide researchers actively working in the area of tree biomechanics with the rare opportunity to come together, generate questions, exchange experimental design ideas, and coordinate scientific efforts on a common site.

The test location was the Davey Tree Company's research arboretum in Shalersville, Portage County, Ohio. This site has been used by the researchers for several projects including some for the Electric Power Research Institute (EPRI) [19], [20] that focused on step and touch potential associated with tree contact with conductors energized at distribution voltages (7-20 kV). Several species of trees commonly found as street trees were established at this location in the 1960's for the purpose of developing and testing new arboriculture practices. The crowns of individual trees in each of the planting blocks had closed to create a continuous canopy. The management objective for the research blocks was to create full crowns similar to those of street and landscape trees. Thinning operations were anticipated to open up the stands of test trees. This provided a population of trees scheduled for removal that were available for destructive testing.

Test Specimens - Branches

Arborists have become increasingly aware of the risks associated with hazard trees over the last several years. As a result, research has focused on the structural integrity of trees. More recently, the issue of branch failure within the crowns of trees has begun to receive attention. A gathering of some 200 practitioners in September 2012 at the Morton Arboretum[1] identified the failure of branches as a leading cause of damage and a significant concern shared by utility, commercial, and municipal arborists. Subsequently a gathering of tree biomechanics researchers identified crown and branch reduction as the third highest research priority.

The investigation focused on branches sufficient size to cause damage to a span of overhead distribution line. The decision was made to focus on branch failures in this investigation, as the more frequent tree failure mode; the frequency of incidences of damage to overhead power systems due to branches is higher than that due to whole tree failures under most weather

[1] *Tree Risk Assessment Symposium: The Biomechanics of Stability, Strength, and Structure,* Morton Arboretum, September 24-25, 2012

conditions. This has been the experience of the author and was confirmed by two sets of data provided by utilities that perform post-interruption site investigations (see Table 3-1). Tree related interruption data are typically stratified by magnitude of outage event. The data presented in Figure 3-1 exclude tree failures that occur during major storms.

Table 3-1
Branch and tree failure rates causing damage at two Midwestern utilities.

Utility Characteristic	Branch Failures	Tree Failures	% Branches
Large multi-state OH distribution system	1470	710	67%
Medium sized OH distribution system	126	80	61%

Another large utility reports an approximate 50/50 split between incidents involving whole tree failures and branch failures during typical weather conditions. At this same company the ratio shifts to 60/40 in favor of tree failures during Major Event Days (IEEE 1366). While whole tree failures during severe weather may represent a greater portion of the total number of incidents, perhaps more significantly the size of whole trees relative to individual branches likely results in greater physical damage done to an overhead distribution system infrastructure during major storms.

The potential for bias in the reporting of tree and branch failures should also be acknowledged. There are at least two reasons that this may be the case. The most reliable data come from after-incident investigations. Portions of a failed tree (e.g. stump, logs, and debris) are more likely to be found by an investigator during a post-interruption site inspection. Individual branches are easier to miss, particularly if the site has been cleared of debris. Secondly, it is not uncommon for tree failures causing the most damage to be the focus of post-incident investigation.

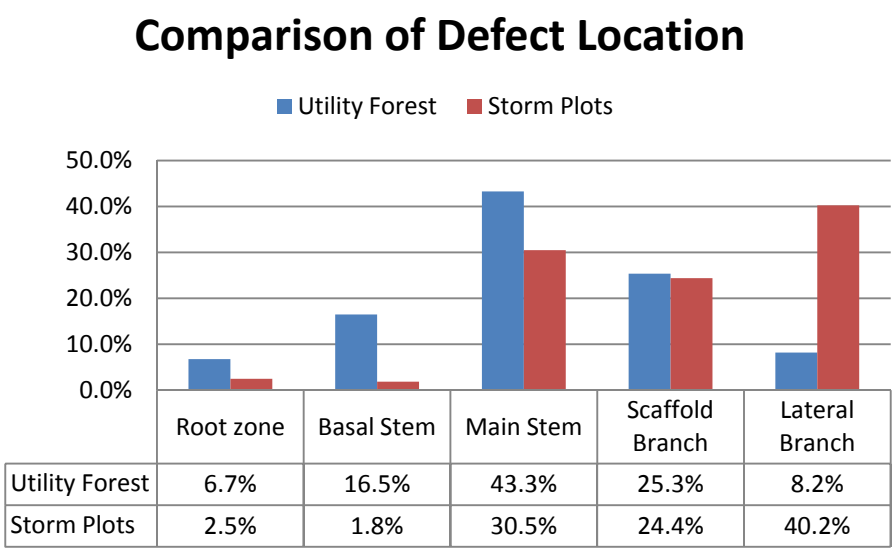

Figure 3-1
Location of defects in the general population verses defects that caused damage.

A condition assessment survey competed for National Grid USA included post incident assessments of tree failures that occurred during a devastating heavy wet snow storm. The location of structural failures in that subpopulation of trees was compared to the presence of

observable defects in the entire population (a.k.a. "utility forest") of trees in close proximity to the overhead distribution system. The results, presented in **Error! Reference source not found.**, reveal the extent to which branch failures contributed to interruptions.

The mass of whole trees can be an order of magnitude heavier than the branches tested, often exceeding 2,500 kg in weight. The destructive potential of whole tree strikes could be quite different than that of branches due to at least three factors: their much greater mass, fall pathway (rotation at a pivot point verses dropping from aloft), and velocity upon striking a target. These factors would need to be considered in an investigation of the destructive potential of whole tree failures. There are no known references that quantify the destructive potential of whole tree failures falling in to distributing line. Qualitative evidence clearly establishes that this too remains an important question.

The decision to focus on branch failures created the opportunity to replicate a series of drop tests. Branch specimens were limited to being from two tree species to build a meaningful sample set within the time constraints of the testing. Branch specimens were fully foliated at the time of harvest. As many as six replications were completed for each specimen: three in full leaf, followed by three with foliage removed.

Table 3-2
Gross characteristics of branch specimens used in the investigation.

Species	# specimens	Mass	Diameter	Length
London planetree (*Platanus x acerfolia*)	3	50 – 110lbs (112 - 245kg)	5.5 – 7.5" (14 -19cm)	15 – 19' (4.5 - 5.7m)
Silver maple (*Acer saccharinum*)	15	6 – 70lbs (14 - 155kg)	3 – 7" (8 - 18cm)	15 - 35' 4.5 - 10.5m

The species selected for use in this investigation demonstrated different crown and branch forms based on their representative structures. Specimens of London planetree had a well-defined central leader and relatively uniform horizontal branches (excurrent growth form). In contrast, silver maple specimens had multiple leaders and relatively short, tapered branches (decurrent growth form).

The specimens of London planetree were deliberately harvested by the researchers for this investigation. The silver maple specimens were generated by another researcher working on the site on a different but related project on storm-damaged trees. That work involved severely topping trees in an effort to simulate storm damage or the malpractice of tree topping. The material being removed was similar to the branch and stem failures that may be expected during severe weather, and provided a ready source of suitable specimens.



Figure 3-2
Silver maple trees being severely topped in an effort to simulate storm damage provided a ready source of specimens.

Branch data gathered included the mass, diameter at the cut end, length, and the height above the ground. The branch diameter and location of the center of gravity was also recorded.

Branch specimen preparation included attaching accelerometers at the center of gravity. Visual targets were also attached in positions close to the accelerometers.

The Target

A rigid section of well casing was used as the target for branch impacts. The pipe had a diameter of 4.5" (10cm), a wall thickness of ¼" (.55cm), and a mass of 66lbs (145kg). It spanned a distance of 13' (4m) and was suspended between steel tripods. The tripods were set on steel plates on sheets of plywood lying on the ground. An accelerometer was attached to the underside of the target immediately below the intended point of impact. Vertical and horizontal range poles were added to provide a means of calibration during video interpretation.

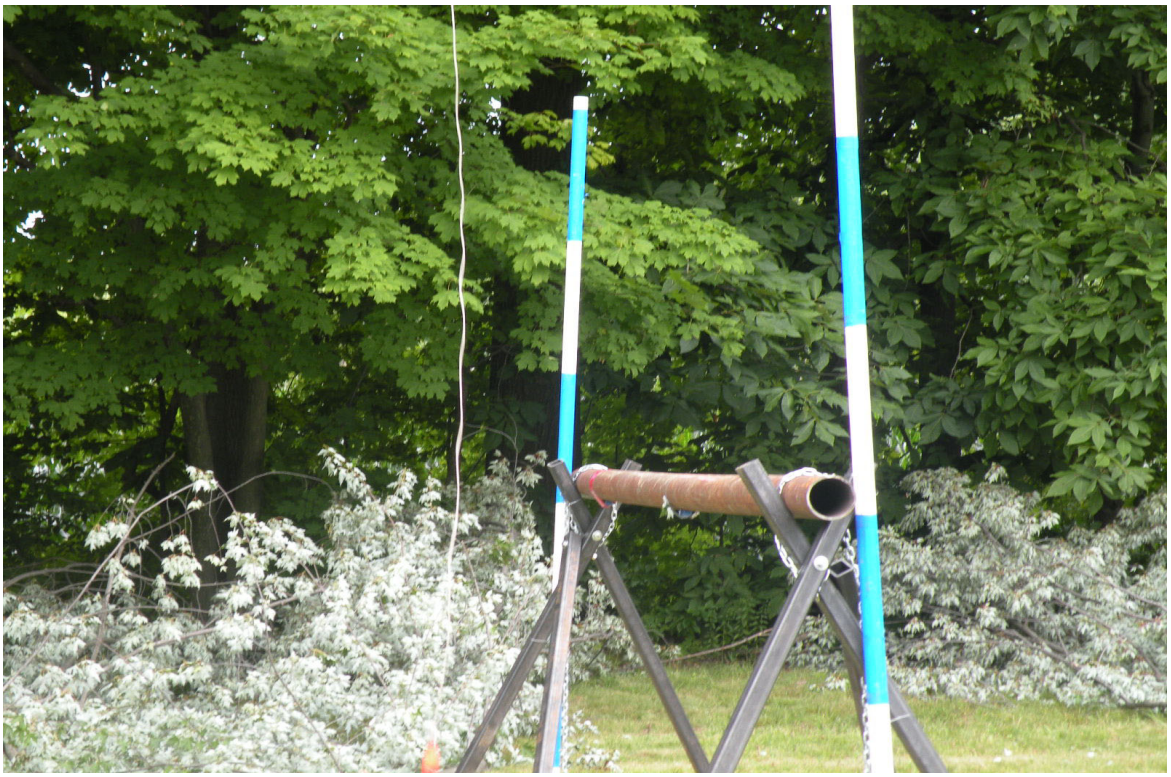

Figure 3-3
Test jig with rigid target

A rigid target was selected for this investigation because it would provide a basis for characterizing the worst-case impact. It was also a matter of simplification; rather than attempt to re-create various overhead line designs, we chose a single common reference that could then be used to model the dynamic behavior of a line strike.

Instrumentation

Data-logging USB accelerometers (Model X16-2, Gulf Coast Data Concepts) were used to record impact data on both the branch and target. Accelerometers were attached to the branch and to the target (pipe) in order to measure the peak force that occurred during the impact. Sampling rates of 12 Hz, 100 Hz and 400Hz were tested initially, with 100 Hz being used as the standard for all tests. The instrument is a tri-axial accelerometer that records X, Y and Z data in units of "g", where 1g = the acceleration due to gravity. The accelerometer g value is multiplied by the mass of the object to determine the force.

A high speed (300 fps) video camera was used to record each branch drop. Still photographs were shot using various digital cameras on site.

Both analog and digital scales were used in weighing the branch specimens. The larger branches required the use of a digital crane scale with accuracy to ±2.3lbs (±5kg).

Test Sequence

Once instrumentation was prepared, a nylon lifting strap was attached to the branch at the center of gravity. A crane was used to lift the specimen to a height of 23' (7m) above the target. The drop height was selected based on the difference between the average height of typical distribution lines, ~25 – 35' (~8-10m), above the ground and the expected height of the canopy of trees in the utility forest.

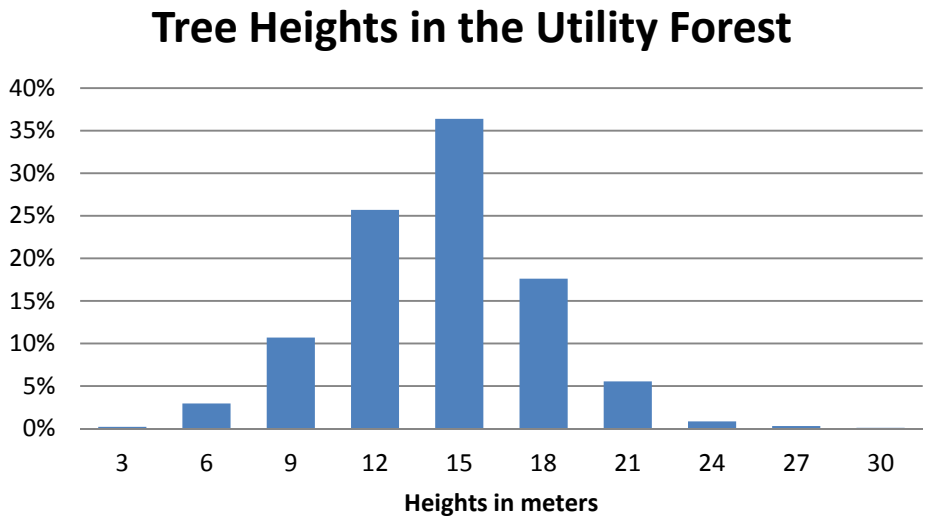

Figure 3-4
Heights of trees in close proximity to an overhead distribution system.

Information on the expected canopy heights presented in Figure 1-1 is based on a condition assessment study completed by the researcher for a utility serving customers in the northeastern US [21]. The utility forest is composed of those trees in proximity to an overhead line that are typically maintained during line clearance pruning operations. It also includes trees beyond the maintained corridor with a potential to cause interruptions. The 23' drop height was intended to approximate a branch falling into a span of distribution line.

A plumb bob attached at the center of gravity of the branch was used to assure that the branch was properly positioned above the target. Once in position, the specimen was released with a quick-release shackle attached to a trip line.



Figure 3-5
A defoliated branch specimen in free fall above the target.

This process of lifting and dropping was repeated three times for each branch. The foliage was then removed and three more drop tests were completed, for a total of six replications. In some cases the branch specimen was broken during the drops, reducing the number of replications. A total of 86 branch drops were completed with 18 branches.



Figure 3-6
Branch specimen and test jig following a drop test.

The full test setup and instrumentation can be seen in Figure 3-6, as a branch specimen that has been dropped is lifted off the target. A yellow nylon lifting strap is attached at the approximate location of the center of gravity. Arrows indicate the location of small blue accelerometers, seen on the target below the impact site and on the upper surface of the branch. A visual target is also located adjacent to the lifting point of balance indicated by the yellow nylon lifting sling. A vertical range pole used in video calibration is shown in the background.

4 ANALYSIS AND RESULTS

There were two different areas of analysis. Data pertaining to the physical characteristics of branches were analyzed in an effort to determine a suitable expression for describing the branch in an intuitive manner, and for use in the second stage of analysis. Data related to the falling branch were used to quantify metrics defining the destructive potential of branch strikes on a target. Both approaches are discussed below.

Branch characteristics

Three data sources were used in an analysis of branch characteristics. Descriptions of the 18 branches that were included in this investigation provided most of the data. Various combinations of diameter and length were evaluated in an effort to determine their relationship with mass. The principle of allometry, used in the study of relationships between the sizes of plant parts, guided this analysis. The second data source was generated by the researchers in an earlier research project [22] looking at branch failure mechanisms. This work contained data on the physical characteristics of 67 branches from six different tree species. Additional data were obtained from some of the literature review sources. Data tables in some of the studies referenced in the literature review contained sufficient detail such that the diameter, length, and mass of branches could be extracted for analysis, although branch mass data were somewhat limited.

The first task was to identify a suitable descriptor of a branch that would serve as an intuitive common reference for each of the expressions of destructive potential described further in this report. Branch weight and diameter are easily understood dimensions. Diameter can be easily determined by observation. The weight of tree branch located above a distribution line is not so easily estimated. The mass of each branch was required for each calculation, but arboriculture practitioners rarely work with mass.

