A PARTIAL REVIEW OF ELECTRICITY DISTRIBUTION RELIABILITY BASED VEGETATION MANAGEMENT IN NORTH AMERICA

by

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A CAUTION TO THE READER

This HBScF thesis has been through a semi-formal process of review and comment by at least two faculty members. It is made available for loan by the Faculty of Natural Resources Management for the purpose of advancing the practice of professional and scientific forestry.

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ABSTRACT

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In recent years, utility vegetation management planners have incorporated a new framework into planning regimes: reliability based vegetation management. This report examines the vegetation management standards of forty North American electricity distributors. Distribution utility vegetation management planners, utility foresters, reliability specialists, and other delegates from the sample provided information related to their respective vegetation management programs. Company profiles and statistics were generated using this information. Study results indicate that, although all vegetation management standards of sample participants exhibit similarities, the ways in which each distributor approaches reliability based vegetation management differ.

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INTRODUCTION

Consistent, secure electricity distribution is essential to North American society. Businesses, institutions, industries and homeowners alike rely on electrical connectivity to meet their daily needs. Within North America, electricity distribution companies are responsible for maintaining vast networks of power lines. Given the geographies of North America, many of these networks run through forested areas. Correspondingly, trees are a significant cause of electricity distribution outages (Guggenmoos 2003).

Regulatory oversight of electricity reliability at the distribution level is ever-increasing. Also accrescent, is the pool of literature, which suggests that not only is utility vegetation management (UVM) often the highest preventative maintenance expense for most electricity distributors, it is also commonly viewed as the major contributing factor in managing utility reliability performance (Hollenbaugh 2006).

Historically, the quintessential UVM program incorporated a strict adherence to specific minimum clearances between vegetation and conductors on a cyclical basis, the establishment of plant species on ROW floors to inhibit in-growth, and the use of herbicides to prevent re-growth.

In recent years, utility vegetation management planners have incorporated a new framework into planning regimes: reliability based vegetation management (RBVM). According to Erin Creekmur of Arizona Public Service, “RBVM utilizes comprehensive outage and tree failure data to determine where and how actions can be taken to improve reliability and performance, independent of growth related cycle maintenance” (Creekmur 2018). When taking this approach, planners utilize data sets, which list historical interruptions and provide supplementary information such as dates and times, cause codes, customers affected, customer minutes, and – often times – data collected during vegetation-related outage causal factors investigations.

Industry experts suggest that utilities are focusing too much on maintaining consistent clearances and not enough on removing the trees and branches that pose relatively higher risks to public safety and electricity reliability (Edison Electric Institute 2014). The problem, though, is that not only are many distributors statistically ignorant of which trees to target, there is even a lack of understanding surrounding which data points must be collected to facilitate successful determination of vegetation-related outage causal factors (Porter 2015).

In *Regulatory Changes to Utility Vegetation Management (UVM) Activities in the U.S.*, William Porter, Director of Consulting at CN Utility Consulting, expressed that, "regulators are not requiring and utilities are not investing in robust outage investigations based on expert vegetation management knowledge" (Porter 2015). Scrutiny such as this has inspired increased investment in comprehensive vegetation-related outage investigation programs. The modes of data collection and data points collected, however, are not highly publicised. As a result, vegetation-related outage causal factors investigation programs lack best management practices (BMP). This lack of BMPs may result in the creation and implementation of investigation programs that are not collecting the most pertinent data points. This is problematic, as reliable data is essential for successful RBVM.

This study seeks to fill RBVM knowledge gaps by reviewing current knowledge and connecting with key figures within North American electricity distribution companies. It seeks to answer the following questions:

Table 1. Questions to be addressed.

1	What vegetation-related outage cause codes are first responders authorized to record during distribution trouble calls?
2	Which electricity distributors are conducting some form of comprehensive vegetation-related outage causal factors investigations, beyond the recording of cause codes (either during the trouble call or after the fact)?
3	For companies who are conducting some form of comprehensive vegetation-related outage causal factors investigations, when are investigations conducted?
4	For companies who are conducting some form of comprehensive vegetation-related outage causal factors investigations, which data points are collected?
5	How do distributors utilize cause code, reliability, and investigations data to practice RBVM?

