

Effects of Tree Mortality on Power Line Security

By

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Abstract:

Others have reported that instances where trees grow into lines rarely result in power outages. The vast majority of tree-related outages stem from tree failure particularly if outages during severe weather events are included. Generally, tree-conductor conflicts resulting from tree failure are classified as unpreventable because the trees are located outside the right of way. In the emerging competitive environment, utilities will require a means of decreasing so called unpreventable outages. The primary locations for unpreventable outages are areas where lines run adjacent to or through natural forest tree stands. Tree mortality exposes a power line to a high risk of tree incidents over time. The risk to the line is directly related to the number of trees within striking distance of the line. Conventional clear widths leave a substantial residual tree risk. Hazard tree removal programs do not provide enduring reliability gains. A new mathematical model, the Optimal Clear Width Calculator, is used to assess the tree risk over variable clear widths and line heights. The risk ratings in the output Line Strike Probability Charts permit quantitative comparisons of construction and maintenance options. The Line Strike Probability Chart indicates that there is a point of diminishing return in line security for dollars invested in additional clear width.

Key Words: utility arboriculture, hazard tree, tree-related outages, tree-conductor contacts, electric system reliability, tree mortality, line strike risk, tree risk quantification

BACKGROUND

It is estimated that North American utilities spend \$2 billion (Rees et al. 1994, EPRI 1995, Goodfellow 2000) to \$10 billion (Ed. Transmission & Distribution World 2002) annually on vegetation management to prevent service disruptions and safety hazards associated with trees contacting conductors. Throughout their one hundred year history, utilities have been challenged by tree-conductor conflicts that continue to plague them today.

Trees are a major cause of power outages, particularly on distribution systems. On distribution systems tree-related outages comprising 20% to 50% of all unplanned outages are common (Rees et al. 1994, Simpson and Van Bossuyt 1996, Johnstone 2001). Tree-related outages exceeding 50% of the total tend to draw attention to the need for remedial action (St. Petersburg Times, FL, May 20, 1999, Megawatt Daily, Dec. 1, 1999, Poole and Clements 2000). While these percentages indicate trees are a major threat to reliability, the convention of excluding outage statistics arising from severe storm events (Louisiana Public Service Commission 1998, Carris 2000, California Public Service Commission 2000, Michigan Public Service Commission 2000, Oregon Public Utility Commission 2001, Finch and Allen 2001), means the extent of the problem is vastly understated.

Utilities are in the business of generating electricity, delivering electricity and/or electrical

service. They invest in and install equipment to condition and transport electricity to the point of use. This equipment, essential to providing the service that constitutes the business, is an asset. That which holds the potential of disrupting the service and thereby the revenue stream constitutes a financial liability. From a utility business perspective, all trees capable of growing into or on failure striking a power line, are not only a legal liability due to human safety and property concerns, but also a financial liability.

Considering the long history of attention and resources focused on reducing or eliminating tree-conductor conflicts, the extent of the ongoing level of tree-related outages suggests something is missing. Utility foresters balance a plethora of competing interests. Challenged to satisfy the need for safe, reliable, economic electric service, easement conditions, property rights, regulations, environmental concerns, tree ordinances, public perceptions, and aesthetics, one understands how it might be difficult "to see the forest for the trees".

Tree-related outage statistics provide information about the extent of tree exposure and efficacy of the line clearance program. However, these statistics are after the fact. The intent of this article is to provide a means of understanding and quantifying the tree risk in advance of failure events. This search for a conceptual framework for sustainable tree-related outage reductions takes a dispassionate view, focusing on trees, how forest stands develop and die, characteristics of the electrical system and utility business, and how they interact to impact reliability.

In developing the conceptual framework, this article will examine from a North American perspective:

- the increasing pressure on utilities to reduce service disruptions
- the source of tree-related outages
- natural tree mortality and predictive modeling of tree mortality
- the implications of tree mortality for conventional hazard tree identification and removal program cycles and intensity
- an approach to quantifying the risk of tree line strikes
- using the cost of changes in tree risk to decide between maintenance options
- the relationship between target clearance and tree risk

The primary audience for this article is utility foresters. Secondary audiences include utility asset managers, utility arboriculture consultants, utility regulators, forest managers and other stakeholders. Terminology used draws both from utility and forestry domains. Standards and units used in examples have been selected based on wide commonality in the North American utility industry.

It will be demonstrated that the majority of the risk associated with the tree liability arises from trees outside the maintained right of way (ROW). Tree failure events that disrupt electric service are weather related (Simpson and Van Bossuyt 1996, Desbiens 2001, Finch and Allen 2001, Rogers 2001, Tomich 2001, Keener undated). Because severe weather may cause healthy, defect-free trees to fail (Simpson and Van Bossuyt 1996, Desbiens 2001, Finch and Allen 2001, Tomich 2001, Keener undated), all trees capable of interfering with power lines are included in the risk assessment. In viewing all trees capable of interfering with power lines as a liability, the assessment of tree risk assumes a worst case scenario. Hence, the quantification of the tree risk

as presented should be seen as the base case which will be modified by other risk factors such as species specific failure characteristics and the frequency of severe storms, drought and pest infestations.