Three sources of branch diameter and mass were analyzed. A comparison of mass and diameter of the branches revealed that diameter was a relatively good surrogate for mass.

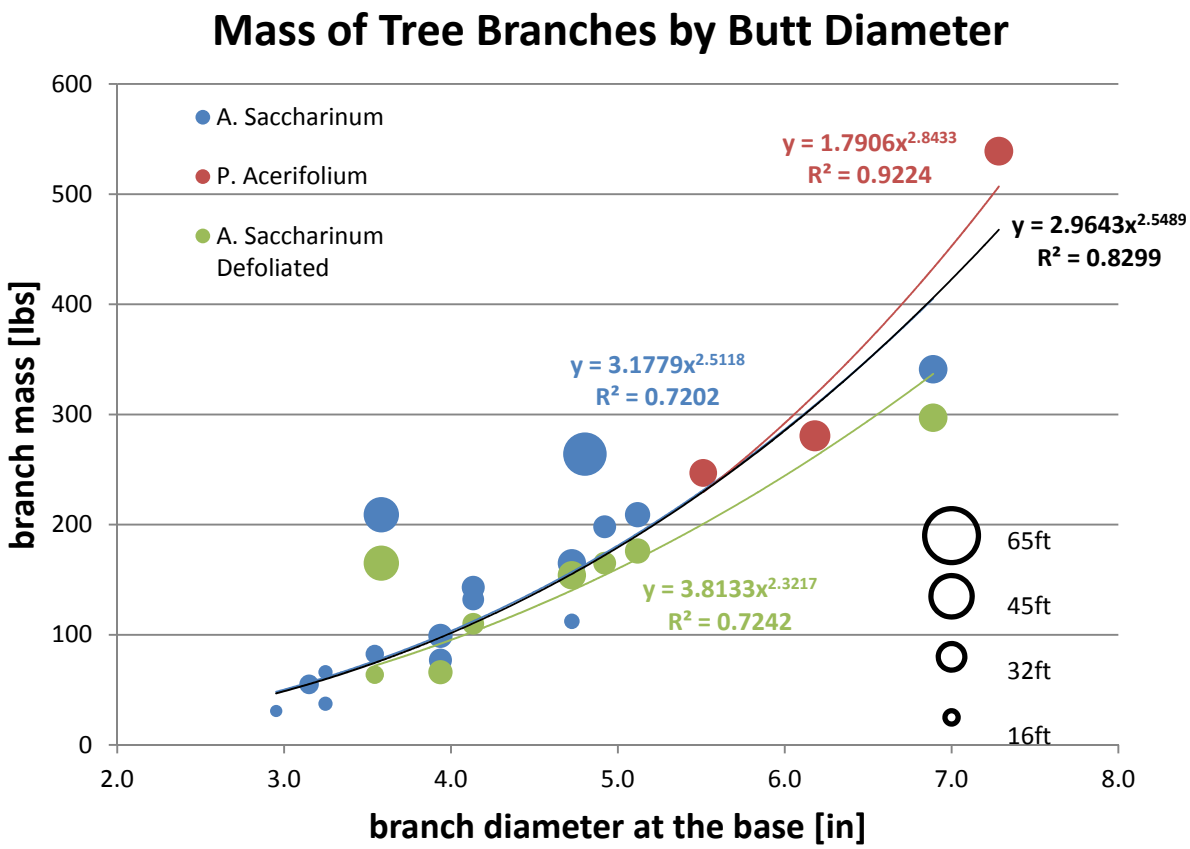

Figure 4-1
Relationship between mass and diameter for branch specimens used in this investigation.

The results of this analysis applied to the branch specimens that were used in this investigation (Figure 4-1) reveal a close correlation between branch diameter and mass. The effect of foliage is also apparent. As expected, branches lacking foliage weigh less than those in full leaf. An assessment of the change in mass between foliated and defoliated conditions found, as expected, that the relative weight of leaves to branch wood (defoliated branch) tended to be greatest for small diameter branches.

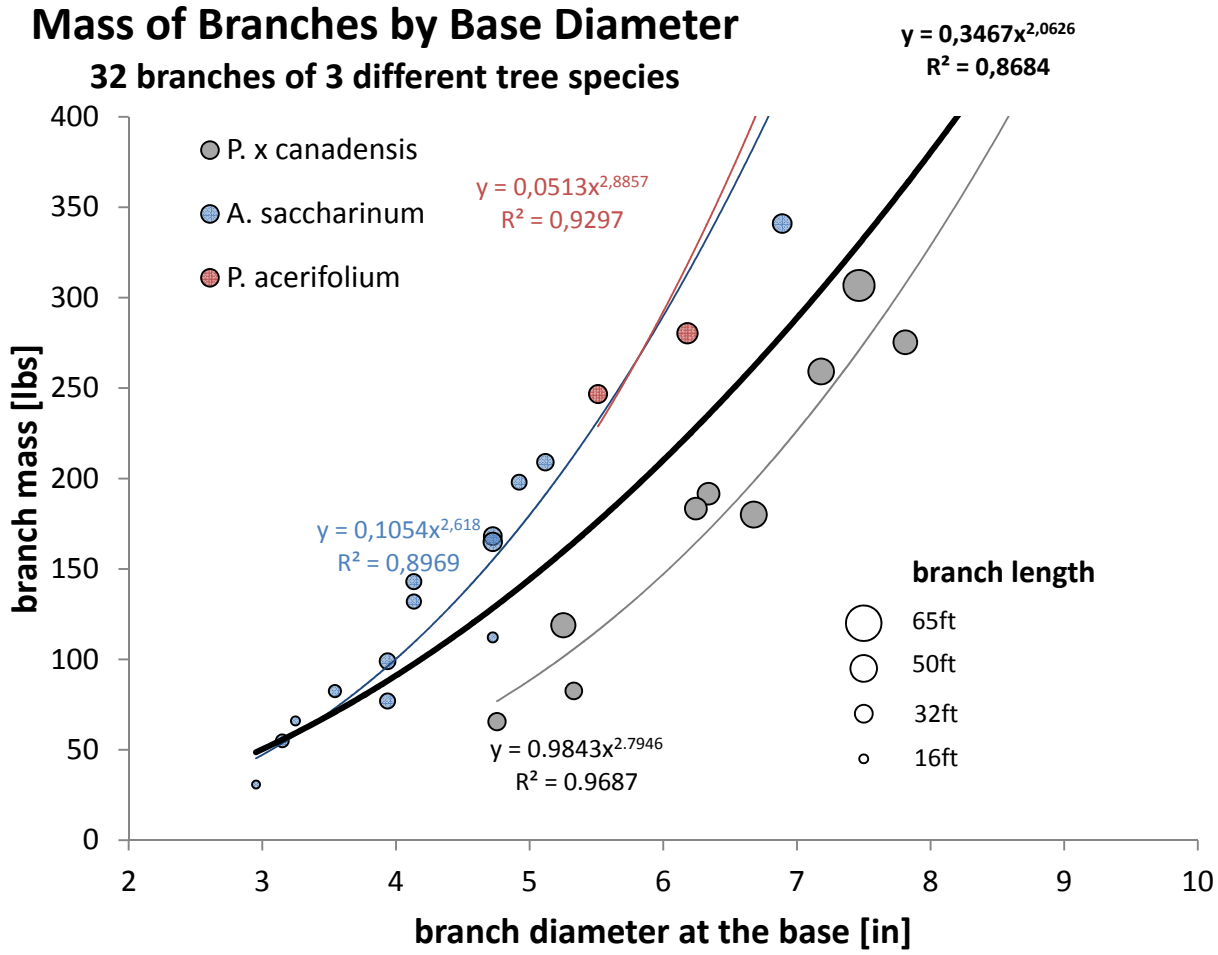

Figure 4-2
Comparison of branch characteristic between species.

The relative strength of this relationship was also present in other datasets. Figure 4-2 presents a comparison of the two specimens in a fully foliated condition, and also includes data on a hybrid cultivar of poplar [13]. As expected, a poplar branch of similar mass would be larger in diameter than either maple (*Acer*) or planetree (*Platanus* spp.)

Table 4-1.
Species-specific characteristics that affect the weight of live branches: density[2] and moisture content[3].

Species	Density (10^3 kg/m^3)	Moisture, sapwood	Moisture, heartwood
Populus spp. *(P. x canadensis)*	0.33	113%	95%
Plantree *(P. acerfolium)*	0.64	130%	114%
Silver maple (*Acer saccharinum*)	0.51	97%	58%

Both of Figure 4-1 and Figure 4-2 suggests that variability between diameter and mass appears to increase with increasing diameter and branch length. This trend was also confirmed in a reference cited in the literature review. Data from [17] pertaining to helicopter logging were used to generate Figure 4-3. The ability of estimate the total weight of a tree is a critical consideration in timber harvesting activities using helicopters to transport trees from the forest to the logging deck. This information would be available for other commercial timber species growing on remote and difficult to access site, and may be a useful reference supporting future work on whole tree failures.

[2] Source – *"The Engineering Toolbox"*, http://www.engineeringtoolbox.com/wood-density-d_40.html

[3] Source – *Physical Properties and Moisture Relations of Wood*. USDA Forest Service, http://www.fs.fed.us/ccrc/topics/urban-forests/docs/physical%20properties%20and%20moisture%20relations%20of%20wood.pdf

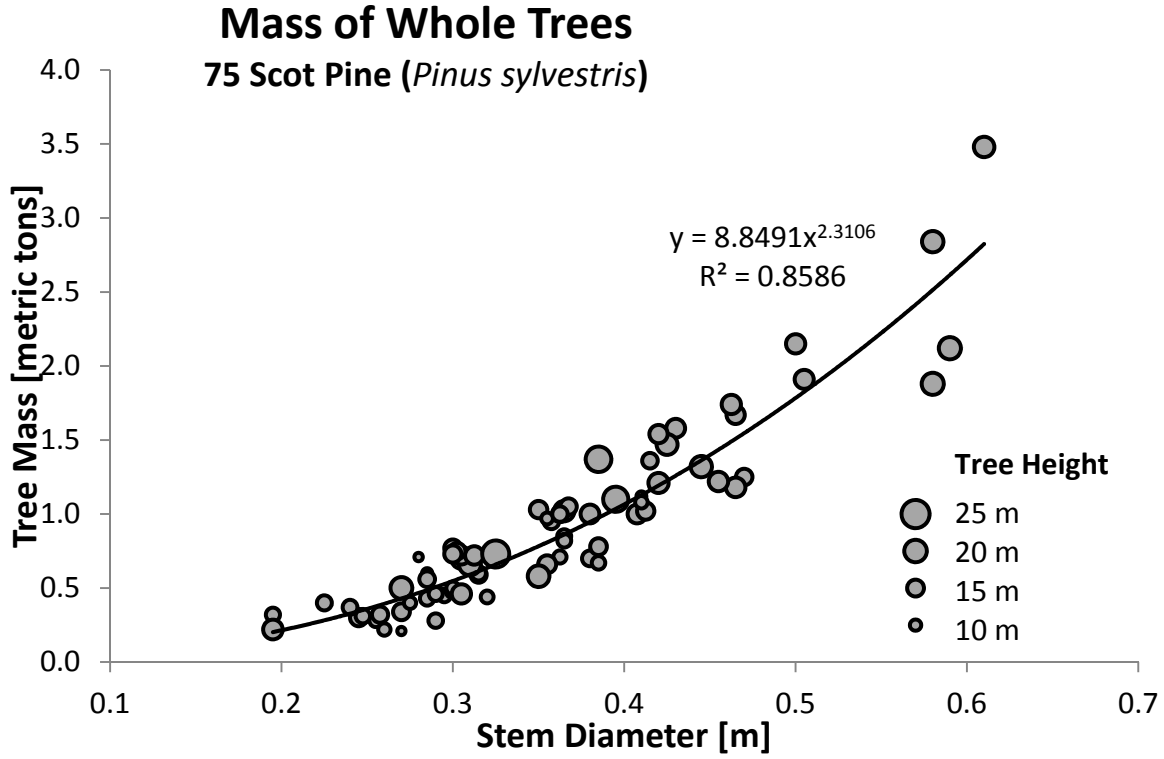

Figure 4-3
Example of distribution of masses and heights of one species based on helicopter logging study

Clearly the relationship between mass and diameter weakens with increasing branch size, length, and for whole trees. However, very large branches and whole trees were outside the scope of this investigation, as they are capable of impact forces on an overhead line that could create significant damage. This investigation was intended to identify the risk of line strikes that could be survivable through changes to energy delivery infrastructure.

Data available

Three types of data were acquired that are useful in characterizing the destructive potential of a falling branch:

1. The mass of the branch, determined by the direct measurement using a scale, affects the potential and kinetic energy, the momentum transfer, and force of impact.
2. The velocity of the falling branch, determined by analysis of high speed (300 fps) video interpretation.
3. The change in acceleration at impact, determined by direct observation by accelerometers on target and branch. The accelerometer on the target captured the g forces experienced due to the branch strike. The peak force, impact time (duration) and displacement (deflection) were measured. Data describing the deceleration of the falling branch as it impacted the target were also available but found to be less useful in predicting the response of the target to a strike.

Video Data

The purpose of the video analysis was to determine the velocity of the branch at the instant of hitting the target. Drop tests were recorded using a high speed video recorder capturing motion at 300 frames per second (fps). A software program (Tracker v 4.82) was used to analyze the motion of the drop recorded on the video.

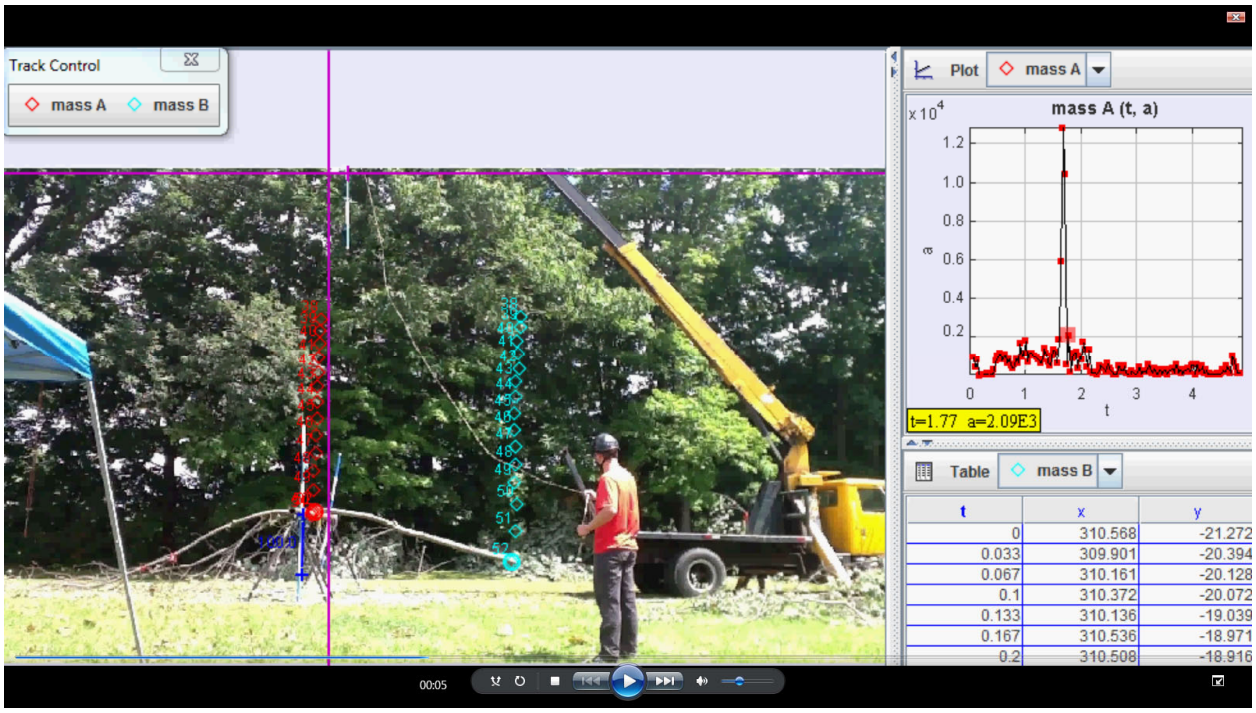

Figure 4-4
Determining velocity by video analysis.