In order to meet the aforementioned objectives, many of North America's electricity distributors were surveyed. Survey data were compiled and analyzed to generate statistics.

LITERATURE REVIEW

Critical to the success of RBVM programs is consistent, reliable data collection. The collection of data points such as interruption durations, customers affected, customer minutes, contributions to reliability indices, and more, are consistent across electricity distributors practicing RBVM, and so, too, are their units of measure. When collecting qualitative data points, however, such as outage causes, electricity distributors differ in the options that first responders may associate with electrical service interruptions (Creekmur 2018). For the purposes of this report, the allowable recordable interruption causes, which vary by electricity distributor, are referred to as "cause codes."

While many pieces of quantitative interruption data, such as durations, customers affected, customer minutes, contributions to reliability indices and more, can be predicted and/or calculated using algorithms and computing software, qualitative data points, such as cause codes, can only be verifiably captured by sending individuals to physical outage locations. First responders typically determine these cause codes during the trouble call process. First responders include, but are not exclusive to, linemen and linewomen, protection and control technicians and technologists, and storm restoration assessors.

To date, very little research compares vegetation-related outage cause codes between electricity distributors. As a result, no one set of vegetation-related outage cause codes are universally acknowledged as being optimal for facilitating successful RBVM. One such study, conducted by the Utility Arborists Association (UAA) surveyed thirty North American electricity distributors. Distributors provided the UAA with a list of their allowed vegetation-related outage cause codes and indicated whether they conduct some form of post-trouble vegetation-related outage investigations (Creekmur 2018). This report aims to build upon the UAA study by surveying additional electricity distributors for allowed vegetation-related outage cause code sets. Furthermore, this report aims to determine not only whether other distributors are conducting comprehensive vegetation-related outage causal factors investigations, but also seeks to gain a better understanding of which data points distributors are collecting during those investigations.

As previously mentioned, many of North America's electricity distributors are now investigating vegetation-related outages beyond the simple determination and application of cause codes. For the purposes of this report, these investigations, which may occur during trouble calls or after the fact, are referred to as "vegetation-related outage causal factors investigations." These vegetation-related outage causal factors investigations collect data points, which are utilized to identify trends in frequencies in the occurrence of vegetation-related outage causal factors. Electricity distributors consider these trends when making RBVM planning decisions, often in an attempt to maximize reliability and public safety, while minimizing costs.

Although some research pertaining to vegetation-related outage causal factors has been conducted, such as in *Tree-Caused Electric Outages* (Simpson and Van Bossuyt 1996) and *Priority Trimming to Improve Reliability* (Rees *et al*. 1994), these studies were conducted in attempts to identify and communicate general vegetation-related outage trends, often focusing on frequencies of general outage causes and presence or lack of particular weather patterns for defined service territories within defined timeframes. These studies do not provide electricity distributors with a framework for establishing their own vegetation-related outage causal factors investigation programs, whose data collection timeframes are indefinite. Nor do they explain the best ways to utilize reliability data to influence UVM planning.

Currently, no studies compare RBVM programs or associated vegetation-related outage causal factors investigation programs between North America's electricity distributors and, as a result, no BMPs for the design, implementation, and monitoring of either program exists. Further research in this field is required.

METHODS

SAMPLE

In total, seventy-three North American electricity distributors were invited to participate in this study. The numbers of customers serviced, kilometers of distribution power lines, vegetation cover and density, and climate varied amongst distributors.

Participants

For the purposes of this report, “participants,” refers to electricity distributors from the sample group, who agreed to take part in the study. Of the seventy-three distributors in the sample group, forty agreed to participate.

Non-Participants

For the purposes of this report, “non-participants,” refers to electricity distributors from the sample group, who either declined to take part in the study or did not respond to invitations to participate. All distributors who did not respond to initial invitations to participate were provided with second invitations, no earlier than two weeks post-initial invitation. Of the seventy-three distributors in the sample group, two declined to take part in the study and thirty-one did not respond to invitations to participate.