Nonetheless, the tree risk assessment can be used on a comparative basis. As such, the quantitative tree risk assessment constitutes a tool that will provide:

- a means for progressive reliability improvements
- another method of assessing the role of trees on circuits experiencing poor reliability
- a means of setting specific, acceptable, residual tree risk levels
- a basis for prioritizing investment to maximize reliability gains and minimize losses
- a means of rationalizing capital investment in equipment or methodologies that prevent tree-caused outages
- a means of illustrating to regulators the need for and prudence of line clearance maintenance decisions and funding

The use of a broad, inclusive definition for the tree liability should not be construed to suggest that utilities reduce the tree risk to zero by removing all trees capable of interfering with power lines. Not only would such a decision be met with public and regulator resistance but also, as will be demonstrated, it would not be financially prudent.

CONTEXT FOR TREE-CONDUCTOR CONTACTS AND SERVICE DISRUPTIONS

In little more than a decade, a firestorm in Washington (Partners in Protection 1999), the burning of a historical California town (EnergyOnline Jun 23, Jul 21 1997, Olsen 2001) and two major western U.S. grid crashes (EnergyOnline Aug 7, Aug 26, Nov 5 1996) have been attributed to tree-conductor contact. In western North America, where summer forest conditions tend to be dry, tree-conductor contacts are a frequent cause of forest fires (EnergyOnline Oct 2, 1997, EnergyOnline Oct 2 1998, Partners in Protection 1999).

Utilities in eastern North America face ice storms (EnergyOnline Jan 8, 1998, Desbiens 2001). In the south and southeastern United States windstorms are relatively frequent events (Electric Perspectives Apr 2001, Tomich 2001, Keener). While the stress these events place on the electrical system results in direct equipment failures, often the majority of outages associated with these events are indirect. They are the result of tree failures (PRNewswire Oct 25 1999, Megawatt Daily Dec 1 1999, Tomich 2001).

The risk of major system outages caused by severe weather events is increasing. Climatologists studying global warming predict greater variability in weather in the future. They forecast the number and severity of major weather events would increase. (Watson et al. 1998) The trend may already be established. During the last 21 years, 48 extreme weather events each with estimated damages exceeding US\$1 billion hit the United States. Of these, 41 have occurred in the last 12 years (Hadden 2001).

The transmission component of the electrical system is experiencing unprecedented load. Due to the business uncertainty associated with evolving regulation towards competitive markets and public resistance to siting new transmission lines, expansion of the transmission system has not

kept pace with growing electricity demand (Owens 2001).

A new trend emerging from Public Utility Commissions is to specify reliability targets that must be met (Kjellstrand 1998, Rights-of-Way Online 1999, Grayson 2001). The number of states in the United States that have set reliability standards increased from three in 1996 to 27 states in 2001 (Bush 2002). A variant is performance based ratemaking, under which utilities will be financially rewarded for exceeding reliability goals and, in some cases, punished for failures to meet them (Grayson 2001). As of 2001, 11 states in the U.S. have penalties and awards for performance (Bush 2002). The effects of major storms on the reliability statistics are excluded from the base targets. However, increasingly Public Utility Commissions are questioning whether a utility's past maintenance practices have not compounded the extent of storm damage (EnergyOnline Sept 4, 1998, Tomich 2001).

With the shift to and expansion of the digital economy, reliability of the electric system takes on previously unimagined significance. The annual U.S. economic loss due to power outages is estimated to range from a conservative US\$50 billion (EPRI) to US\$100 billion (Bank of America)(Lewis 2001).

In a recent RKS Research & Consulting survey (Business Wires Features, January 29, 2001) 75% of the respondents said it "doesn't matter which company supplies... electricity, as long as delivery is reliable".

Evolving customer and regulator expectations suggest an approach of classifying tree-related outages as non-preventable will no longer be acceptable. The need for reliable service has increased dramatically. Due to costs, the digital economy is completely intolerant of outages (Lewis 2001). One might expect the most flexibility and tolerance with light load residential and small commercial customers. However, it is unknown how long these customers, dependent on electric service for security, comfort, productivity, convenience and recreation, will continue to be forgiving for outages stemming from major storm events. Failure to address the reliability issue will drive customers to adopt the emerging distributed generation technologies to free themselves of the grid.

SOURCE OF TREE-RELATED OUTAGES

To reduce tree-related outages it is necessary to examine the origin of tree-related outages (Rees et al 1994, Guggenmoos 1996, Simpson and Van Bossuyt 1996, Goodfellow 2000). Tree-related outages can be classified into two groups based on fault type:

- those attributable to tree growth;
- those attributable to tree failure.

When a pruning program begins to fall behind, tree branches grow into conductors. Initially, as branches begin to make contact with energized distribution conductors the shoots tend to be "burned off" through momentary contact (**Figure 1**). Rarely, at this early stage of tree-conductor contact would we expect a fault to occur. Rees, of Baltimore Gas & Electric, attributed only 2% of all tree-related outages to trees growing up into a line (Rees et al. 1994). Guggenmoos showed tree growth to account for 2% to 10% of tree-related outages on TransAlta Utilities' distribution

Figure 1

New growth has been "burnt off"
from occasional line contact
(centre of photo).

system (Guggenmoos 1996). Finch, reporting on Niagara

Mohawk's tree-caused outages, indicates tree growth accounts for 14% of outages (Finch and Allen 2001), while Rogers explains part of the reasoning behind Puget Sound Energy's Tree Watch program is that only 13.5% of tree-related outages are attributable to tree growth (Rogers 2001). From these geographically, ecologically diverse utility systems a common thread emerges: tree growth into power lines accounts for less than 15% of all tree-related outages. A marked increase in outages due to growth is not likely to occur until the pruning program is so far behind cycle that tree branches are of a more substantial diameter and in simultaneous contact with two phases (Rees et al. 1994, Goodfellow 2000, Finch and Allen 2001).