Analysis determined branch position and time through the fall. Calibration was based on a defined distance for each drop and visual reference axis at the target location. The time interval between frames is known, and the software determines the number of pixels moved, from one frame to the next. Distance is determined using calibration scales and the velocity is then calculated by dividing the distance by the time interval.

This method introduced some error in velocity data. Visual targets on falling branches with many leaves sometimes resulted in the software having difficulty in identifying small area of pixels that moved from one frame to the next. The image contrast and quality in a few drops meant that a manual interpretation of some drops was required. Some error was introduced by inconsistency in image acquisition speed. The dynamic reactions of some branches on impact and momentary occlusion of targets created some challenge in identifying peak velocity at impact. There was considerable "noise" in the peak velocity curve. In a few instances, the velocity value was quoted above the theoretical maximum so the peak velocity value was corrected. This error was less than 5%.

Accelerometer data

At rest, accelerometers record the acceleration of gravity, which has a value of 1g. During the drop period, from 23ft to the point of impact, the object falls under the force of gravity and accelerates at 32ft/s^2 (9.81 m/s). During this drop period the mass is effectively weightless and the accelerometer records a value of zero. The accelerometer data therefore records the drop as a period of zero data.

At impact the accelerometers record the deceleration of the branch and the accompanying acceleration of the pipe. The peak values are recorded. The duration of the impact is also recorded with the resolution depending on the sampling speed of the accelerometer.

The magnitude of acceleration was calculated from the X, Y and Z components of the tri-axial accelerometer. This method meant that the orientation of the accelerometer did not influence the final value quoted for the drop test. A software program (LABVIEW) was used to read each file, calculate the result and generate graphs of the data for visual inspection.

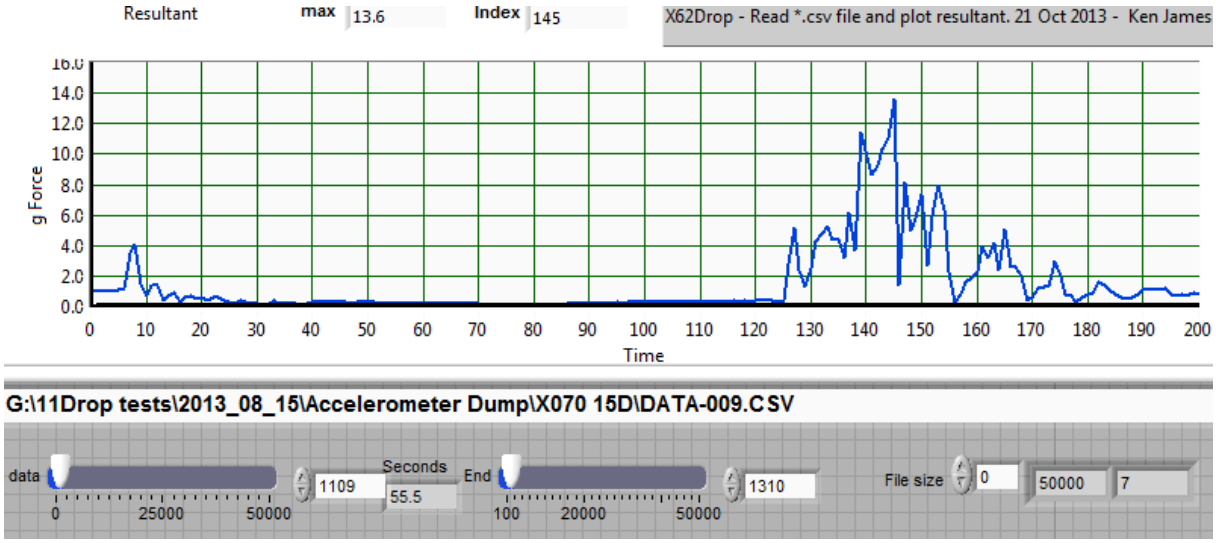

Figure 4-5
Determining peak acceleration experienced by a branch specimen during drop test. Note the x – axis is in no. of samples, taken in 0.01s intervals

The graph presented in Figure 4-5 illustrates the data provided by the accelerometer on a branch during a drop test. The graph begins with the specimen in position, where it experiences the force of gravity (1g). The first peak at ~0.07 occurs as branch is released. As it falls it accelerates the g-force experienced is nearly zero. Impact with the target occurs at ~1.25s. Peak acceleration (deceleration) occurs at ~1.45s. The dynamic response of the branch continues for approximately another half second. The corresponding response of the rigid target to the branch impact can be sees in Figure 4-6.

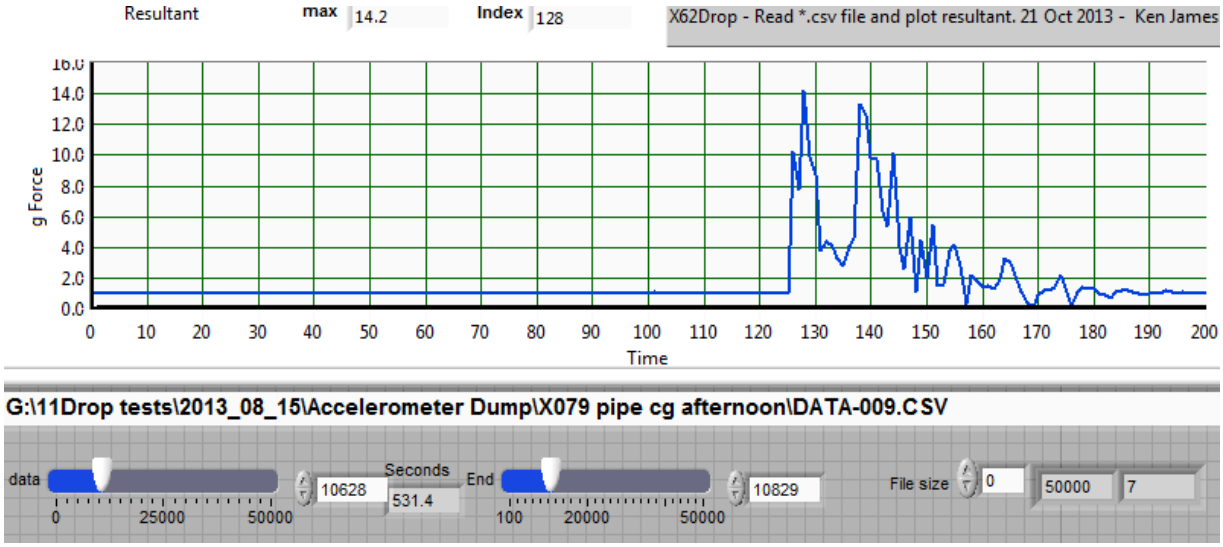

Figure 4-6
Determining peak acceleration experienced by the rigid target during drop test. Note the x –axis is in no. of samples, taken in 0.01s intervals.

As expected the target is as rest as the test begins, and continues to experience 1g until impact at ~1.25 sec. The resulting acceleration experienced by the target peaks soon thereafter. The initial peak value is used in calculating the force of impact.

Accelerometers were also placed on specimens as they were being harvested in an effort to characterize a simulated branch failure braking free from aloft in a crown and falling to the ground.

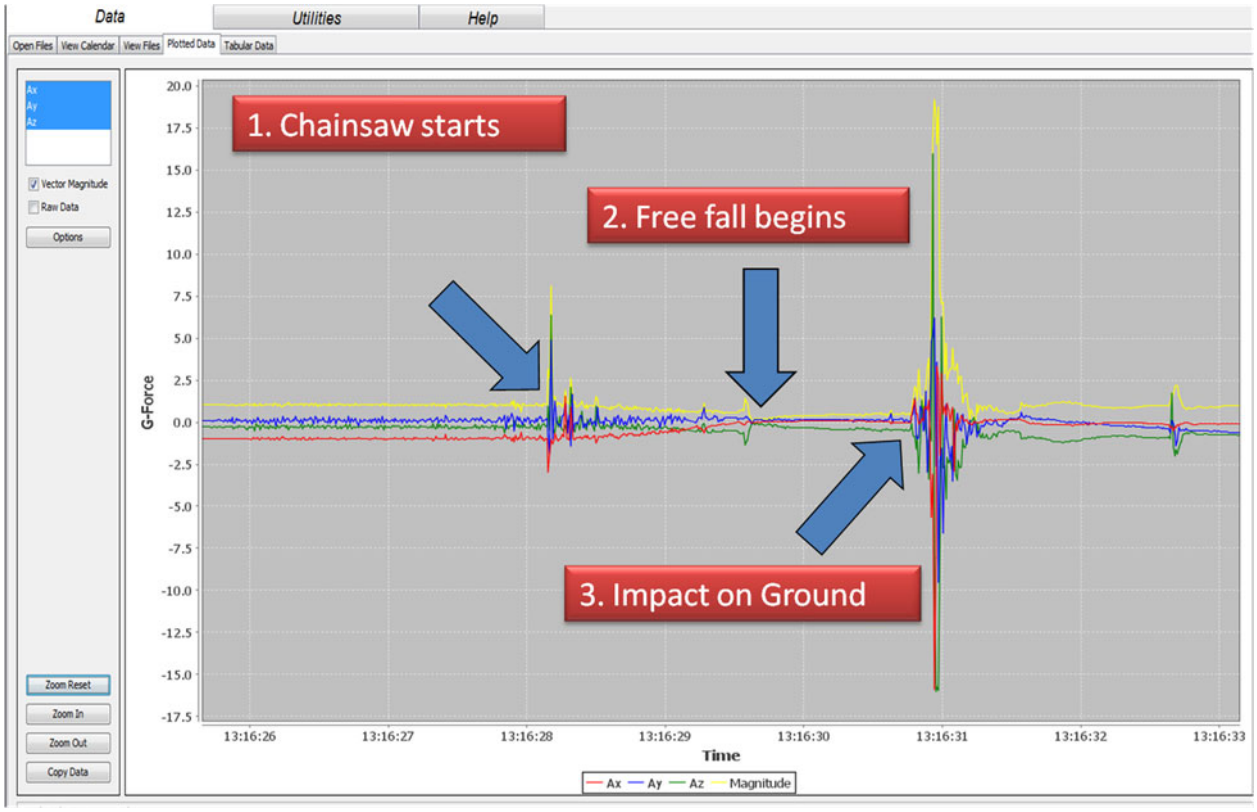

Figure 4-7
Accelerometer data from a branch as it is harvested from a tree and falls to the ground.

The initial disturbance captured in Figure 4-7 is caused by the arborist working aloft and the chainsaw cut. The specimen then begins to fall and is initially encumbered by other trees before reaching free fall (0g). Finally an impact occurs, first as small limbs make contact, and finally as the main branch section strikes the ground.

Limitations in the precision and accuracy of accelerometer data have the potential to introduce error. Impacts occur rapidly, often with millisecond changes. In some cases the sampling rate of 100 Hz may not have been fast enough to record the peak values. The error in the peak value at 100Hz is estimated at 10%. This is believed to be reasonable for the purpose of these drop tests.

Characterizing destructive potential

The destructive potential of the branch on the target at the point of impact was of primary interest for this investigation. This can be expressed with four metrics: potential energy, kinetic energy, momentum, and force

Potential Energy of a Branch

The potential energy of a branch at rest prior to failure can be calculated using the following formula:

Potential Energy (J) = mass * height *acceleration

Potential energy is a function of the mass of the branch, vertical distance above the target, and the rate of acceleration of the branch. The mass of each branch was determined. The height of each drop was a constant 23'. Since the intent of this investigation was to describe worst-case values, the constant for acceleration due to gravity was used in this calculation. The resulting value is the theoretical maximum energy available at impact.

Kinetic Energy of a Falling Branch

The kinetic energy of a branch as it falls toward a target can be calculated using the following formula:

$$\textit{Kinetic Energy (J) = 1/2 mass * velocity}^2$$

The kinetic energy of a falling branch immediately before impact was determined using data acquired in this investigation. The mass of each branch was determined. The velocity of the falling branch prior to impact was determined by video analysis. The actual velocity achieved by the falling branch is due to gravitational acceleration less an allowance for aerodynamic drag. The kinetic energy of the branch describes the maximum amount of energy actually available during the target strike

The potential energy of a branch at rest and the kinetic energy of a branch in free fall immediately prior to striking a target were calculated. Figure 4-8 presents a comparison of these two forms of energy. As expected, some of the energy represented in the branch at rest is lost to aerodynamic drag as the branch falls toward the target.

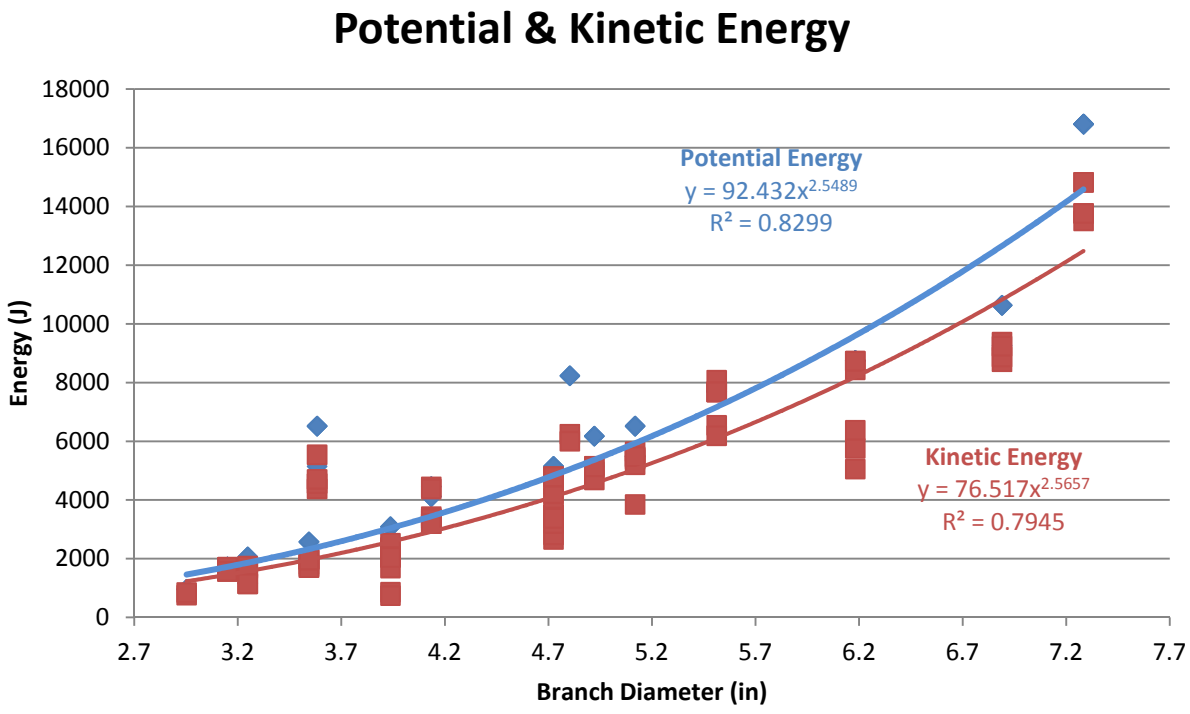

Figure 4-8
Energy available for transfer from branch to target.

A similar assessment of the effect of drag can be seen in a comparison of the kinetic energy associated with branches in full leaf as opposed to leafless, as they would be during the dormant season. Obviously this seasonal effect would not be relevant for conifers.