SURVEY

Questions

Following extensive research and consultation with electricity regulators, a series of survey questions was generated. These questions are presented in Table 2.

Table 2. List of questions for distributors.

1	What vegetation-related outage cause codes are first responders authorized to record during distribution trouble calls?
2	Does your company conduct some form of comprehensive vegetation-related outage causal factors investigations, beyond the recording of cause codes (either during the trouble call or after the fact)?
3	If your company does conduct some form of comprehensive vegetation-related outage causal factors investigations, when are investigations conducted?
4	If your company does conduct some form of comprehensive vegetation-related outage causal factors investigations, which data points are collected?
5	How does your company utilize cause code, reliability, and investigations data to practice RBVM?

Administration

In order to ensure that information received by study participants is representative of actual UVM practices, contact information for distribution UVM planners, utility foresters, and reliability specialists was requested from each participant. Distributor representatives were surveyed via their preferred method of communication.

The information gathered through the survey process was utilized to generate company profiles. In order to ensure data accuracy, distributor delegates were asked to confirm whether their company profiles accurately represented their UVM standards. Upon receipt of delegate responses, company profiles were modified appropriately.

RESULTS

CAUSE CODES

The first survey question posed to participants was, "What vegetation-related outage cause codes are first responders authorized to record during distribution trouble calls?"

The number of recordable vegetation-related outage cause codes varies greatly by distributor. Of the forty participants, nine allow first responders to record only one possible vegetation-related outage cause code. In all of these cases, the one allowed vegetation-related outage cause code communicates only that a distribution electrical outage was in some way caused by a tree, with no distinction in tree location or specific tree structure (i.e. crown, trunk, branch, or other) that was in contact with the phase. Examples of these cause codes include, "tree" and "vegetation-related."

The greatest recordable number of vegetation-related outage cause codes used by a distributor is nineteen. This distributor allows first responders to record tree location (on or off ROW), tree health, outage contributing weather conditions, preventability, and more, using unique cause codes.

Figure 1 communicates the distribution in number of distributors by number of allowed recordable vegetation-related outage cause codes. The mode number of allowed recordable vegetation-related outage cause codes is three.

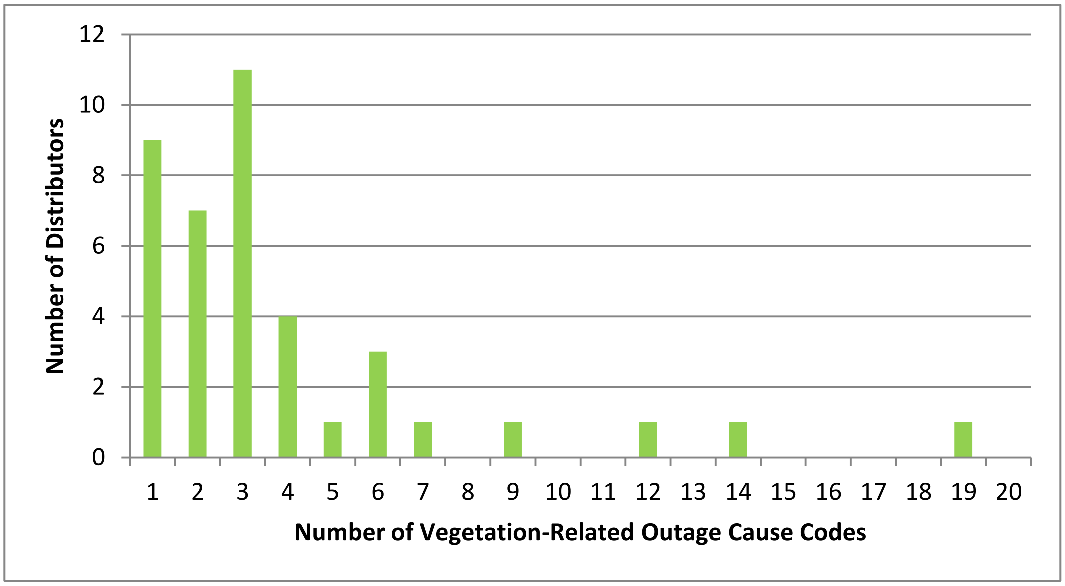

Figure 1. Number of distributors by number of vegetation-related outage cause codes.