Notwithstanding, this finding should not be interpreted to mean that trees growing into distribution lines are not a risk. Safety and fire hazard risks increase in relation to the

decreasing clear distance between trees and bare conductors and number of incidents of tree-conductor contact. These risks represent a legal liability not only to utilities but also directly to utility executives and directors (Guggenmoos 1996, EnergyOnline Daily News Jun 23 1997, EnergyOnline Daily News Jul 21 1997).

Tree-conductor contacts arising from tree failure will in most cases result in a fault by:

- breaking the conductor or bringing it to the ground;
- bringing phases into contact with each other;
- making a substantive bridge between phases allowing a carbon path to develop, leading to a short (Rees et al. 1994, Goodfellow 2000, Finch and Allen 2001).

Where maintenance practice does not remove overhangs, some electrical faults will arise from trees within the right of way (Finch and Allen 2001), however, the majority of tree-caused outages are due to the failure of trees outside the right of way. The number of trees capable of striking the line from outside the right of way vastly outnumbers the trees on it. This is particularly true for distribution lines, which comprise roughly 90% of the electric grid. North American distribution line heights are generally 6.1 to 9.1 m (20-30 feet). Maintained right of way width for distribution lines is commonly 6.1 to 9.1 m (20-30 feet) with a clear width of 3 to 4.5 m (10-15 feet) (See **Figure 2**). Where such distribution lines run through 24.2 m (80 foot) tall tree stands, the maintained right of way area represents only 12% to 19% of the total area from which tree-conductor conflicts can arise. Along transmission lines, where voltages are higher, a greater percentage of the area from which tree conflicts could arise needs to be and typically is maintained as right of way. The maintained portion may comprise 100% of this area but more commonly comprises 30% to 70%. The tree risks in the transmission line wire zone are readily recognized (EnergyOnline Aug 7, Aug 26, Nov 5 1996, Goodfellow 2000) and providing adequate funding, are generally addressed. Hence, it is the off right of way trees that will constitute the larger source of outages, particularly under severe weather conditions.

Figure 2

Clear Width: the distance measured on the ground from the trunks at the tree line to the nearest conductor.

On TransAlta's distribution system, where all overhangs were removed, 90% to 98% of tree-caused outages were due to tree failure (Guggenmoos 1996). It is estimated that 95% or more of these failures were trees beyond the maintained right of way. Finch reports 86% of tree-caused outages result from trees outside the right of way (Finch and Allen 2001). Similarly, on the west coast, Rogers reports that 66% of PSE's outages are caused by trees greater than 4.5 m (15 feet) from the nearest conductor (Rogers 2001). If tree-related outages are to be substantially reduced, off right of way trees will need to be addressed.

Addressing the safety and reliability risks of off right of way trees represents an enormous challenge to utilities. Power lines run through or adjacent to an enormous number of trees. Thirty-three percent of the United States and 56% of Canada are forested (Smith and Sheffield 2000, Forestinformation.com). Most of these trees are natural. Only 7% are planted (Forest Service 2001). The extent of the liability will vary geographically. Maine is 90% forest covered, while Iowa has only 5.7% forest cover (Forest Service 2000). In U.S. urban areas tree cover is 27% (Forest Service 2001).

On distribution systems where a large portion of the tree-related outages are attributable to tree growth, the pruning maintenance cycle is too long and divorced from the tree inventory and tree growth rates. Conceptually, this problem is easy to resolve since the underlying cause of this condition is inadequate funding. Where tree failure is the major source of tree-related outages, resolution of the problem is more complex and certainly not as apparent.

TREE MORTALITY AND IMPLICATIONS FOR UTILITY MAINTENANCE PRACTICE

Trees may be power line hazards because of lean, a poor anchoring medium, poorly formed narrow angle crotches, codominant leaders and other structural defects. Such trees are removed in a hazard tree program. But what of trees that have no physical defects yet succumb to competition for light, water and nutrients? An examination of natural tree mortality is warranted.

Data for lodgepole pine (*Pinus contorta*) in Alberta (Johnstone 1976) reveals between age 20 and 100 years there are about 4000 trees per hectare that die (**Table 1**). Lodgepole pine is a fire origin species. Stands are even-age and quite uniform. In the first 30 years the trees are not of a height where they are likely to cause service interruptions. In Table 1, the column Relevant Mortality provides a cumulative total of dead trees per hectare in excess of 11.8 m (39 ft) in height. The mortality is considered relevant as these trees, in the vicinity of a distribution lines,

Table 1

Lowest density [1236/ha at 70 years] yield
table for Lodgepole Pine on an 'Average Site' in
Pinus contorta Alberta after Johnstone 1976