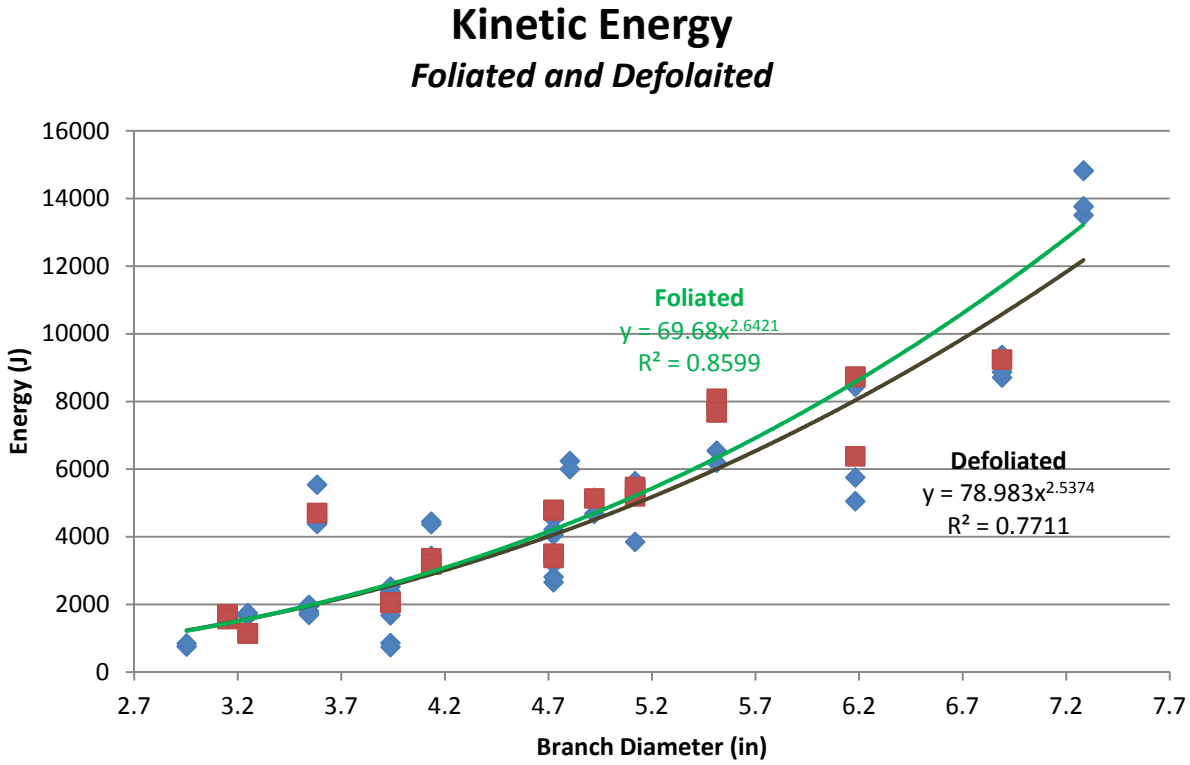

Figure 4-9
The effect of aerodynamic drag on fully foliated and defoliated branches.

Branches that were dropped in the leafless condition reached higher velocities at impact than those in full leaf, though the difference in velocity was not substantial. It should also be noted that none of the specimens achieved terminal velocity during any of the replicated drop tests. The drop distance was selected to represent typical field conditions. These replications suggest that impact velocities are limited by the relatively short fall distances between most branches in the upper crowns of trees and adjacent overhead lines. Since the branches were still accelerating prior to impact, branch failures on very tall trees and trees well up slope of the line have the potential to result in considerably higher kinetic energy available at impact with an overhead line. Given much greater fall distances, other factors may come into play such as changing orientation and streamlining by foliage. Both these factors would be expected to increase the speed of a falling branch and likely delay the time of fall required to reach terminal velocity.

Momentum of a Falling Branch

The momentum of a falling branch as it falls toward a target can be calculated using the following formula:

Momentum (kg m/s) = mass * velocity

The transfer of momentum from branch to target is a function of the mass of each branch and its velocity immediately prior to impact. The mass of each branch was determined. The velocity of the falling branch prior to impact was determined by video analysis.

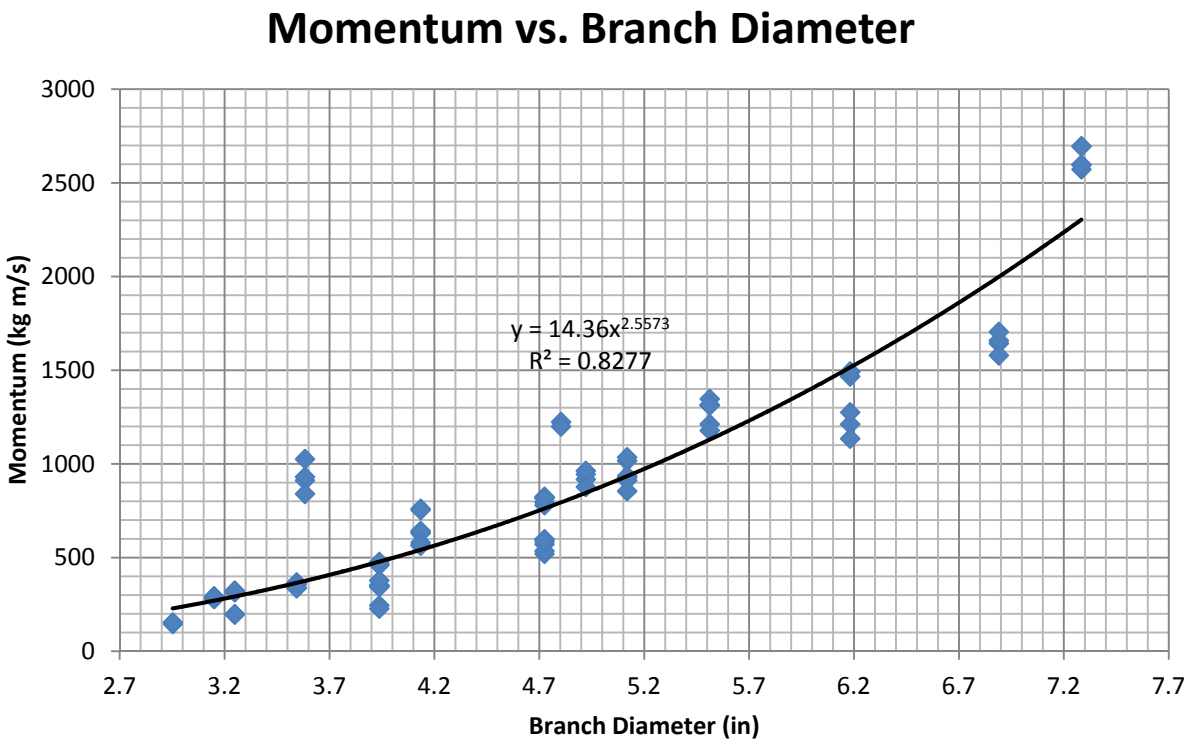

Figure 4-10
Momentum available for transfer from branch to target.

Branch momentum immediately prior to impact was calculated. The momentum of the branch at this point is available for transfer to the target upon impact. As expected, momentum increases with diameter, which in turn is an expression of mass.

Force of Impact

The force of impact experience by the target due to a falling branch strike can be calculated using the following formula:

$$Force_{target}(N) = mass_{target} * acceleration_{target}$$

The force of impact on the target is a function of the mass and acceleration of the target. The mass of the target was known and remained constant throughout the testing. Data were acquired describing rate of acceleration of the target by direct measurement. The composite tri-axial peak rate of acceleration was recorded by accelerometer and used to determine the force of impact. The rate of acceleration experienced by the target due to the impact of the branch is the most relevant data set for this investigation.

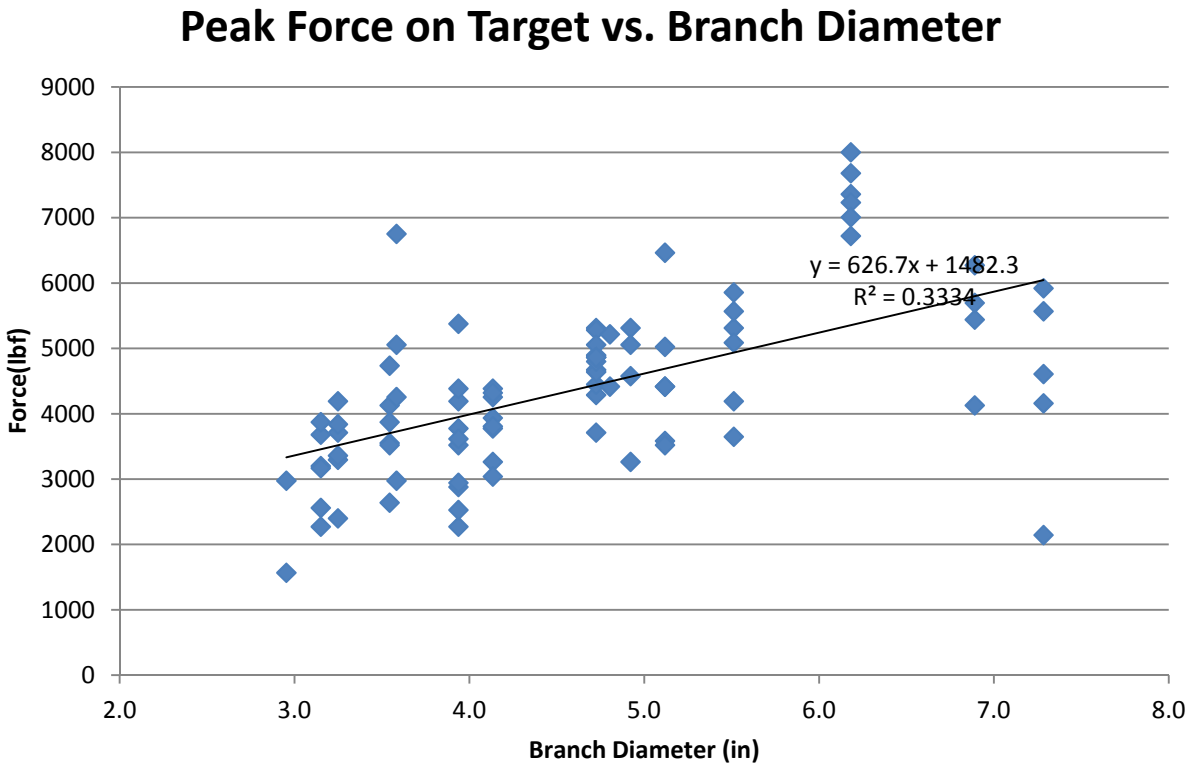

Figure 4-11
Force experienced by rigid target due to branch strikes

As was noted in the discussion of branch characteristics, the relationship between mass and diameter weakens as diameters increase. Observations for the largest branches 6.2 and 7.3" (15.7 and 18.5 cm) demonstrate this point. Both are relatively large diameter specimens of London planetree.

During any impact there is a transfer of energy from one object to another. The peak force will depend on both the amount of energy transferred and the time over which the energy is transferred. Because the time of impact is very short in these tests, when the branch hits the pipe, the peak accelerations are high.

If the time of impact were longer, as would be the case when a branch hits a power line, the peak acceleration and peak forces would be less as the energy transfer process is expended over a longer period of time.

Therefore these drop tests onto a pipe can be considered as a "worst case" when comparing how branches are likely to impact power lines.

Discussion

The first three metrics, potential energy, kinetic energy and momentum, describe the destructive potential of a line strike by a branch. Each is predictive in nature. All are calculated using variables that describe the situation prior to impact. They define attributes that are independent of the target. In other words, they are independent of whether the target is a rigid pipe or span of overhead distribution line.

Force, on the other hand, is dependent on the target characteristics and response due to impact by a branch. The response of an overhead distribution line is much more dynamic than a rigid pipe, and is dependant on a number of factors such as:

- Conductor type
- Span length and tension
- Flexibility of conductor attachment points, cross arms, and poles
- Guying and other pole attachments

The rigid target used in this investigation simplified the analysis and presents a worst-case scenario. The force of impact on a span of overhead conductor would be less than the force observed on the rigid target system, and the flexibility of the overhead line would absorb some of the impact.

Accumulated Weight of Snow and Ice on Branch Mass

The tests completed in this project took place August while trees were in full leaf. Dormant conditions were simulated by stripping leave. Accumulations of wet snow or ice can add significantly to the total mass of a falling branch, thereby increasing destructive potential.

Prior work by the researchers [21] provides some guidance on how much addition weight may be added by frozen precipitation. The mass of ten heavily loaded silver maple (*Acer saccharinum*) branches were selected and carefully cut from the trees that were in full leaf during an October wet snowstorm. A concerted effort was made to retain as much of the snow load accumulated on the foliage as possible during the removal and weighing process. Each branch was weighed and the combined weight of the branch and accumulated snow was recorded. The branches were then set aside and reweighed two days later after the snow had melted and the foliage was dry. The weight of accumulated snow was calculated by comparing the snow-covered and unloaded branch weights. The weight of accumulated snow averaged 165% of branch weight, and ranged from 100% to nearly 300%.

Subsequent work by the researchers [22] included developing a method for simulating the weight of ice accretion on branches, and was used to develop ice loading simulations for 90 branch segments. These data could be minded to develop a similar indication of potential ice loading on.

Limitations

The branches selected for testing in this experiment weighed at least 31lbs (14 kg). This was assumed to be large enough to cause physical damage to a typical overhead distribution line.

This may not capture the risk of damage due to line strikes by the smallest branches. Marshall [18] reported that simulation modeling of branches weighing 21-26 lbs (9.5-11.8 kg) falling from a height of 15 feet (<5 m) produced forces that exceeded 100% of an overhead system's designed mechanical load capacity. However, the theoretical branches used in those simulations were relatively short ±40" (±1 m), larger diameter (2.75 – 4") pieces of wood. The effect of aerodynamic drag for a fully leafed branch would be expected to reduce the impact force. The potential for error in observational and interpretative data is also acknowledged. The sensitivity of the scale used to determine the mass of the larger specimens was on the order of 5%, which is higher than would have been preferred. The velocity of specimens immediately prior to impact was determined by video interpretation. The velocity of some defoliated specimens was determined to be greater than the theoretic maximum velocity, 26.2mph. When this occurred, the velocity was reset to 26.2mph (11.7 m/s) based on assuming acceleration due to gravity through a 23ft fall. Finally, it was possible that the sampling frequency (100 Hz) of the accelerometer on the rigid target may not have captured the absolute peak velocity due to the rapid response of this kind of target. A comparison of data captured at 100 Hz and 400 Hz revealed this to be a source of error. However, all acceleration data used in the analysis were collected at a common frequency of 100Hz. This level of fidelity provided adequate data logging and storage capacity, and increased the efficiency of the data gathering process.

5 SUMMARY

This project has established some new insights in the destructive potential of branches. The four quantitative metrics of potential energy, kinetic energy, momentum, and force have been thoroughly discussed. There are some additional observations worthy of summary discussion.

Mass vs. Diameter

Analysis demonstrated that diameter is a good proxy for mass. Branch diameter is easily estimated by direct observation from the ground. Branch mass is not. Branch diameter should be useful in developing risk assessment methods, once the consequences of branch strike data on a rigid target are applied to typical overhead distribution infrastructure.

Potential vs. Kinetic Energy

Analysis demonstrated only a small difference between potential and kinetic energy. Therefore it is a good proxy for estimating kinetic energy at the point of impact. Potential energy is easily estimated by direct observation from the ground, and only requires an estimate of mass (based on diameter) and the height of the branch in question above the target (e.g. an overhead distribution line). Kinetic energy on the other hand would require an estimate of branch velocity. Potential energy should be useful in developing risk assessment methods, once the consequences of branch strike data on a rigid target are applied to typical overhead distribution infrastructure.

Leaves vs. Leafless

Analysis demonstrated only a small difference in fall velocities and rates of acceleration, and resulting values of kinetic energy, momentum, and force. This is likely due to the relatively low velocity ranges observed for drops of 23ft. Shorter distances would result in even lower velocities. Therefore is no need to consider the presence or absence of foliage in risk assessment methods.

Other Branch Failure Modes

This project focused on detached branches in free fall making direct hits on a target. A glancing blow was not simulated. It is also not uncommon for branches to fracture and remain attached to the main stem. In this case the arc of sweep of the failed branch. The effective mass and velocity of such a branch failure would be different than for the same branch in free fall. In either of these cases the force experienced by the target would be expected to be lower than free fall values.

Whole Tree Failures

This project did not consider the destructive potential of whole tree failures. Tree failure in the soil/root plate and stem fractures will result in different level of kinetic energy, momentum, and force available to a target strike.

6 RECOMMENDATIONS

This project has established a quantitative basis describing the destructive energy and resulting force experienced by a target struck by a falling branch. The values established are based on branch strikes on a rigid target, and are intended as worst case estimates. This information should be applied to study the structural load bearing capacity and behavior of overhead electric distribution lines:

1. Existing designs should be evaluated to determine those least likely to survive a branch impact strike of the magnitude characterized in this study. It should be possible to develop a means of ranking the relative robustness of in-service line types, leading to refinement in the industry's approach to risk based condition assessment work. An assessment of vegetative conditions associated with in-service plant of the most fragile designs could then be made in an effort to identify and mitigate elevated likelihood of branch failures.