VEGETATION-RELATED OUTAGE CAUSAL FACTORS INVESTIGATIONS

The second survey question posed to participants was, “Does your company conduct some form of comprehensive vegetation-related outage causal factors investigations when vegetation-related outages occur on your distribution system?”

Of the forty participants, twenty-two report that they conduct some form of comprehensive vegetation-related outage causal factors investigations when vegetation-related outages occur on their distribution system. Figure 2 highlights this distribution.

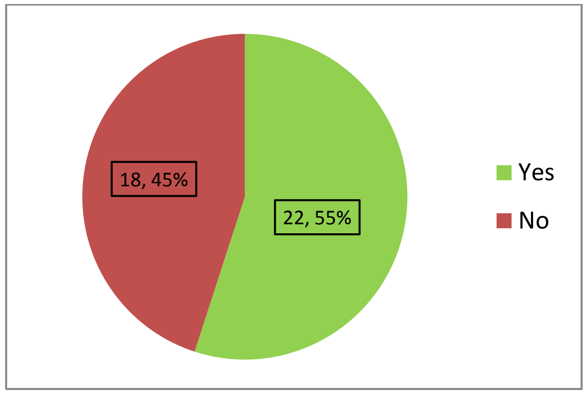

Figure 2. Number and percentage of participants who conduct vegetation-related outage causal factors investigations.

Data Collection

The third and fourth survey questions posed to participants were, “If your company does conduct some form of comprehensive vegetation-related outage causal factors investigations, when are investigations conducted?” and “If your company does conduct some form of comprehensive vegetation-related outage causal factors investigations, which data points are collected?,” respectively.

A list of when investigation-conducting distributors initiate their investigation protocols and a summary of data points collected by investigation-conducting distributors are communicated through Tables 3 and 4, respectively.

Table 3. Thresholds for initiations of investigation processes.

We perform follow-up investigations on all TREE FELL tree-related outages. We don't currently investigate the other tree outage options.
We are investigating all vegetation preventable outages. We conduct a formal outage investigation within 1-3 days after the incident.
All tree-caused outages that result in a substation breaker operation are field investigated/verified within 24 hours of the event. A protocol has been established to receive "near real-time" notifications of these events and the notice is pushed out to field level personnel.
We follow up on all the Blue Sky day tree events.
Usually during the trouble call.
Information is collected after a vegetation-related outage affecting more than 500 customers occurs, or when a vegetation-related outage occurs on a circuit that has been chosen to be more closely monitored. For outages of 100-499 customers, the vegetation management department investigates whether the tree was on or off ROW and inputs that information into the outage records.
All vegetation-related outages that are over 500 customers, and any vegetation-related outages on circuits that have had cycle pruning done on them in the last year.
On vegetation-related outages affecting more than 50 customers, contractors working for the vegetation management department conduct additional field investigations as to the precise cause of the outage.
Post-outage, the Line Clearing department investigates all outages affecting 100+ customers.
Outages are tracked in accordance with guidelines set forth in State Regulations (Code of Maryland (COMAR)) Title 20: Public Service Commission; Subtitle 50: Services provided by electric companies. These regulations set standards for maintenance activities, public outreach and accountability. These regulations also establish criteria for data capture for tree outages. For all electric companies, any incident that results in 100 persons or more who experience an outage due to a tree are investigated and companies are only exempt from this process for declared state of emergencies, i.e. hurricanes, extended snow events (3 days or more), etc.
We send out a forester to investigate any outage greater than 10,000 customer minutes or affecting greater than 100 customers.
Foresters field check all the "Tree growing into primary caused outages".
We use a spreadsheet to track all tree-caused outages affecting over 100 customers or if the duration lasts longer than 8 hours.
We do a 100% investigation on outages affecting 500 customers or greater, when the tree/branch comes from outside of the ROW. We also investigate any tree caused outage where the tree came from inside the ROW and the customer count is over 50.
We perform detailed investigations of vegetation coded outages that affect our mainlines (the line from the substation to the first protective device or fuse) and those outages that affect 100 customers or more.