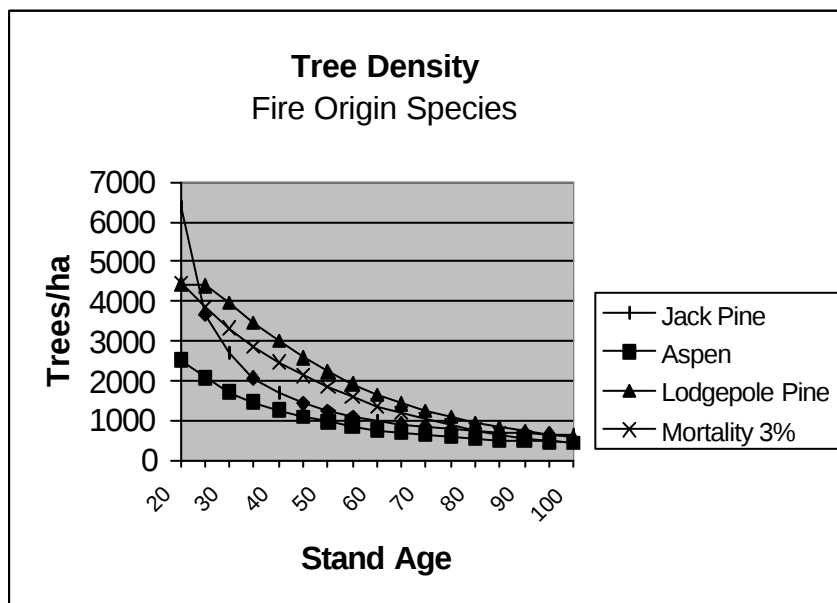
Age	Trees per Ac	Trees per Ha	Dom-Ht (ft)	Dom-Ht (m)	Relevant Mortality
20	1793	4431	26	7.92	0
25	1780	4398	29	8.84	0
30	1603	3961	34	10.36	0
35	1403	3467	39	11.89	494
40	1215	3002	44	13.41	959
45	1047	2587	49	14.94	1374
50	902	2229	53	16.15	1732
55	777	1920	57	17.37	2041
60	670	1656	61	18.59	2305
65	578	1428	64	19.51	2533
70	500	1236	67	20.42	2726
75	434	1072	69	21.03	2889
80	378	934	72	21.95	3027
85	331	818	74	22.56	3143
90	292	722	76	23.16	3240
95	261	645	78	23.77	3316
100	235	581	79	24.08	3380

Adapted from: Johnstone 1976

Note: Relevant Mortality refers to trees > 11.8 m (39 ft)

hold the potential to cross phases, start fires and disrupt service. Typical distribution line height is 6-9 metres (20-30 ft). Tree mortality that poses a threat to distribution lines is almost 3500 trees per hectare over 70 years. Putting that into a utility context, a hectare is about one mile by twenty feet wide. For a power line running alongside such a lodgepole pine forest there are about 3500 trees that die over an 70-year period within a 20 foot strip just outside the maintained right of way. Taking, for the sake of simplicity, a straight line average, that amounts to an annual average of 50 trees per hectare (20 ft. X 1 mile) that become susceptible to failure.

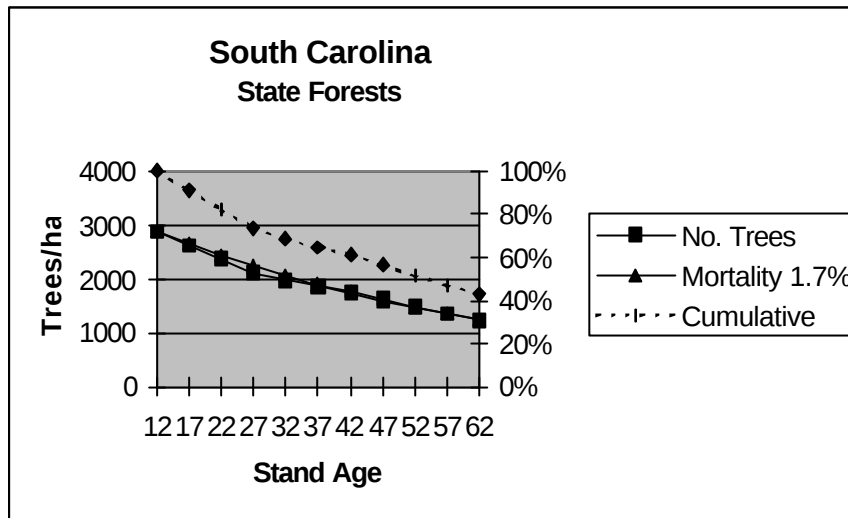
Of course only a percentage of these 50 trees per hectare capable of striking the line on failure, will do so. However, we can reasonably expect that the number of tree-caused outages is directly proportional to the degree of exposure, measured in standing hazard trees.

Figure 3

Source: Johnstone, W.D. 1976 & Plonski's Yield Tables
Natural tree mortality numbers in the thousands of trees/ha. Most of the dying trees pose a potential risk to power lines.