2. The findings of this investigation should be used in an engineering investigation of potential improvement in overhead line design. It may be possible to reduce the risk of branch strikes by developing more robust designs for use in system improvement upgrades and new construction projects.

3. Findings from this investigation may also support the development of branch strike consequence rankings based on branch diameter and line type. Utility arborists applying risk assessment standards (ANSI A300 Part9) and best management practices (ISA Tree Risk Assessment) follow a basic rating method that considers both the probability and consequence of failure. To do so will require engineering analysis that will translate worst case strikes on a rigid target to the dynamic response of a line strike.

4. The findings of this investigation could also be in an engineering investigation of potential applications of "break away" hardware. That strategy could reduce the potential of conductors, cross arms, and poles breaking when a span is impacted by a branch failure, reducing restoration and repair times.

5. The study could be replicated to simulate both a glancing blow. Likewise the methods could be modified to simulate line strikes by branch that fail and that remain attached to the main stem. In this case the arc of sweep of the failed branch.

This project did not focus on characterizing the force of impact due to the structural failure of entire trees. The damage potential of line strikes by whole trees is clearly a cause of concern to the industry.

6. A similar study intended to establish a quantitative basis describing the destructive energy and resulting force experienced by a target struck by an entire tree should be considered. There are some important differences including mass, the manner in which trees fall over, and their position relative to lines. However the test methodology, instrumentation, and analytic methods developed in this the investigation of branch strikes can be adapted to a study of whole tree failures.
7. Other tree species should be examined with regard to their most likely failure mechanisms and the tests replicated under those circumstances (e.g. main stem failures on certain evergreens, etc.)

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Appendix E

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Appendix F: Using Vegetation Management, LiDAR and Infrastructure Data in Modeling Weather-Induced Damage to Electric Distribution Networks

Using Vegetation Management, LiDAR and Infrastructure Data in Modeling Weather-Induced Damage to Electric Distribution Networks

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Description: This reader will learn the value of different data related to vegetation management, tree height, and infrastructure data for predicting hurricane damage on distribution networks.

Abstract

In this paper, we investigate the use of vegetation management (i.e. tree trimming) and LiDAR-derived hazardous tree information (HazPix) for predicting damage to the eastern division of Connecticut Light & Power (CL&P) service territory during Hurricane Sandy (2012). In addition, we show the benefit of using attributes of the overhead lines (e.g. percentage of bare or covered wire; percentage of backbone or lateral circuit). Random forest regression was used to predict a binary response variable denoting whether or not any damage occurred in a 0.5-km grid cell. Five model forcing complexities were evaluated by selecting the model with the most improved error metrics. Although all model forcing complexities improved the damage prediction relative to a baseline model, the model forced with HazPix data was the most accurate model for predicting hurricane damages. Additionally, we ran a sensitivity analysis using the HazPix data that showed a moderate increase in the number of HazPix could increase hurricane induced damages by more than 20%. As LiDAR data becomes more widely available for New England, HazPix can be incorporated to improve existing damage prediction models and facilitate vegetation management impact assessment studies.

Keywords: Electric distribution network, damage prediction model, vegetation management, utility infrastructure, storm hardening, LiDAR, random forest, machine learning

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1. Motivation

Connecticut has been subjected to prolonged power outages due to the interaction of trees and overhead lines during major storms (i.e. Storm Irene and the October nor'easter in 2011, and Hurricane Sandy in 2012). Hurricane Sandy was especially damaging for Connecticut, with >500,000 customers without power at peak and >15,000 damages ("trouble spots") mostly caused by branches or entire trees falling onto the overhead lines. Exacerbating matters, Connecticut residents "live at nature's doorstep": Connecticut has the highest woodland/urban ratio in the United States [1], so major storms are potentially more damaging in Connecticut than anywhere else in the country.

Trees provide a host of benefits; trees provide habitat for wildlife, shade for cooling, and are aesthetically pleasing to view. Electric utility companies are tasked with managing these tree stands surrounding overhead lines to maintain acceptable reliability for customers (e.g. limiting the number of interruptions and duration of outages). The management of trees and other flora around overhead lines is known as vegetation management (VM); a multi-faceted program that consists of managing trees by trimming above, below and on the side of overhead lines; and the management of vines and shrubs. In the field of damage prediction modeling, land cover has primarily been used to represent the local tree conditions around overhead lines [2].

In this paper, we evaluate how different model forcing complexities related to trees can improve damage prediction models. Specifically, we evaluate the benefit of VM data and a new LiDAR-derived hazardous tree pixel dataset we created as an alternative to land cover data. Additionally, we also evaluate whether the inclusion of detailed data about the overhead lines (i.e. bare or covered conductors; backbone or lateral circuits) can improve the model error metrics. Given the temporal and spatial constraints of the data, we focus our paper exclusively on

damages during Hurricane Sandy (2012) in eastern Connecticut. *Note: our paper does not entail which individual data are most effective for preventing damages; rather, we seek to identify those forcing data that are best for predicting the occurrence of damage, and then connect this research to impact assessment studies.*

2. Background

Many models have been created to predict storm damages for distribution networks using statistical [3-5], data mining [6, 7] or hybrid approaches [8]. Examples of variables used in the damage models include: wind gust, sustained wind, soil moisture, attributes of the electric infrastructure (i.e. sum of isolating devices, line length) and land cover [5, 9]. Given that land cover has generally been used to represent the trees around the overhead lines, we seek in this study to show that incorporating additional tree-related data around the overhead lines could improve the accuracy of damage prediction models.

2.1 Detailed Utility Infrastructure

The distribution network is comprised of overhead and underground lines (excluded from our study). Certainly hurricane damages would be reduced if the overhead lines were undergrounded, but cost can be prohibitive [10]. The overhead distribution network has many attributes that contribute to whether or not damage occurs; including different conductor types; pole size, age and material; cross-arm size, material and configuration; and operating voltage. In order to simplify our study, we chose to focus on attributes directly related to the conductors. We generalized all of the conductor categories that are discussed in [11] into two general categories: bare or covered conductors (Table 1). The reasoning behind the reduced classification was that different conductor types suffer from different types of damage (i.e. incidental touching of trees

for bare conductors, destruction of conductors for bare and covered conductors), occurring with varying frequency.

In addition to conductor type, the distribution network can also be divided into two circuit categories: backbone and lateral circuits. A backbone circuit is defined as "the portion of the three-phase distribution circuit beginning at the substation and ending at transitions to single- or multi-phase circuitry protected by single phase devices"; a lateral circuit (or side tap) is defined as "a single or multi-phase portion of a distribution circuit that is supplied by the backbone feeder and protected by single-phase devices" [12]. An analysis by Burley [13] showed that backbone circuits for CL&P had lower interruption rates (trouble spots/mile of overhead line) than lateral circuits, which he attributed to Enhanced Tree Trimming (ETT) programs in the late 1990s and early 2000s. The backbone interruption rate for Storm Irene (2011) and the October nor'easter (2011) was 46% and 55% better than lateral lines, respectively. With the knowledge that backbone circuits perform better than lateral circuits because they have been maintained better led us to segregate overhead lines by circuit type (backbone or lateral) in addition to conductor type (bare or covered).

2.2 Vegetation Management

Although there is a sizeable amount of research devoted to VM, right-of-ways (ROWs) and transmission lines, there is considerably less research for distribution networks. However, the general consensus of research is that VM can decrease outages for storm and fair-weather days. Guikema [14] showed that trimming on distribution circuits decreased outages during fair-weather days, and Poulos [15] showed, among other conclusions, that risk trees were generally present in areas that had forested and residential land uses and low to middle elevations. Utilities cannot trim everywhere all the time because VM must be done with a limited budget (delivering

electricity at low rates while being proactive is a difficult compromise). VM programs must balance the proactive with the reactive: utilities need to trim the most in areas that have lowest reliability, but also need to be proactive and keep circuits on an appropriate trimming cycle to prevent future damages. Although multiple VM trim cycle strategies exist (generally, 3 – 6 years), Kuntz et al. [16] showed that an optimized vegetation management program as a function of utility cost and customer cost could yield an improvement in reliability (4 – 6%) and a (9%) reduction in total cost. Utilities employ a variety of trimming treatments based on tree conditions, past reliability and customer needs: standard maintenance tree trimming (SMT) usually occurs in lower risk areas, and a more aggressive form of VM known as enhanced tree trimming (ETT, described more in Section 4.4) is used in areas with higher risk.

2.3 LiDAR-Derived Tree Height Information

Utility trimming locations are incomplete data, because such data do not provide quantitative data related to the local tree conditions (they only provide insight into the VM that occurred). However, airborne Light Detection And Ranging (LiDAR) makes it possible to develop accurate models of tree heights and locations over large areas. Airborne LiDAR data have been used for more than a decade to model the heights of forest canopies [17]. Canopy height models (CHM) are digital representations of a forest canopy and can make it possible to identify trees that are within striking distance of power lines. The identification of these trees provides a direct physical basis for damage prediction models. Identifying tree crowns is an ongoing challenge in the field of remote sensing with deciduous trees being particularly difficult to map without very high resolution LiDAR data. Thus, we use “hazardous tree pixels” as a proxy for hazard trees. We define hazardous tree pixels (HazPix) as 1-m pixels in a canopy height model (CHM) that are tall enough and close enough to contact a power line in the event of

a whole or partial tree failure. Multiple hazardous tree pixels can correspond to a single tree; however, intuitively there should be a high correlation between the number of hazardous tree pixels and number of hazard trees in a given area.

This paper is divided into seven additional sections. Section 3 describes the study area; Section 4 describes the data used in more detail; Section 5 describes the methodology and error metrics; Section 6 presents the results, followed by a discussion in Section 7; Section 8 is a sensitivity analysis involving HazPix, and Section 9 includes the conclusion and future areas of research.

3. Study Area and Spatial Resolution

The study area (Figure 1) is eastern Connecticut due to the availability of LiDAR data over the region (see explanation in Section 4.5.1). CL&P delivers power to nearly every town in eastern Connecticut except for three (Bozrah, Lebanon, and Norwich) that are served by other utilities. A spatial grid resolution of 0.5-km was used to aggregate the data; resulting in 9,000 0.5-km grid cells covering the study area. Our gridded approach allowed the explanatory variables to be represented as the average conditions in each grid cell. All explanatory data with the exception of the weather simulation data was processed at the 0.5-km grid resolution (weather simulation data was processed at a 2-km grid – see Section 4.2 for details). Eastern Connecticut has a diverse landscape: from a coastal southern region to northern hilled topography with the Thames River valley running through the center. Population is most concentrated along the shoreline, along the river valley, and around the University of Connecticut in Storrs and Mansfield.

4. Data

4.1 Binary Response Variable

Damages to the overhead lines are known as trouble spots; trouble spots are geographic locations that require a line crew to restore power [12]. A trouble spot is different from an outage; an outage is the number of downstream customers affected from a trouble spot, a trouble spot is a point location and is independent of the customers affected. Of the 9,000 0.5-km grid cells in our spatial domain, 1,320 had one trouble spot, 440 had more than 1 trouble spot, and no grid cell had more than 8 trouble spots. This led us to investigate binary response models that used a balanced sampling approach to investigate the accuracy of damage model predictions. An indicator of "1" was assigned to the variable "BinaryTS" if damage occurred in the grid cell; otherwise a "0" was assigned.

4.2 Weather Simulation and Verification

For this study, we used the weather events simulations described in Wanik et al. (submitted); the events were simulated using the Advanced Research (ARW) dynamics core of the Weather Research and Forecasting Model (WRF) version 3.4.1 [18]. Each event simulation was dynamically downscaled from analyzed fields provided by the Global Forecast System (GFS, at 6 hourly intervals with 1.0 degree grid resolution) produced by the National Center for Environmental Prediction (NCEP). In order to minimize initial condition (IC) and boundary condition (BC) uncertainty, the events were modeled as hindcast (e.g. the GFS analyses were used to derive both the model's IC and BC updates). For the WRF setup, three nested domains (at 18-km, 6-km, 2-km grid cell resolution) were created to gradually downscale from the 1.0 degree (~111 km) GFS analysis to a 2-km grid resolution, using a topography dataset at 30 arc-second

(~1 km) resolution. Since we used 0.5-km resolution (sixteen times finer than 2-km resolution) to aggregate the other explanatory variables in our models, the centroid of each 0.5-km grid cell that fell within the 2-km grid cell of the WRF model analysis was assigned the weather of that corresponding 2-km grid cell.

To capture the dynamics of the storm severity, we used a 4-hour running window to calculate the mean and maximum of weather variables. The mean value was calculated to provide the average "intensity" of the storm, while the maximum was calculated to represent the maximal intensity during the peak of the storm (Figure 2). A maximum and mean parameter was created for each of the wind and precipitation variables we calculated. The maximum value was the peak value during the storm; the mean was taken from the average of the 4-hour running window that contained the maximum value. In addition, we also calculated the duration of wind above designated thresholds for gust and sustained wind (Figure 2). All variables were calculated over for the duration of the simulation (48 hours). A list of wind and precipitation variables that were simulated and used as predictors in the models is listed in Table 1.

We next present an abridged discussion on the verification of wind speed data. The numerical weather simulation of Hurricane Sandy was evaluated against actual wind speed observations using airport station meteorology data provided by the National Centers for Environmental Prediction (NCEP) ADP Global Upper Air and Surface Weather Observations [19]. Specifically, above ground wind speed at 10 m ("sustained wind speed") was compared to the modeled wind speed taken at the individual airport weather stations. Sustained wind speed was calculated by taking the mean of a 4 hour running window that contained the maximum value, spanning the duration of the simulated event. The error analysis was performed on the data pairs (WRF and NCEP ADP stations) of sustained wind speed time series and the

corresponding sustained wind speed values from each station location. The model simulation for Sandy exhibited predictions close to the observed values. The mean bias (MB) was low (0.56 ms^{-1}) and the correlation varied from 0.6 to 0.8 depending on the weather variable. The uncertainty ratio (characterized as the ratio of standard deviation from modeled to observed fields) was 1.2, indicating strong similarity in the predicted and observed variability of wind simulations.

4.2 Infrastructure

"Storm hardening" of the distribution network refers to using more resilient infrastructure and practices in order to improve system reliability. In order to fully evaluate the characteristics of the distribution network within the context of storm hardening, a full and reduced dataset of infrastructure was prepared for our analysis. Given the previous work by Burley [13], which showed that there were significant decreases in damage between backbone and lateral circuits (attributed to tree trimming), and decreases in damage between bare and covered conductors (due to faults from incidental touching of trees and overhead lines), we wanted to show if this data provided any better information for the model. The reduced dataset included only the sum of isolating devices per grid cell (i.e. fuses, switches, transformers, and reclosers). The full model included additional information on circuit type (backbone or lateral), conductor type (bare or covered) and the sum of isolating devices per grid cell. The lengths by circuit design and conductor type were normalized by the total overhead line length and converted into percentages (i.e. "percentage backbone and bare conductor per grid cell"). To ensure there wasn't a linear combination of variables, the "backbone covered" category was left out of all models forcing complexities.

4.3 Land Cover

The methodology used in Wanik et al. (submitted) was applied in this study to calculate the land cover around power lines using the 2006 land cover data over eastern Connecticut but at the 0.5 km grid resolution [20]. Specifically, the shapefile of CL&P's overhead lines was overlain on top of 30 m resolution land cover data from the University of Connecticut's Center for Land Use Education and Research (CLEAR). A 60 m buffer was created around the lines to capture the surrounding land cover around power lines. Points were placed uniformly every 30 m along each side of the buffer, and were spatially joined to the land cover layer. The percentage of points in each land cover category was calculated for each 0.5-km grid cell. Of all the land cover categories available, the percentages of deciduous and coniferous forest were combined into a single variable called "PercentForest" (the sum of the deciduous and coniferous percentages). All other land cover variables were excluded from our analysis. Using the processed land cover data, it was determined that trees species in eastern Connecticut are five times more likely to be deciduous than coniferous.