Table 4. Summary of data points collected by investigation-conducting distributors.

#	Question	Yes	% Yes	No	% No
1	Does the investigator record a cause for the interruption?	20	91	2	9
2	Does the investigator record the height at failure (bole) for the outage-causing tree?	3	14	19	86
3	Does the investigator record the diameter at failure (bole) for the outage-causing tree?	7	32	15	68
4	Does the investigator record the diameter at failure (branch) for the outage-causing tree?	10	45	12	55
5	Does the investigator record whether the outage-causing tree was overhanging the phase?	11	50	11	50
6	Does the investigator record the species of the outage-causing tree?	22	100	0	0
7	Does the investigator record the height of the outage-causing tree?	12	55	10	45
8	Does the investigator record the DBH of the outage-causing tree?	16	73	6	27
9	Does the investigator record the age/life stage of the outage-causing tree?	3	14	19	86
10	Does the investigator record the distance from the stump of the outage-causing tree to the phase?	10	45	12	55
11	Does the investigator record whether the outage-causing tree was located on or off ROW?	19	86	3	14
12	Does the investigator record the direction from the stump of the outage-causing tree to the phase?	8	36	14	64
13	Does the investigator record whether the outage-causing tree was leaning towards the phase?	2	9	20	91
14	Does the investigator record the wind exposure for the outage-causing tree?	3	14	19	86
15	Does the investigator record the geographic coordinates for the outage-causing tree?	8	36	14	64
16	Does the investigator record whether the outage-causing tree showed evidence of decline?	18	82	4	18
17	Does the investigator record whether the outage-causing tree was compromised by disease?	16	73	6	27
18	Does the investigator record whether the outage-causing tree was compromised by insects?	14	64	8	36
19	Does the investigator record whether the outage-causing tree was compromised by wildlife?	10	45	12	55
20	Does the investigator record whether the outage-causing tree was compromised by structural defects?	17	77	5	23
21	Does the investigator record specific types of defects that compromised the outage-causing tree?	17	77	5	23
22	Does the investigator record slope information for the outage-causing tree?	3	14	19	86
23	Does the investigator record soil conditions for the outage-causing tree?	10	45	12	55
24	Does the investigator record whether weather contributed to the interruption?	15	68	7	32
25	Does the investigator record the wind speed at the time of the interruption?	4	18	18	82
26	Does the investigator record whether the interruption was predictable and/or preventable?	13	59	9	41
27	Does the investigator have the option to provide additional comments or notes?	22	100	0	0
28	Does the investigator take photographs of the outage-causing tree and/or the surrounding circumstances?	5	23	17	77
29	Does the distributor store investigations data in a geodatabase?	2	9	20	91

Outage Cause

One common data point, collected by most distributors (91%) during investigations, is outage cause. This data point often expands on the initially determined cause code. For example, a vegetation-related outage may be attributed a cause code of “vegetation-related” by a lineman during a trouble call. The investigation process may further elaborate on the cause code by indicating that the “vegetation-related” outage was specifically caused by crown, trunk, branch, or other contact. Similarly, more detailed cause codes may be expanded further. For example, a vegetation-related outage may be initially attributed a cause code of, “tree/whole tree failure.” The investigation process may further elaborate on this cause code by indicating that the, “tree/whole tree failure,” outage was specifically caused by a live trunk failure, dead trunk failure, live uproot, dead uproot, or other.

Whole Tree Contacts

For the purposes of this report, “whole tree contact” distribution electrical outages refer to service interruptions, caused by tree-to-phase contact, following uprooting or bole fractures.

Whole tree contact outages are caused by danger trees, hazard trees, or trees whose heights are less than their distance to phase, whose failures create domino effects, which cause danger tree-to-phase or hazard tree-to-phase contact.

Height at Failure.

Height at failure refers to the height at which a bole fractured to cause an electrical service interruption. This data point is not collected when whole tree failures are caused by uprooting.

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, three require that investigators record height at failure, when investigating whole tree contact outages caused by bole fractures.

Diameter at Failure (Bole).