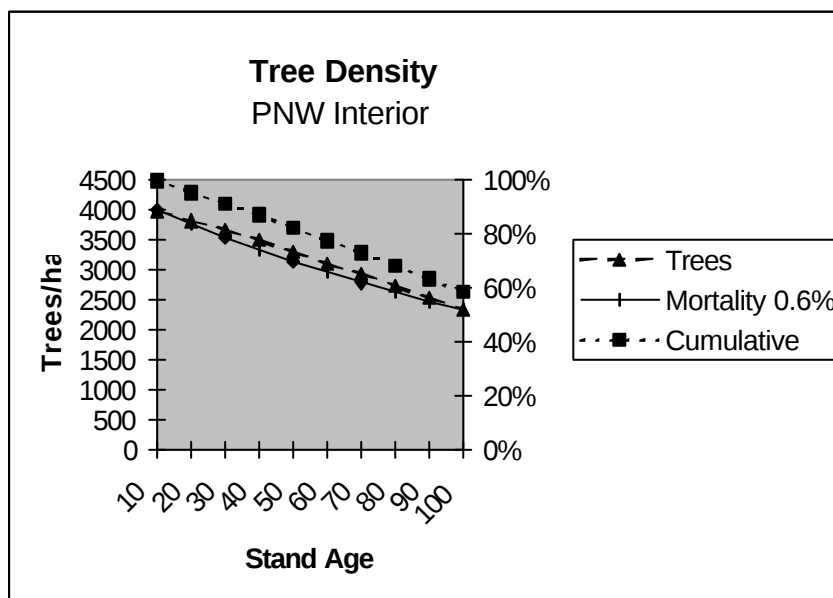
Other fire origin species, jack pine and trembling aspen (*Pinus banksiana*, *Populus tremuloides*), of the Canadian boreal forest (**Figure 3**) follow a similar pattern of mortality. Over 50 years the stand density declines 70%. For young South Carolina forests (**Figure 4**) predominated by pines (*Pinus spp.*), oaks (*Quercus spp.*), maples (*Acer spp.*), yellow poplar (*Liriodendron tulipifera*) and blackgum (*Nyssa sylvatica*), which would typically evolve

into uneven age stands, stand density is found to

Figure 4

Source: Crookston, Nicholas L. 1997. Suppose: An Interface to the Forest Vegetation Simulator.

Sixty percent of the trees in the stand die over 50 years. Over 40% are tall enough to disrupt distribution service.

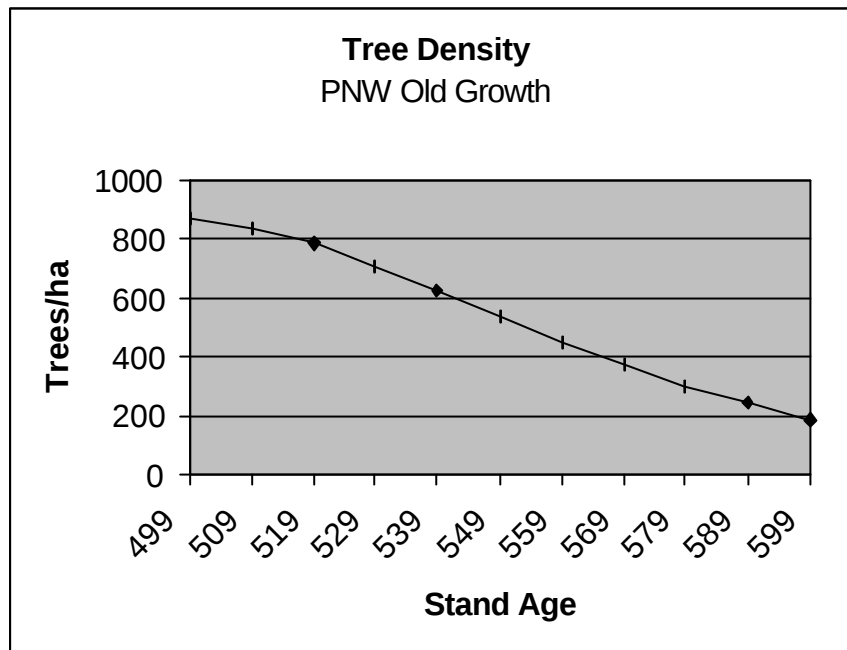
Figure 5

Source: Crookston, Nicholas L. 1997. Suppose: An Interface to the Forest Vegetation Simulator.

Considering accretion and higher mortality of small diameter trees (Johnson 1990), the average

decline 60% over 50 years (Crookston 1997). Tree mortality for the South Carolina forest stands represented in **Figure 4** amounts to 36 trees $\text{ha}^{-1} \text{yr}^{-1}$ ($\text{mi}^{-1} \text{yr}^{-1}$ over a 20-foot width). Mortality skewed to small diameter class trees as one would expect for uneven age stands is not a factor as there is no accretion built into the stand model used (Lilly 2000). Still, not all of the trees have the height to interfere with power lines. Most do however, since they achieve 12.1 m (40 ft) in height in 20 years. Eliminating the short trees from the South Carolina data to focus on annual mortality relevant to utilities, reduces the rate to 23-25 trees $\text{ha}^{-1} \text{yr}^{-1}$.

Some of the lowest tree mortality rates appear in the U.S. Pacific Northwest. Using the Suppose simulator (Crookston 1997), forests stands comprised of Douglas fir (*Pseudotsuga menzeisii*), ponderosa pine (*Pinus ponderosa*), western larch (*Larix occidentalis*), Grand fir (*Abies grandis*) and lodgepole pine show a 40% stand reduction over 90 years (**Figure 5**).

Figure 6

Source: Crookston, Nicholas L. 1997. Suppose: An Interface to the Forest Vegetation Simulator.

Very old tree stands continue the pattern of decreasing tree stand density over time.

annual mortality relevant to utilities is 18 trees per hectare.