4.4 Vegetation Management

The primary objective of vegetation management is to remove overhead risk (which includes all dead, dying, diseased, insect infested and structurally weak branches), while considering tree species, condition, growth rate and location. The Enhanced Tree Trimming (ETT) specification during 2009 – 2012 along the roadside varied for backbone and lateral circuits. Regarding ETT roadside clearance for lateral circuits, the clearance zone is from the conductor, 8 feet to the side, 20 feet overhead and cut brush flat to the ground; for backbone circuits, the clearance zone from the conductor is clear overhead and cut brush flat to the ground. Comparatively, the Standard Maintenance Trimming (SMT) specification during 2009 -2012 was less aggressive. For SMT

roadside clearance for lateral circuits, trimming must provide a minimum of 20 feet of overhead clearance within reach of a 55 foot lift unit; for backbone circuits, trimming must re-clear to previous overhead clearances within reach of a 70 foot lift unit. In all cases, if greater than one third of the tree was removed, the entire tree should be removed (when appropriate).

The eastern Connecticut vegetation management data was acquired by CL&P as annual planning shapefiles for years 2009 – 2012. Vegetation management polygons and polylines (Figure 3) were spatially joined with the overhead lines per grid cell and the corresponding percentage of vegetation management by circuit type and conductor type were calculated (i.e. "percentage of backbone bare lines that received ETT", see Table 1 for details). Instead of measuring vegetation management as "years since last trim" per circuit (as many electric utilities do), we present the average conditions within a grid cell by conductor type (bare or covered) and circuit type (backbone or lateral). We account for vegetation management efforts by summing the length of treatment by wire type in each grid cell and normalizing by line length. A linear decay function (Equation 1) was applied to the SMT to express the diminishing benefit of such treatments as time passes (e.g. given that CL&P strives to be on a 4 year trimming cycle, a 25% decay was applied for each passing year). A cumulative function (Equation 2) was applied to ETT because the benefit of such trimming activities is thought to be longer lasting and more effective than SMT.

For each conductor type and circuit design:

$$SMT\ Value = \sum_{j=2009}^{2012} SMT_j \cdot r \cdot (2012 - j) \quad (1)$$

$$ETT\ Value = \sum_{j=2009}^{2012} ETT_j \quad (2)$$

In the above two equations; SMT and ETT refers the percentage of lines that were trimmed during the year, respectively; the year is j; the linear decay rate (25% per year) is *r*. Note that Sandy occurred in 2012 and our trimming data started in 2009. Refer to Table 1 for a summary of the different variables related to vegetation management. Grid cells with low overhead line length could have multiple VM planning shapefiles on the same circuit, which would inflate trimming values to >100%. In these cases, a value of 1 was assigned to these pixels, because trimming likely didn't occur more than once in the same year.

4.5 Calculating Hazardous Tree Pixels (HazPix)

4.5.1 LiDAR Data Description

Airborne LiDAR data were acquired for nearly 4,600 km^2 in eastern Connecticut from November 3 – December 11, 2010 [21] (Figure 1). The data were collected with a Leica ALS60 Airborne Laser Scanner at an altitude of approximately 2,000 meters above ground level. At this altitude, the ALS60's beam divergence of 0.22 millirads creates a footprint of roughly 44 cm on the ground. The scanner's pulse rate was 117.9 kHz and the pulse wavelength was 1064 nm. The flight line overlap was 50% and the data provider eliminated data between the geometrically usable portions of the swaths. The maximum scan angle of the sensor was 16.5^0 from nadir and it recorded up to 4 returns per laser pulse. The dataset has an overall density of 1.56 returns / m^2 with a maximum point spacing of 0.7 meters, excluding water bodies. The horizontal accuracy of the dataset is equal to or better than 1 meter RMSE. The project's principle contractor processed the LiDAR data to create a bare-earth Data Elevation Model (DEM), at a 1-meter resolution, with building features removed. Dewberry [21] evaluated the accuracy of the DEM using 62 surveyed ground control points distributed through non-vegetated, grass, and forested terrains. The vertical RMSE for the DEM, based on ground control points, was estimated at 5 cm in non-

vegetated terrain, 17 cm for grassy terrain, and 21 cm in forest terrain. The primary purpose of the LiDAR dataset was to develop the bare-earth DEM for use in conservation planning, floodplain mapping, dam safety assessments, and hydrological modeling [21].

4.5.2 Canopy height model

A canopy height model, based on airborne LiDAR, was created following the methods described in [22]. The CHM was created by subtracting the bare-earth DEM, created by Dewberry [21], from a digital surface model (DSM) that we created from the LiDAR data. The DSM corresponded to the maximum elevations in the tree canopy and was aligned to the DEM grid and had the same 1-meter resolution. The cell values for the DSM were determined by taking the maximum of all non-ground first-return points within a given cell. Because the overall density of the LiDAR dataset was 1.56 returns / m^2, the majority of non-water pixels in the DSM grid contained at least one first-return point. The first-returns were filtered to remove points that obviously did not correspond to features on the earth's surface (e.g. large birds in flight). These anomalous points were identified by comparing each first-return to all points within a 2.5 meter radius. Points were discarded if they were more than 30 meters taller than any other points within the neighborhood. We selected the 30-meter threshold because it approximates the upper limit of canopy heights in northeastern forests and thus it represented a reasonable maximum elevation difference for points along forest gaps and edges. Considering the point spacing of our airborne LiDAR data, we assumed that continuous data gaps larger than 3 meters in radius were likely to correspond to water, which tends to absorb LiDAR energy [23]. The bare-earth DEM values were assigned to the cells in these larger data gaps that were presumed to correspond to water bodies. A test of 52 1x1 km sample areas showed that only 12.9%, on average (std. dev. = 3.4), of the areas consisted of data gaps for which there was no first-return data. More than 91% of

these gaps were less than 1 meter in radius; approximately 7% of the gaps were 1-2 meters in radius; and approximately 1% of the gaps were 2-3 meters in radius. Thus, we interpolated the values for cells in the DSM data gaps, smaller than 3 meters in radius, by taking the median of the known values in the cells' eight nearest neighbors. Cells with fewer than three known nearest neighbors were filled using a 2nd or 3rd interpolation pass.

4.5.3 Hazardous Tree Pixels (HazPix)

Hazardous tree pixels consisted of CHM grid cells with heights taller than the minimum height required to strike the power lines in the event of a whole or partial tree failure. The minimum hazard pixel height (H_{min}) for a given location was calculated as:

$$H_{min} = (d^2 - H_{line}^2)^{0.5} \qquad (3)$$

We assumed the power line height (H_{line}) was 10 meters; we calculated distance (d) to a 15 meter buffer around the power lines (Figure 4). The buffer reflects the uncertainty of the power line locations, which we measured to have a median horizontal position error of 11.8 meters (std. dev. = 9.9 m). Based on the above methodology, hazardous tree pixels were extracted throughout the study area (Figure 1) and hazard pixel counts were summarized at the 0.5-km damage model grid resolution. The counts were then normalized by total overhead line length (resulting in HazPix/km) for use in the models.

5. Methodology

5.1 Model Description

The statistical software program R [24] was used to complete all modeling and analyses. The R package "randomForest" [25] was used to predict the binary response variable ("BinaryTS").

We selected the random forest model due to its architecture, flexibility (it can model continuous or categorical response variables), and satisfactory performance in the literature for predicting hurricane damages [7] and outages [26, 27]. Random forest [28] is an extension of the classification and regression tree ("decision tree") model [29]; whereas a decision tree makes a series of logical "if-then" statements from a single pass through the training partition, the random forest uses a random subset of the training data and a random subset of explanatory variables to fit multiple decision trees [28]. The predictions from all of the decision trees are referred to as the "forest" – the average of the forest predictions are used as the final prediction. Random forests are relatively easy to interpret compared to other machine learning models (i.e. neural network) and tend to have robust performance.

5.2 Model Forcing Complexities

A simpler model (e.g. a model with less explanatory variables) is preferred to a model with more explanatory variables if they have similar model performance. To ensure that predictors are not adding unnecessary complexity in the model structure, five model forcing complexities (Table 1) were used to investigate the added value of incorporating: (a) vegetation management, (b) the LiDAR-derived hazardous tree pixel dataset and (c) detailed infrastructure in the damage prediction model. The baseline model (Model 1) was built for the purpose of comparing subsequent models with added data, and consisted of a full set of weather variables and land cover, and a reduced subset of infrastructure variables. The second model (Model 2) was built to show the improvement of including detailed infrastructure data with the land cover data; the third model (Model 3) was built to show the improvement of Model 2 with additional vegetation management data; the fourth model (Model 4) included the data from Model 2 with the HazPix data; the fifth model (Model 5) included all of the detailed infrastructure, vegetation management

and HazPix data (and no land cover data). To compare the benefit of HazPix and land cover, Models 1 – 3 used land cover data to represent the local tree conditions and Models 4 and 5 used HazPix as an alternative to land cover.

5.2 Performance Assessment Methodology

When forecasting rare events, it's important to use a balanced sample for model training. If an event (i.e. true positive) only occurs 10% of the time, a model can be 90% accurate by saying damage won't happen 100% of the time. The balanced random forest (BRF) algorithm proposed by Chen et al. [30] consisted of down-sampling the majority class, but concede that down-sampling may result in a loss of information from the majority class. In order to maximize the information of the majority class, we chose to repeat the BRF algorithm 10,000 times and compared the error metrics of the five models for each iteration. This resulted in a distribution of the error metrics for each model we investigated. A different form of validation is k-fold validation, which uses random subsets of the model validation partition to test the model performance. We think our repeated balanced sampling (RBS) algorithm is an interesting alternative to k-fold cross validation; in k-fold validation, influential observations in the training or validation partition may falsely improve (or degrade) the model error metrics. The RBS algorithm allows for a distribution of the model error metrics to be created from the 10,000 iterations, which provides a better view of how the model will perform with different training and validation data.

Below is a description of the RBS algorithm for comparing the error metrics different model forcing complexities:

- Create a balanced sample using all of the true positives (1,760 true positives) with a random sample of 1,760 out of 7,240 true negatives.
- Partition 70% of the data for model training and 30% of the data as a holdout sample for model validation.
- Fit the 5 random forest models using the same model training data, and use the holdout sample to evaluate model performance.
- Calculate error metrics (area under the curve, true positive rate, true negative rate, false omission rate, proportion correct, Cohen's kappa, bias score) based on the confusion matrix data.
- Repeat 10,000 times. For each iteration, select which model had the best result for each error metric.
- Create a table that counts how many times each model was the best for each error metric; compare performance to baseline model (Model 1).
- Rank models by how many times on average they were chosen as having the best error metrics.

5.3 Error Metrics

The R package "SDMTools" [31] was used to calculate various contingency table metrics to describe the model performance more completely. Specifically, we used 7 metrics for model comparison: area under the curve (AUC), false omission rate (FOR), true positive rate (TPR), true negative rate (TNR), proportion correct (PC), Cohen's kappa (K) and bias score (BIAS). We chose metrics that highlight the skill of the model predicting true positives (TPR), true negatives (TNR), true negative omissions (FOR), overall accuracy (AUC, PC), spatial accuracy (K), and tendency of the model to overestimate or underestimate events (BIAS). For the following

equations (Eq. 4 through 7); TP (true positive) refers to the counts of true positives; TN (true negative) refers to the counts of true negatives; FP (false positives) refers to the counts of false positives; and FN (false negatives) refers to the counts of false negatives.

$$FOR = \frac{FN}{FN+TN} \quad (4)$$

$$TPR = \frac{TP}{TP+FN} \quad (5)$$

$$TNR = \frac{TN}{TN+FP} \quad (6)$$

$$PC = \frac{TP+TN}{TP+TN+FP+FN} \quad (7)$$

$$\mathrm{K} = \frac{2\big((TP*TN)-(FP*FN)\big)}{(TP+FN)(FN+TN)+(TP+FP)(FP+TN)} \quad (8)$$

$$BIAS = \frac{TP+FP}{TP+FN} \quad (7)$$

A brief description of the various error metrics we used is now presented. The area under the Receiver Operating Characteristic curve (AUC) is an accuracy metric that shows the model discrimination (the ability to correctly identify true negatives positives); an AUC of 1 represents a perfect prediction, an AUC of 0.5 or less represents a test that is no better than chance. The false omission rate (Equation X) is the chance of having the condition among those that test negative; a FOR of 1 indicates that all predictions for negatives were false, a FOR of 0 indicates that there were no false negative. The true positive rate (TPR), also known as sensitivity, is how many times TP was correctly predicted given a positive reading; a TPR of 1 indicates a model is

perfect at predicting true positives, a TPR of 0 indicates a model that is incapable of predicting true positives. The true negative rate (TNR), also known as specificity, is a measure of how many times negatives are actually predicted; a TNR of 1 indicates a model is perfect at predicting where damage won't happen, a TNR of 0 indicates a model cannot predict where damage doesn't happen. The proportion correct (PC) is simply a measure of how many observations are correctly identified; a PC of 1 indicates a perfect predictor, a PC of 0 indicates a predictor that can't identify where damage does (or doesn't) happen. Cohen's kappa statistic (K, also known as Heidke Skill Score in meteorology) is a measure of how many times a prediction is guessed by chance. A K of 1 indicates perfect spatial accuracy, whereas a K of 0 indicates no spatial accuracy.

6. Results

6.1 Comparison to Baseline Model

Only model validation error metrics will be presented in subsequent sections; there will be no discussion of model training results because these results are presumed to be (artificially) better than the model validation results. The error metrics of Model 1 were used as baseline to compare subsequent models with increasingly complex model forcing (Models 2 through 5). As mentioned in the previous section, the validation strategy used repeated balanced sampling (RBS) with 10,000 iterations to select which model performed the best for each of the five models across the six different error metrics. The frequency of how many times each model was selected the "winner" is summarized in Table 2. The following points are made about results from Table 2. Models 2 – 5 were selected more frequently for most error metrics than the baseline model (Model 1). Model 4 was the most frequently selected for AUC, TNR, PC, and K

error metrics, while Model 5 was the most frequently selected for TPR and FOR. Although Model 5 was selected most frequently for these two metrics, Model 4 was the second most selected model. Under the RBS validation strategy we used to compare the five model forcing complexities, Model 4 proved to be the best model for the following error metrics: AUC, TNR, PC and K (Tables 2 and 3). Although Model 4 was "better" (more frequently selected) than Model 1 for TNR, it was only marginally better, which may indicate that a simpler model forcing complexity may yield better predictions of the true negatives. The next best model was Model 5, the most complex model, and was most frequently selected for two error metrics (FOR and TPR). To compare model performance, each model was ranked (1 – 5) across all error metrics based on frequency (where 1 is considered the most frequent and 5 is least frequent.) The average of these individual error metric rankings was computed to select the best overall model. Overall, Model 4 was the best model followed by Models 5, 3 and 2 (Table 4). From a physical perspective, the superiority of Model 4 is attributed to the model forcing complexity that included HazPix, which in turn gives the best representation of local tree risk and more accurate damage predictions (more on this will be discussed in Section 7).

6.2 Kernel Density Plots

The kernel density plots in Figure 5 show the improvement of Model 4 compared to the Model 1 (baseline model) across all error metrics. The range of AUC, TPR, TNR and PC values for Models 1 and 4 (0.58 – 0.72) are generally indicative of models that are poor (0.6 – 0.7) or fair (0.7 – 0.8) classifiers for deciding or not damage occurrence. The range of K values for Models 1 and 4 (0.19 – 0.43) are generally considered fair classifiers. To understand the FOR values, the range of FOR values (0.25 – 0.44) are associated with models that, when predicting, have a 25% - 44% chance of incorrectly predicting a negative value. The maximum

improvement for each metric between Models 1 and 4 was significant: 6% for AUC, 5% for FOR, 9% for TPR, 7% for TNR, 6% for PC, and 13% for K; however, the average improvement for each metric between Models 1 and 4 was 1% for AUC, 2% for FOR, 2% for TPR, 1% for PC, 2% for K and no improvement on average for TNR. Figure 5 shows a clear separation between the histograms for each category except for TNR where the distribution of values nearly overlapped. Additionally, the bias score statistics in Table 5 confirms that each model doesn't overestimate or underestimate the occurrence of damage. The minimum bias score for any model was 0.87 and the maximum bias score was 1.15, and the average and median bias scores were between 0.99 and 1.01.

7. Discussion

We have evaluated the error metrics of five model forcing complexities related to storm hardening and system resilience, and investigated the improvement of each complexity in a hurricane damage prediction model. As more variables related to the distribution network infrastructure and local tree height data (HazPix) were added to the model forcing complexity, there were improvements in the model error metrics. A comparison of Model 1 and Model 2 shows that the model with more detailed infrastructure data performed better than the model with less detailed data. A comparison of Model 2 and Model 3 shows that if tree height data isn't available, the next best model was one that included VM data and detailed infrastructure data. If tree height data is available, the tree height data in combination with the detailed infrastructure data would likely provide the best error metrics. The combination of the vegetation management, HazPix, and detailed infrastructure data may not improve prediction accuracy better than the tree height model due to over-fitting.