Diameter at failure (bole) refers to the diameter of the bole at the point where it fractured to cause an electrical service interruption. This data point is not collected when whole tree failures are caused by uprooting.

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, seven require that investigators record diameter at failure (bole), when investigating whole tree contact outages caused by bole fractures.

Branch Contacts

For the purposes of this report, "branch contact" distribution electrical outages refer to service interruptions, caused by branch-to-phase contact, following branch fractures.

Branch contact outages occur when branches of danger or hazard trees fracture and contact overhead power lines or other distribution assets. These branches cause electrical service interruptions by physically damaging overhead power lines or other distribution assets, or by bridging multiple phases (Guggenmoos 2007).

Diameter at Failure (Branch).

Diameter at failure (branch) refers to branch diameter at the point where it fractured to cause an electrical service interruption.

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, ten require that investigators record diameter at failure (branch), when investigating branch contact outages.

Branch Overhanging Line.

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, eleven require that investigators record whether the outage-causing branch was overhanging the conductor prior to the outage, when investigating branch contact outages.

Growth Contacts

For the purposes of this report, “growth contact” distribution electrical outages refer to service interruptions, which are caused by branch-to-phase contact, in the absence of branch fractures.

Growth contact outages occur when intact branches of danger or hazard trees contact overhead power lines. Most commonly, these branches cause electrical service interruptions by bridging multiple phases.

Species

The mechanical properties of wood vary substantially by tree species (Forest Products Laboratory 2010). These mechanical properties heavily influence a tree's resilience to environmental factors such as snow loading and high velocity winds. Some tree species are also more prone to developing particular defects, which may also affect resilience. Furthermore, pathogens, diseases, and fauna are often selective in the tree species that they damage and/or inhabit (Schoonhoven *et al*. 2005) (Augustine and McNaughton 1998). Consequently, recording tree species information during vegetation-related outage causal factors investigations is imperative.

All of the twenty-two participants who conduct vegetation-related outage causal factors investigations require that investigators record species information, when investigating vegetation-related outages.

Tree Height

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, twelve require that investigators record the height of outage causing trees, when investigating vegetation-related outages.

Tree Diameter

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, sixteen require that investigators record the diameter of outage causing trees, when investigating vegetation-related outages. Tree diameter is typically measured at 1.3 meters or breast height.

Tree Age/Life Stage

A tree's age or life stage heavily influences its resilience to environmental factors. For example, mature trees are often more susceptible to insect damage and diseases (Healthy Forest Partnership 2014). Mature trees are also more likely to exhibit physical damage and rot due to the fact that they have existed longer than their juvenile counterparts. On the other hand, many damaging insects are selective, and may prefer juvenile wood and/or growth (Schoonhoven *et al*. 2005).

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, three require that investigators record tree age or life stage, when conducting investigations. Ages may be presented in years or through qualitative terms.

Distance from Stump to Phase

For the purposes of this report, "distance from stump to phase" refers to the distance from the stump of the outage-causing tree to the phase's nearest possible point or point of tree-to-phase contact.

Vegetation maintenance programs, which solely focus on maintaining minimum clearances through trimming, do not often adequately prevent vegetation-related outages on electrical distribution ROWs. The selective removal of danger and hazard trees in conjunction with cyclic tree trimming is now the preferred method employed by many vegetation management planners.

Determining the distances from stumps of outage-causing trees to the phases that they contact not only allows vegetation management planners to make better informed danger and hazard tree planning decisions, it allows them to justify those decisions, as well.

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, ten require that investigators record distance from stump to phase, when conducting investigations.

Inside/Outside ROW

For the purposes of this report, "inside/outside ROW" refers to whether the outage-causing tree was located on or off ROW. Similar to distance from stump to phase data points, inside/outside ROW data points can be used to identify trends, which can empower vegetation management planners to make well-informed danger and hazard tree planning decisions.

The recording of inside/outside ROW data points is often required when the measuring and recording of distance from stump to phase data points is not required. Vegetation management planners can determine whether outage-causing trees are located on or off ROW by considering minimum clearance requirements and distance from stump to phase data points. The collection of both data points is, therefore, redundant.