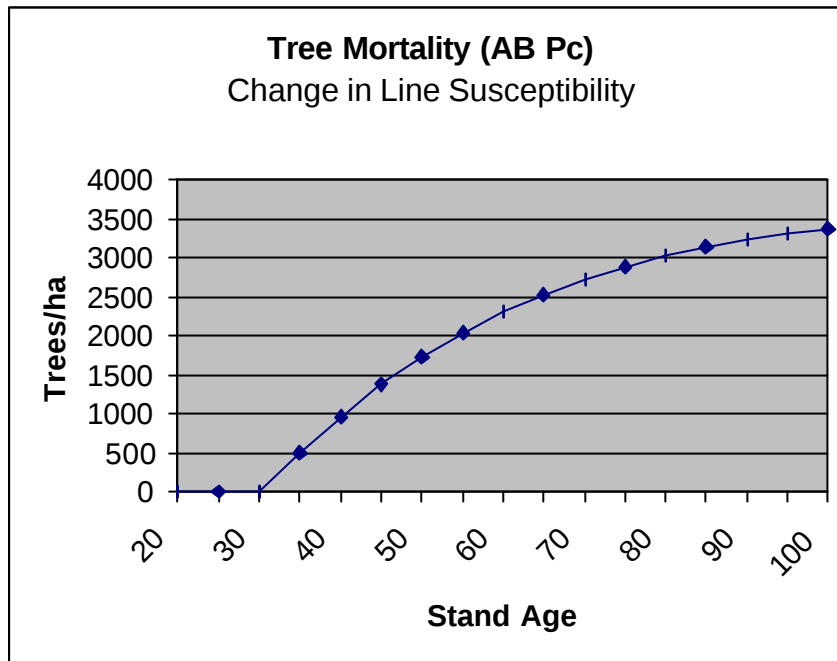
All of the preceding forest stands examined have been young stands. Old stands, however, follow the same pattern (**Figure 6**), though the average annual mortality in trees is lower because the number of trees in the stand is lower. For this 500-year-old stand of ponderosa pine and Douglas fir (Crookston 1997) the predicted average annual mortality is 7 trees per hectare. Given that only 6% of U.S. timber is more than 175 years old and that 55% of the U.S. forests are less than 50 years old (Forest Service 2001),

most electric line exposure will be to forest stands having a relatively high tree density.

The diverse forest stand examples provided show that while the total number of trees and the rate of mortality varies by species and location, the trend of a declining viable tree population over time, is common. It is true for even age and uneven age stands. Inter and intra-species competition for light, water and nutrients drives the decline in tree population. Periods of stress caused by drought or pests accelerate the rate of mortality.

To understand the implications of the declining tree density on power line security, the data for lodgepole pine in Alberta (Johnstone 1976) is graphed to highlight the number of dead and decadent trees (**Figure 7**). The mortality data has been altered to exclude trees that die before achieving a height that is likely to pose a serious risk to a distribution line (Relevant Mortality in **Table 1**). Death in trees is a process that may occur over months to years and dead trees may stand for extended periods of time. **Figure 7** shows how the risk to power lines accumulates. It provides a stimulus for further inquiry and examination of the rate of hazard tree development in the context of utility maintenance operations.

From the data used to generate Figures 3 through 6, illustrating the viable stand populations, tree mortality ranging from 7 to 50 trees per hectare per year were derived. It has been stated that one hectare equals 1 mile by 20 feet. When the height of trees is considered, evaluating the hazard

Figure 7

Source: Adapted from Johnstone 1976, Guggenmoos 1996.

The risk to a power line due to tree mortality builds up rapidly. From a stand age 30-40 years hazard tree additions are about 100 trees/ha per year.

over only the first 20 feet of the adjacent forest will generally be inadequate. Summing mortality for three hectares or over 60 feet per mile would appear a more reasonable approach. For example, this assumption would fit a distribution line with a 3 m (10 foot) clear width adjacent to 21.2 to 24.2 m (70 to 80 foot) trees or a transmission line with a 9.1 m (30 foot) clear width adjacent to 27.3 to 30.3 m (90 to 100 foot) trees. Based on the need to consider the risk arising over 60 feet rather than 20 feet, the number of dead trees posing a risk to power lines then increases by a factor of 3 to: 21 to 150 trees $\text{mi}^{-1}\text{yr}^{-1}$ per ROW side.

The natural phenomenon of decreasing viable tree density over time for forests represents an enormous risk to line security. However, this risk is frequently ignored and not quantified due to the fact that the trees comprising this risk are usually outside the right of way. While inventories may include off right of way hazard trees, it is a static snapshot of conditions at a particular time. There has not been a predictive model for the development of hazard trees. Rather, utilities that recognize off right of way hazard trees as substantial risk to line security tend to have a program of cyclical field inspections to monitor and identify hazard trees. Assuming a five year cycle for hazard tree identification and removal, the lowest tree mortality rate found (U.S. Pacific Northwest interior) necessitates the removal of 105 (21 trees $\text{mi}^{-1}\text{yr}^{-1}$ X 5 yrs) trees per mile per ROW side per maintenance cycle. For lodgepole pine and other fire origin species the required removals expand to 750 (150 trees $\text{mi}^{-1}\text{yr}^{-1}$ X 5 yrs) trees per mile per ROW side. This requirement is two orders of magnitude above what would be considered by the utility industry a typical hazard tree program. Considering the rate of tree mortality, a hazard tree program that successfully removes the emergent risk of line strikes would necessarily be a major operation. It would be noticed in the utility arboriculture industry much as Puget Sound Energy's Tree Watch program has been (Rogers 2001).