Of all the variables we investigated, HazPix was the best representation of trees around the power lines; and the model that included HazPix (Model 4) was the best classifier for predicting damages. The model rankings show that added data may improve damage predictions during hurricanes, and that the detailed infrastructure with HazPix data may be best to improve damage predictions. When analyzed with respect to the actual range of values for each error metric, the results for Model 4 (HazPix model) are generally indicative of "fair" classifier. Though moderate in terms of percent improvement, this paper shows that added data about tree conditions can improve damage predictions if such data are available.

The added value of HazPix is a function of the overhead line location accuracy in the GIS data. We found that that the actual location of overhead lines could vary with a median horizontal accuracy of 11.8 meters from the location specified in the shapefile. Further, though not investigated, we suspect there can be issues with scale that are inhibiting model performance. Given the spacing of isolating devices, it is more likely that damage was actually recorded in an adjacent pixel on 0.5-km resolution. Presenting the problem using a circuit-based approach would correct the trouble spots happening in adjacent trouble spot, but this would not solve the issue with overhead-line accuracy (only more accurate overhead line data can fix this). Correction schemes exist: utility poles can be differentiated from other features by their height and small cross-section. Pole heights are consistently between 10.5 – 12.0 m and tree trimming typically ensures that other features of comparable height are not adjacent to the poles. Thus, we suspect that utility poles can be detected as a cluster of LiDAR returns having: 1) a maximum height of 10-12 m, 2) a horizontal footprint < 2 m across, and 3) located within 15 m of a reported pole location. In order to be detected, poles will likely need to include a cross-arm and not be sheltered by tree cover; however, accurate locations for these poles are the most critical.

Poles lacking a cross-arm tend to be on lateral circuits which have less impact on overall power outages when compared to backbone lines. Furthermore, poles sheltered by tree cover are likely to occur in heavily forested areas where the precise location of a pole should make little difference in terms of the HazPix count – power lines are still likely to be near heavy forest cover regardless of a random 15 m shift in location. In addition, recent LiDAR data is available for Northwestern Connecticut where trees are more coniferous and population is sparser; a future study could compare the performance of Model 4 over eastern CT, northwestern CT, or both regions combined.

8. Sensitivity Analysis with HazPix

Lastly, we present a sensitivity analysis with the HazPix data to show how altered HazPix with all other variables held constant might affect the total number of grid cells with damage during Hurricane Sandy. With the understanding that Model 4 is a "fair classifier", these results should be considered qualitative. Model 4 was trained with a balanced sample from the original data (including the actual HazPix values); and as a model test, we used the same model calibration data but with altered HazPix values to show how the damage predictions would vary across theoretical HazPix conditions. Under this framework, the only thing that is different between the training and test data was the HazPix value (all weather and infrastructure data were held constant). We used four altered HazPix values for the test data, which can be thought of as HazPix thresholds; specifically the values we used were the 10th, 25th, 50th, and 75th quantiles (Q_{10}, Q_{25}, Q_{50}, Q_{75}) of the distribution of all HazPix data (8, 21, 39, 70 HazPix/m, respectively). We used the model forced with the Q_{10} HazPix as the baseline to which test models forced with the Q_{25}, Q_{50} and Q_{75} could be compared to. Our simulation shows that higher HazPix values

would result in a greater amount of pixels with damage. By increasing the HazPix value, hurricane damages could increase by 8% (Q_{25}), 17% (Q_{50}) or 22% (Q_{75}) relative to the Q_{10} baseline (Figure 6). The results suggest a logarithmic relationship between HazPix quantiles and the relative change in predicted damages, which may indicate some that extremely forested areas may provide some wind sheltering and actually decrease the occurrence of damage.

9. Conclusions

We have presented a study that shows the inclusion of data related to localized tree conditions (HazPix and vegetation management) and utility infrastructure data can improve damage prediction models with a binary response. Under our repeated balanced sampling (RBS) validation strategy, we found that any model with more complex data performed better than the baseline model; and that the forced with utility infrastructure and HazPix was the best model overall. Improving the accuracy of damage predictions will help emergency preparedness efforts and support vulnerability assessment studies related to infrastructure hardening activities. The use of binary response variable for damage prediction modeling may complement other existing damage prediction models (i.e. models with a continuous response). Further, the models we present in this study, which used data aggregated at a high resolution (0.5-km), may give more confidence to outputs from other damage prediction models that were built from data with coarser resolution (2-km).

Decision-makers should use an array of models (with different model forcings or different modeling types) to best understand the uncertainty of model predictions. When choosing to improve existing models, they should also weigh the benefit of a possible improvement versus the cost (i.e. what data are available versus what data can be collected and

the time and cost it takes to analyze them). Based on these constraints, a utility can then decide on the level of complexity that can be afforded to the modeling. In addition to the random forest model, other probabilistic models like Bayesian Additive regression trees (BART) [32] may be appropriate to investigate these tree-related data.

HazPix was the variable that best represented the local tree conditions, but there are many other data that can be captured related to HazPix that can improve the damage models; including orientation (N, E, S, W) of HazPix relative the overhead lines, and canopy closure variables which can give an assessment of the overlying tree canopy density. Other tree-related data might include storm forensics (reports from tree crews about tree-related faults). Given the recent availability of LiDAR data in Connecticut, future studies on the subject could include (1) a comparison of the effect of HazPix in northwest Connecticut with eastern Connecticut; or (2) the inclusion of canopy closure, HazPix orientation and wind direction as predictors into the damage prediction model; or (3) creating a map of tree-risks in Connecticut using the expanded HazPix data. There are many ways to look at distribution networks – on a grid using average conditions, on a circuit, or even on the isolating device level. We think that each of these scales could be investigated with these data for future studies. Studies that used the tree-related data in tandem with the network configuration data (e.g. starting at the substation and following the conductor downstream to a terminal end) would be particularly attractive.

Recently, CL&P was approved by its regulators, the Connecticut Public Utility Regulatory Authority (PURA), to implement a five year, $300M system resiliency plan. The goal of the plan was to increase system reliability by pursuing targeted infrastructure hardening improvements and increasing vegetation management efforts. As the system resiliency plan is

underway, we continue to collect and analyze relevant data for improving damage prediction for overhead lines and to support hardening impact analyses.

Acknowledgements

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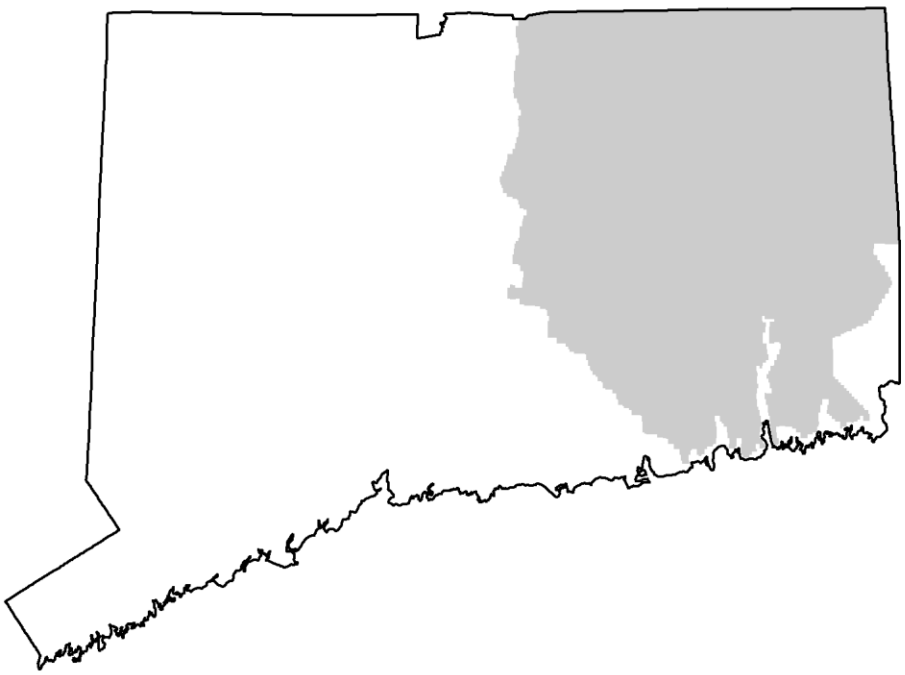

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663 **Figure 1**: Distribution of the 4600 km^2 LiDAR data in eastern CT over the study area.

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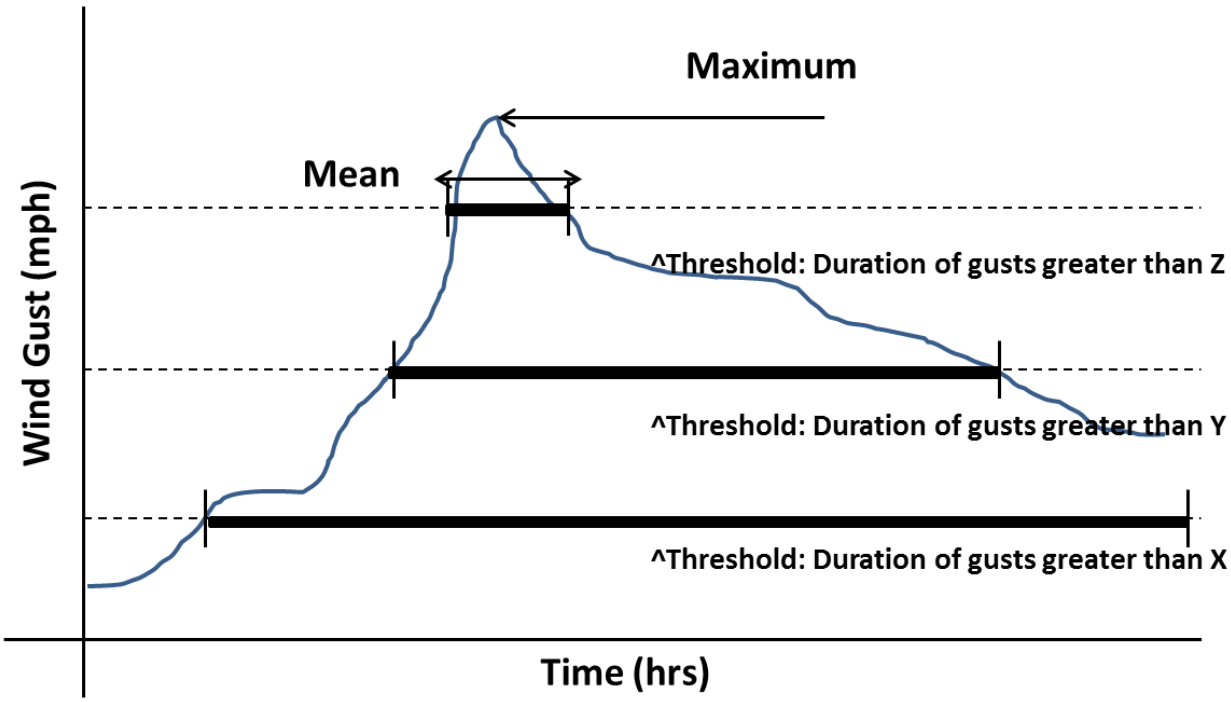

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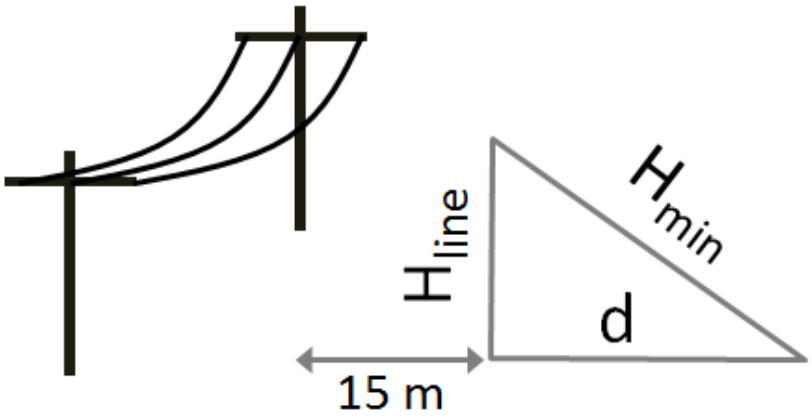

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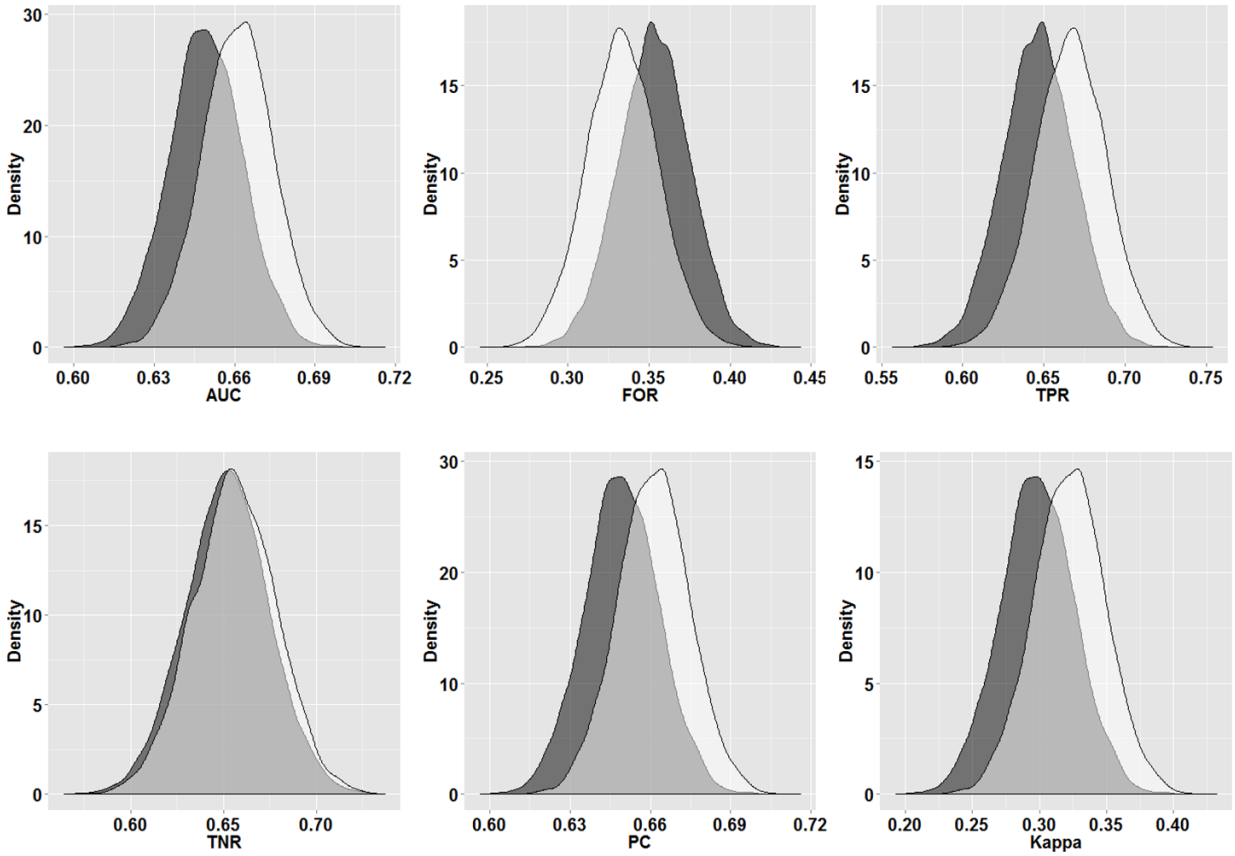

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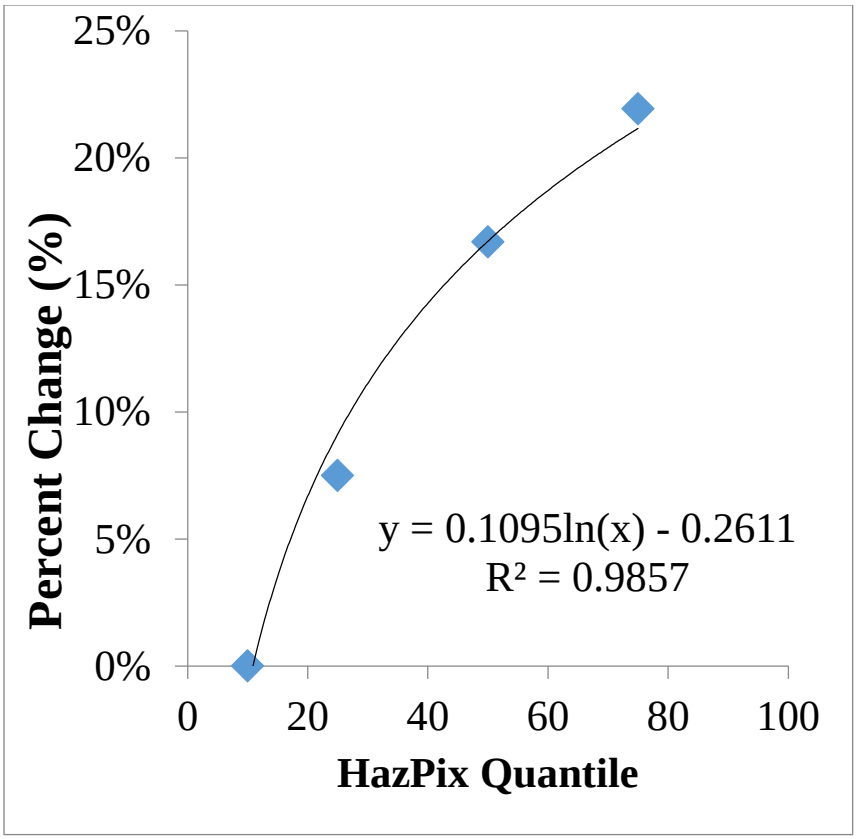

Figure 6: Relative changes in predicted damage from baseline (Q_{10} HazPix quantile) for other HazPix quantiles (Q_{25}, Q_{50}, Q_{75}).