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, nineteen require that investigators record on/off ROW data points, when conducting investigations.

Direction of Felling

For the purposes of this report, "direction of felling" refers to the direction from the stump of the outage-causing tree to the tip of the most centralized leader of its crown, when an outage occurs due to whole tree contact.

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, eight require that investigators record direction of felling data points, when conducting investigations.

Leaning Towards Line

Whether a tree was leaning towards an overhead conductor can be difficult to determine when considering outages caused by whole tree contacts following bole fractures. For the purposes of this report, when these types of outages occur, "leaning towards line" refers to whether the angle between the remaining stump's lateral edge and the ground is such that the outage-causing tree was most likely leaning towards the overhead power line whose service was interrupted.

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, two require that investigators record whether outage-causing trees were leaning toward overhead power lines, when conducting investigations.

Wind Exposure

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, three require that investigators record wind exposure, when conducting investigations.

Geographic Coordinates

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, eight require that investigators record the geographic coordinates for the outage-causing tree.

Evidence of Stress or Decline

Certain symptoms and damage are often characteristic of stress and decline in trees. Visual examples may include sudden or uncharacteristic changes in crown colour, distortion of leaves and stems, defoliation, growth stimulation, reduced growth, spots and lesions, rots, and more (Dunster *et al*. 2017).

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, eighteen require that investigators indicate whether outage-causing trees showed general signs of stress or decline.

Compromised by Disease

For the purposes of this report, "compromised by disease" refers to whether the outage-causing tree exhibited clear evidence of being affected by disease. Symptoms include dieback, foliage discoloration, decay, galls, wilting, and more (Dunster *et al*. 2017).

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, sixteen require that investigators record whether outage-causing trees were compromised by disease.

Compromised by Insects

For the purposes of this report, "compromised by insects" refers to whether the outage-causing tree exhibited clear evidence of being affected by insects. The actual presence of insects, entry and exit holes, galleries, nests, and more may indicate that outage-causing trees were compromised by insects. The presence of insects may cause dieback, structural weaknesses, decline, and death (Dunster *et al*. 2017).

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, fourteen require that investigators record whether outage-causing trees were compromised by insects.

Compromised by Wildlife

For the purposes of this report, "compromised by wildlife" refers to whether the outage-causing tree exhibited clear evidence of being affected by wildlife. Evidence of such activities varies depending on animal species. Porcupines, for example, may strip large sections of bark, beavers gnaw the bases of trees, and woodpeckers create cavities (Hygnstrom *et al*. 1994).

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, ten require that investigators record whether outage-causing trees were compromised by wildlife.

Compromised by Defects

For the purposes of this report, "compromised by defects" refers to whether the outage-causing tree exhibited clear evidence of being affected by defects. Structural defects come in a variety of forms. Cracks, weak branch unions, decay, cankers, and more all constitute structural defects (Dunster *et al*. 2017).

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, seventeen require that investigators record whether outage-causing trees were compromised by defects.

Specific Defects.

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, seventeen require that investigators record specific types of defects that affected the outage-causing tree, when conducting investigations.

Slope

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, three require that investigators record the slope at the stump of the outage-causing tree.

Soil Conditions

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, ten require that investigators record the soil characteristics at the stump of the outage-causing tree.

Weather

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, fifteen require that investigators record the weather at the time of the electrical service interruption.

Wind Speed.

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, four require that investigators record the wind speed at the time of the electrical service interruption.

Predictable/Preventable

Distributors differ in the ways in which they define whether a vegetation-related distribution outage is predictable and/or preventable. In most cases, though, outages are considered predictable and/or preventable if the outage-causing tree *should have* been addressed (trimmed or removed) during the previous cycle, according to UVM standards, but was overlooked/missed.

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, thirteen require that investigators record whether the vegetation-related outage was predictable and/or preventable.

Additional Comments

All of the twenty-two participants who conduct vegetation-related outage causal factors investigations allow investigators to record additional comments, when conducting investigations.

Photographs

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, five require that investigators take photographs of the outage-causing tree and/or surrounding circumstances, when conducting investigations.