Utility arborists and researchers have focused considerable effort on better hazard tree identification. While this is useful, the sheer volume of trees dying under normal conditions

suggests that unless the maintenance cycle is drastically reduced and the number of hazard trees identified and removed per cycle is greatly increased, the risk of tree-line contacts will not be meaningfully reduced. Complicating the matter is that better than half the trees that fail show no noticeable defects (Simpson and Van Bossuyt 1996, Finch and Allen 2001). Shifting from typical hazard tree programs to ones that fully address natural tree mortality would escalate the costs at least twenty times. This casts doubts on the feasibility of improving line security through a hazard tree program. The examination of natural tree mortality leads to the conclusions that improving line security through a hazard tree program will be extremely challenging and where gains are made, the results will not be enduring.

QUANTIFYING TREE MORTALITY

Tree mortality rates will depend on local tree species and conditions. A cursory review of various stand data suggests annual mortality rates ranging from 0.5% to 3% will be quite common (Johnstone 1976, Plonski 1981, Campbell and Liegel 1996, Crookston 1997, Harmon 1999, Curtis et al 2000, Forest Service 2001). The lowest tree mortality rates uncovered in this review occurred in the interior Pacific Northwest. Annual mortality rates of 0.3% to 0.5% were observed in ponderosa pine forests (Harmon 1999). Mortality in coastal forests of Sitka spruce and western hemlock is highly variable ranging from 0.8% to 3.0% per year (Harmon 1999).

Examination of local forest stand data representative of the area will reveal the annual mortality. While this determination is necessary, annual percent mortality is not directly useful. Application requires the current tree density be known so as to transform percentage to trees per unit (i.e. mile) of line. It is expected that most North American utilities will find tree mortality will annually add 50 to 150 trees $\text{mi}^{-1}\text{yr}^{-1}$ per 60 feet of treed ROW side to the workload. Given such a spread, utilities will want to quantify the tree risk specific to their area. A model that can predict tree mortality based on current or found tree densities would be useful. A comparison of the number of trees added to the workload through mortality versus the number removed by the hazard tree program will reveal the impact of tree mortality on future workload. This may prove useful in attracting more funding for vegetation management.

In calculating the annual tree losses, as was done for lodgepole pine, a straight-line average was used for the sake of convenience. This may appear fitting for the Pacific Northwest interior (**Figure 5**) and even the South Carolina mixedwood forests (**Figure 4**). Mortality rates in fire origin species (**Figure 3**) clearly do not follow a linear pattern.

The percent annual mortality in **Figures 3, 4** and **5** is modelled. The same geometric progression was used in each case, altering the mortality rate for the best fit to the observed data. The algorithm used is:

$$P_{tn} = P_{t0} \times 1/(1 + MR)^{tn - t0}$$

Where:

P is tree population (trees/ha)

MR is mortality rate

t0 is the stand age in years at the start of the period

t_n is stand age in years at the end of the period considered

Using this equation to predict the residual tree population a good fit was achieved for several different forest types (Figures 3,4&5). It can be seen that a calculated 3% rate of annual mortality produces a curve that fits fire origin species quite well, while an annual mortality rate of 1.7% fits the South Carolina mixedwood example where the tree density changes appear linear. Thus, at low mortality rates this equation yields a declining population approaching a straight line whereas higher mortality rates result in a curved population decline. While this algorithm provides a tight fit between forecast and actual stand mortality for the provided examples, the number of stands considered is small. This algorithm is not suitable as a predictive tool for all forest stands. Its output will need to be compared to local forest stand data to pre-test its utility. Should it be found lacking, error can be restricted by limiting forecasts of mortality to 20 years or less. For longer term predictions, local forest researchers will be able to provide suitable algorithms (Crookston 1997) .

Discussion has focused on tree mortality in unmanaged stands. Since this tree mortality is based on competition for light, water and nutrients, forest management practices such as commercial thinning that effectively decrease competition between trees will decrease both the mortality rate and the number of dead trees. Lines running through managed stands are not devoid of line strike risks but the rate of tree mortality may be half that of the unmanaged stands (Curtis et al. 2000).

RISK REDUCTION THROUGH HAZARD TREE REMOVAL

Most utilities strive to handle the risk of off right of way tree-caused outages through a hazard tree identification and removal program. To determine if this constitutes a reasonable and effective approach requires an examination of a typical hazard tree program and the rate of development of hazard trees or tree mortality.

To assess the potential of a hazard tree program to mitigate the risk of tree-line strikes an example for a 69 kV line will be used. This voltage, in the lower end of transmission service, is chosen because the tree-conductor clearances maintained will fall between those for higher voltage transmission lines and the lower voltage distribution lines.

Assume the following conditions:

- A 69 kV line is set on an 18.3 m (60 foot) right of way.
- The line is built on 3 m (10 foot) cross arms and the average conductor height is 12.2 m (40 feet)
- 60% of the line runs adjacent to a forest edge.
- Dominant tree height is 25.9 m (85 feet) and tree density is 620 trees/ha (250 trees/Ac).
- A hazard tree program is in place. It is on a five-year cycle and removes an average of 18.75 trees per kilometre (30 trees per mile).