707 **Table 1:** List of variables included in models

Variable	Description	Type	Units	Model 1	Model 2	Model 3	Model 4	Model 5
Season	Weather	Categorical	-	X	X	X	X	X
Duration of wind at 10 meters above 9 m/s	Weather	Continuous	hr	X	X	X	X	X
Duration of wind at 10 meters above 13 m/s	Weather	Continuous	hr	X	X	X	X	X
Duration of wind at 10 meters above 18 m/s	Weather	Continuous	hr	X	X	X	X	X
Duration of wind gusts above 18 m/s	Weather	Continuous	hr	X	X	X	X	X
Duration of wind gusts above 27 m/s	Weather	Continuous	hr	X	X	X	X	X
Duration of wind gusts above 36 m/s	Weather	Continuous	hr	X	X	X	X	X
Duration of wind gusts above 45 m/s	Weather	Continuous	hr	X	X	X	X	X
Total accumulated precipitation	Weather	Continuous	mm	X	X	X	X	X
Wind stress	Weather	Continuous	unitless	X	X	X	X	X
Wind gust	Weather	Continuous	m/s	X	X	X	X	X
Wind at 10 m height	Weather	Continuous	m/s	X	X	X	X	X
Snow water equivalent	Weather	Continuous	kg/kg	X	X	X	X	X
Soil moisture	Weather	Continuous	mm/mm	X	X	X	X	X
Precipitation Rate	Weather	Continuous	mm/hr	X	X	X	X	X
Sum of Assets	Infrastructure	Continuous	count	X	X	X	X	X
Percent Backbone Bare	Infrastructure	Continuous	%		X	X	X	X
Percent Lateral Bare	Infrastructure	Continuous	%		X	X	X	X
Percent Lateral Covered	Infrastructure	Continuous	%		X	X	X	X
Percent Forested	Land Cover	Continuous	%	X	X	X		
Percent Backbone Bare - ETT	Vegetation Management	Continuous	%			X		X
Percent Lateral Bare – ETT	Vegetation Management	Continuous	%			X		X
Percent Lateral Covered - ETT	Vegetation Management	Continuous	%			X		X
Percent Backbone Bare - SMT	Vegetation Management	Continuous	%			X		X
Percent Lateral Bare – SMT	Vegetation Management	Continuous	%			X		X
Percent Lateral Covered - SMT	Vegetation Management	Continuous	%			X		X
HazPix per kilometer	Hazardous Tree Pixels	Continuous	HazPix/km				X	X

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Table 2: Counts of which model is the winner using the RBS algorithm (10,000 iterations)

Model	AUC	FOR	TPR	TNR	PC	K
Model 1	658	477	477	2475	658	658
Model 2	1530	1486	1486	1833	1530	1530
Model 3	1646	1754	1754	1700	1646	1646
Model 4	**3706**	3118	3118	**2486**	**3706**	**3706**
Model 5	2460	**3165**	**3165**	1506	2460	2460

Table 3: Relative improvement in the error metrics compared to baseline model (Model 1)

Model	AUC	FOR	TPR	TNR	PC	K
Model 1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Model 2	132.5%	211.5%	211.5%	-25.9%	132.5%	132.5%
Model 3	150.2%	267.7%	267.7%	-31.3%	150.2%	150.2%
Model 4	**463.2%**	553.7%	553.7%	**0.4%**	**463.2%**	**463.2%**
Model 5	273.9%	**563.5%**	**563.5%**	-39.2%	273.9%	273.9%

Table 4: Selecting the best model overall using the ranking scheme

Model	Rank(AUC)	Rank(FOR)	Rank(TPR)	Rank(TNR)	Rank(PC)	Rank(K)	Average Rank	Final Rank
Model 1	5	5	5	2	5	5	4.5	5
Model 2	4	4	4	3	4	4	3.8	4
Model 3	3	3	3	4	3	3	3.2	3
Model 4	**1**	2	2	**1**	**1**	**1**	**1.3**	**1**
Model 5	2	**1**	**1**	5	2	2	2.2	2

Table 5: Analysis of bias scores for all models

	Model 1	Model 2	Model 3	Model 4	Model 5
Mean	0.99	1.01	1.01	1.01	1.01
Standard Error	0.00	0.00	0.00	0.00	0.00
Median	0.99	1.01	1.01	1.01	1.02
Mode	0.99	1.01	1.02	1.00	1.02
Standard Deviation	0.03	0.04	0.04	0.04	0.04
Range	0.25	0.27	0.26	0.27	0.26
Minimum	0.87	0.87	0.88	0.88	0.88
Maximum	1.12	1.14	1.14	1.15	1.15
Count	10,000	10,000	10,000	10,000	10,000

Appendix G: Definitions of Data Fields for Needed Outage Data

Appendix G: Definitions of Data Fields for Needed Outage Data

This appendix contains definitions of each data field recommended for future data gathering in Section 5 of this report. See Section 5.5 for a summary of these data needs. Table G-1 lists the data needs, which are further described below.

Basic Information to Collect

Basic information consists of 12 data fields that are needed to perform rudimentary reliability calculations and form the basis for making better informed decisions to improve resiliency.

- **Unique Identifier** - A unique identifier to serve as a reference
- **Date/Time of Interruption** - Specifies the exact date and time the interruption started.
- **Date/Time of Restoration** - Specifies the exact date and time the interruption started.
- **Duration** - This is the calculated difference (in minutes) from the beginning of the interruption to the end of the interruption.
- **State/Region/Division** - Provides granular information about the general geographic area within a utility of the outage location. This can be used to prepare reliability measures for individual states if a utility has multiple states within its possession or it can be used to evaluate operating divisions within a company.
- **Number of Customers Interrupted** - The number of customers who experienced the loss of service. This is generally the number of customers downstream of the fault clearing device.
- **Fault Clearing Device Location (Pole #/GPS)** - The location of the fault clearing device. This will allow a utility to track number of operations at a location and can help pinpoint an area in need of reliability enhancements.
- **Fault Clearing Device Type** - Identify if the fault clearing device was a fuse, recloser, switch, breaker, etc.
- **Interruption Cause** - The root cause of the interruption using IEEE 1782's categories.
    a) *Equipment* - Defective piece of distribution system equipment
    b) Lightning - Lightning caused the interruption
    c) Planned - Interruption performed only after required customer notification as part of planned work
    d) Power supply - Failure in the transmission system caused distribution outage
    e) Public - Act of the public cause the interruption
    f) Vegetation - Vegetation growth or failure caused the interruption
    g) Wildlife - Interruption caused by animals
    h) Unknown - Definitive cause cannot be identified.
    i) *Other* - Any other cause. Some examples include: errors in construction, maintenance, operating, or protecting; overload; and contamination.

Table G-1. Data that Utilities Need to Gather to Better Prioritize Resiliency Options

Basic Information	Unique Identifier	Construction Information	Fault/Damage Location (Pole #/GPS)
	Date/Time of Interruption		Component Damaged/Failed
	Date/Time of Restoration		Pole Break Location
	Duration		Pole Construction Type
	State/Region/Division		Number of Phases at Fault Location
	# of Customers Interrupted		Conductor Size/Type
	Fault Clearing Device Location (Pole #/GPS)		Age of Pole/Equipment
	Fault Clearing Device Type (GPS)		Identify Mainline/Lateral/Secondary
	Interruption Cause		# Circuits at Fault Location
	Detailed Cause Information	Vegetation Information	Inside/Outside Clearance Zone Identified
	Weather at Time of Interruption		Side Distance Tree/Limb Came From
	Storm Identifier		Vegetation Failure Mode
Operational Information	Size/Rating of Clearing Device		Trim Spec for Fault Location
	# of Phases Interrupted		Direction Tree/Limb Fell From
	Dispatch Date/Time		Diameter
	Crew Arrival Date/Time		Compromised Tree/Limb
	Voltage Class of Interrupted Area		Species
	Restoration Action		
	Switching Performed with Cross Reference		

Basic Information to Collect (Continued)

- **Detailed Interruption Cause Information** - Provides a more granular reason for the outage. For example, an interruption cause by equipment failure will specify the exact piece of failed equipment. See Table G-2 for a Detailed Interruption Cause Chart.
- **Weather at the Time of Interruption** - Provides the type of weather experienced at the time of the interruption.
- **Storm Identifier** - This field is used to indicate if this outage was part of a larger storm event restoration effort. If the outage was part of a larger storm restoration, it should indicate if this was classified by IEEE Major Event Day (MED) day event criteria or by utility specific criteria.

Operation Information to Collect

Operational information for each outage consists of 7 data fields that provide insight into the operational efficiencies of restoration and indicates how a utility handles service interruptions.

- **Size/Rating of Clearing Device -** Species the fuse size, relay pickup current, transformer size, etc. for the fault clearing device.
- **Number of Phases Interrupted -** Specifies the number of phases interrupted.
- **Dispatch Date/Time -** This is the date/time when a crew was dispatched and given the order to begin service restoration. This information will be used to calculate the time an outage waits in a queue (Dispatch Date/Time minus Interruption Date/Time) and the time to travel to the outage (Crew Arrival Date/Time minus Dispatch Date/Time).
- **Crew Arrival Time -** This is the date/time when a crew arrived at the outage and began patrolling and restoration work. This information will be used to calculate the repair time for the outage (Restoration Date/Time minus Crew Arrival Date/Time) and the time to travel to the outage (Crew Arrival Date/Time minus Dispatch Date/Time).
- **Voltage Class of Interrupted Area** - Specifies the nominal operating voltage of the interruption area. If a service was interrupted, list the secondary voltage and not the primary voltage.
- **Restoration Action -** Provides the details of how electrical service was restored. This should be a prepopulated multi-select check list of common restoration actions. Some example restoration actions include:
    - *Removed Limb/Tree from Line*
    - *Replaced Broken Pole*
    - *Repaired Broken Conductor*
    - *Replaced Equipment*
    - *Reset Fuse*
    - *Reset Recloser*
- **Switching Performed with Cross Reference -** This indicates that switching was performed to partially restore an affected area without getting all customers on (sectionalized the outage). There should be cross references to other outage records unique identifiers to tie together the steps of restoration.

Construction Information to Collect

Construction information for each outage consists of 9 data fields that provide insight into construction standards of affected areas and can identify equipment failure trends and areas for construction improvement.

- **Fault/Damage Location (Pole and GPS) -** This identifies the physical location where the cause for the interruption took place. This is the spot where the tree fell into the line, the transformer failed, car hit a pole, etc. It may sometimes be the same as the clearing device location.
- **Component Damaged/Failed -** This is a multi-select list of components that were damaged/failed. The list includes common company assets such as: cutout, transformer, pole, cross arm, recloser, splice, conductor, insulator, etc. If no components are checked, the outage will categorized as an electrical outage (transient contact with no permanent damage) instead of an outage due to mechanical damage.
- **Pole Break Location -** This is only used if a pole was broken. This identifies the exact point of failure on the pole. There are four areas on the pole to identify: Base of pole, below third party attachments, at third party attachments, and above third party attachments.
- **Pole Construction Type -** At the location of the fault, identifies the framing for the pole. Choices include: horizontal cross arm, spacer, vertical, single phase ridge pin, armless construction, multiple circuits.
- **Number of Primary Phases at Fault Location -** The number of primary phases at the fault location: Single Phase, Two Phase, or Three Phase.
- **Conductor Size/Type** - Identifies the material type and size of the conductor used. For example, 336 Bare Aluminum AA
- **Age of Pole/Equipment** - This is the age of the pole/equipment that failed at the time of the outage. This information will help determine the asset life of equipment.
- **Identify Mainline/Lateral/Secondary -** This pinpoints the circuit topography location of the fault.
- **Number of Circuits at Fault Location -** The number of circuits on the shared structure where the fault occurred.

Vegetation Information to Collect

Vegetation information for each outage consists of 8 data fields that provide insight into the effectiveness of vegetation management (VM) programs and ways to better plan VM resources to increase resiliency.

- **Inside/Outside Clearance Zone -** Indicates if the vegetation was inside or outside the clearance zone.
- **Side Distance Tree/Limb Came From -** The side distance (in feet) the tree/limb came from.

- **Vegetation Failure Mode** - Identify what made contact with the electrical line. Drop down list can be prepopulated with common failure modes including: uprooted tree, broken trunk, vine growth, broken limb, etc.
- **Trim Spec for Fault Location** - Identify if the normal trim specification for the fault location is in an enhanced trimming or a standard trimming area.
- **Direction Tree/Limb Fell From** - Indicate geographic direction: North, East, South, or West
- **Diameter** – This is a field to collect the diameter size for the vegetation failure mode.
- **Compromised Tree/Limb -** Indicate if the tree/limb was diseased, dead, or infested from a drop down list.
- **Species** - Identify the tree species

Table G-2. Detailed Interruption Cause Chart

Interruption Cause	Detailed Cause	Interruption Cause	Detailed Cause
Equipment	*Switch/Disconnect*	**Power Supply**	*Substation Equipment*
	Cutout		*Transmission Equipment*
	Connector	**Public**	*Customer Initiated*
	Crossarm		*Road/Highway Rebuild*
	Fuse		*Other*
	Recloser	**Public**	*Vehicle Hit Pole*
	Guy/Anchor		*Vehicle Hit Wires*
	Insulator		*Vehicle Hit Padmount*
	Pole		*Vehicle Hit Guy Wire*
	Splice		*Gunfire*
	Transformer		*Fire*
	Regulator		*Sabotage/Vandalism*
	Lightning Arrester		*Dig-In*
	Bracket		*Foreign Object*
	Capacitor		*Non-Utility Contractor Error*
	Conductor/Cable	**Vegetation**	*Vines*
	Line Hose		*Tree Growth*
	Manhole/Pull Box		*Tree/Limb In Clearance Zone*
	Meter		*Tree/Limb Outside Clearance Zone*
	Platform	**Wildlife**	*Squirrel*
	Sectionalizer		*Bird*
	Stress Cone		*Snake*
	Terminator	**Unknown**	*Indeterminable*
	Tie Wire	**Other**	*Improper Coordination/Settings*
Lightning	*Indirect Effect, Tree Dropped On Line*		*Operating Error, Utility/Utility Contractor*
	Substation Equipment		*Tree Trimmers, Utility/Utility Contractor*
	Transmission Equipment		*Improper Design/Equipment*
	Direct Strike To Line		
	Indirect Effect, Equipment Failure		

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