GIS/Geodatabase

Of the twenty-two participants who conduct vegetation-related outage causal factors investigations, two store their data sets in GIS or a geodatabase, rather than a traditional, non-spatial database.

DATA UTILIZATION

The fifth survey question posed to participants was, “How does your company utilize cause code, reliability, and investigations data to practice RBVM?” Due to several requests from distributors, specific responses are not detailed in this report.

DISCUSSION

The results from this study suggest that, although North American electricity distributors – for the most part – do practice some form of RBVM, practices vary greatly by distributor. To some extent, this seems reasonable, as regulations, budgets, climates, topographies, and forest covers vary, as well. However, fundamentally important aspects of UVM programs such as the removal of hazard trees and utilization of reliability data to prioritize UVM activities are absent in many distributors' planning regimes. Hazard tree removal and reliability data considerations are imperative to distribution reliability improvements and UVM budget optimization.

The results from this study suggest that since William Porter's statements in 2015, many North American electricity distributors have increased investment in distribution vegetation-related outage causal factors investigations. The lack of consistency across investigations programs, however, indicates that, in general, distributors are designing their programs independently of each other, in the absence of BMPs.

The data from this study also suggest that the lack of collaboration between distributors and a deficit of literature related to distribution vegetation-related outage causal factors investigations, has possibly led to the creation of investigations programs which, often times, do not collect actionable data. Compounding this problem is the issue of under-qualified staff. In other words, many electricity distribution UVM departments do not employ individuals who are sufficiently qualified in statistics and/or data management. As a result, RBVM analyses are, often times, rudimentary.

As previously mentioned, twenty-two of the forty sample participants conduct some form of distribution vegetation-related outage causal factors investigations. Notable is the fact that only two of the twenty-two investigation-conducting distributors store their investigations data in a geodatabase. The benefits of geodatabases are numerous and the costs and labour to create and operate a geodatabase are similar to those involved with creating and operating non-spatial databases. The utilization of geodatabases to store investigations and reliability data facilitates the generation of high definition maps, which allow UVM planners to view their data spatially, as a mosaic of layers. For example, planners can import reliability data by circuit or circuit segment, investigations data, and regional weather, fire cycle, species at risk, insect/pathogen distribution, and forest resource inventory maps, and view each layer simultaneously. The locations of regional weather stations can be imported as well. Through queries, planners can then easily determine which regional weather stations are in closest proximity to the exact points of tree-to-phase contacts. Planners are then able to associate comprehensive weather data with specific service interruptions.

Sample participants are divided over whether distribution vegetation-related outage causal factors investigations are economically responsible. In other words, some distributors are of the opinion that the potential proportional improvements to safety and reliability, derived from investigations data, do not outweigh the costs of designing, implementing, and monitoring such programs.

With some distributors utilizing as few as one vegetation-related outage cause code, one distributor utilizing nineteen vegetation-related outage cause codes, and numerous distributors falling somewhere in between, also dividing sample participants is the debate over the optimal number of distribution vegetation-related outage cause codes. To some degree, cause codes are bound to differ by distributor, as local conditions vary. With that said, such great differences between cause code sets indicates that – as a whole – the North American electricity distribution UVM industry has yet to agree on a framework for optimal cause code sets.

CONCLUSION

The majority of sample participants *are* incorporating RBVM into their UVM planning regimes, although the way in which distributors practice RBVM varies across the sample group.

It is recommended that when electricity distributors design vegetation-related outage causal factors investigations programs, they first review the academic literature surrounding general tree mortality, and consult with their peer utilities. It is also recommended that peer utilities adopt the same – or similar – vegetation-related outage cause code sets. This would facilitate inter-distributor apples to apples comparisons of vegetation-related outage frequencies, by modes of failure.

Given many distributors' hesitancies around cost effectiveness, peer distributors should consider aligning vegetation-related outage causal factors investigations programs. This would facilitate the creation of a central repository, in which participating distributors would input data collected through their respective investigations programs, which would then be made available to all participants. Distributors are not in competition and data sharing would translate to each distributor spending proportionally less per investigation.

Perhaps, in time, inter-company collaboration and research will inspire consistency across North American electricity distributors' RBVM frameworks.

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