(An informal survey (2001-2) of seven utilities found that hazard trees are removed as a part of the normal maintenance cycle. The maintenance cycle ranged from 3 to 7 years except in Hawaii where the cycle is much shorter. Most hazard tree programs removed about 5 trees mi^{-1} with the most intense averaging 10-15 trees mi^{-1} . A hazard tree program removing 30

trees mi^{-1} was viewed as very aggressive and a major undertaking by all the utilities surveyed.)

From this we can calculate that:

- Clear width = 7.6 m = 25 feet ((60 ft ROW - 10 ft cross arm)/2)
(Clear width is the distance measured on the ground from the trunks at the tree line to the nearest conductor. See **Figure 2**.)
- Trees up to 22.7 m (75 feet) from the nearest conductor could strike the line (as determined by triangulation)
- Residual trees occur over 22.7 m - 7.6 m = 15.1 m (75 ft - 25 ft = 50 ft) per ROW side of exposure
- The residual tree population is 947 trees/km = 1515 trees/mi. ((50 ft X 5280 ft/mi)/43560 sq.ft./Ac X 250 trees/Ac)
- The residual tree population is decreased by 2% through the hazard tree program (30 trees mi^{-1} /1515 trees mi^{-1})

A good hazard tree identification and removal program may substantially improve line reliability. However, the risk addressed by the hazard tree program is only that of trees perceived to be susceptible to failure. The risks associated with the impact of lightning, severe wind and ice loading on healthy, structurally sound trees are not addressed by a hazard tree program as sound, healthy trees are not removed. This risk is not insignificant. Many utility foresters will attest to the fact that as many as half the trees that fail show no noticeable defects. An Eastern Utilities study found that only 44% of the trees or limbs that failed had an indicator of structural weakness (Simpson and Van Bossuyt 1996). Niagara Mohawk found of the trees that failed, 36% were dead and 64% were live (Finch and Allen 2001).

A 2% reduction in the residual tree population examined in the context of typical tree mortality rates of 0.5% to 3% per year (Johnstone 1976, Plonski 1981, Campbell and Liegel 1996, Crookston 1997, Harmon 1999, Curtis et al 2000, Forest Service 2001) reveals that the benefit of even a very aggressive hazard tree program as used in this example will only be significant for a relatively short time. Most of the reliability gain will erode prior to the next maintenance cycle. Since we cannot predict which of the residual trees will next become decadent, the enduring outcome of the example hazard tree program is no more than a 2% reduction in tree-line strike risk.

Given the same tree characteristics, the residual tree population is lower for higher voltage transmission lines due to a greater maintained tree-conductor clearance and line height. Thus removing 18.75 trees km^{-1} (30 trees mi^{-1}) would yield a greater risk reduction. Conversely, for distribution lines, due to smaller maintained tree-conductor clearances and lower line heights, the residual tree population is higher and hence, removal of 18.75 trees km^{-1} (30 trees mi^{-1}) yields a smaller percentage change.

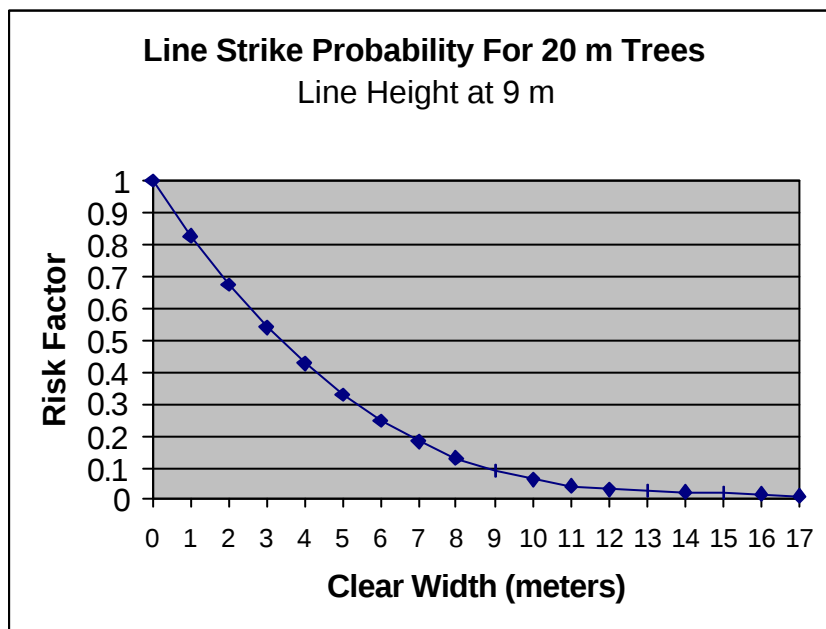
This example serves to illustrate the extent of the risk arising from off right of way trees is not meaningfully addressed, in an enduring fashion, through a typical hazard tree identification and removal program.

QUANTIFYING THE RISK OF TREE LINE STRIKES

For power lines running adjacent to or through forests or natural tree stands the risk of tree-conductor contact is directly related to the number of trees within striking distance of the line. The risk far outweighs the risk arising from trees considered part of the normal maintenance regimen, which places the emphasis on trees within the ROW requiring pruning. The rate of tree mortality has been shown to constitute a far greater risk to reliability than has been previously recognized. How might the tree risk be mitigated?

The tree risk can be quantitatively mitigated by decreasing the number of trees capable of striking the line either by increasing the clear width or the line height.

Figure 8



Where clear width is 0, the risk is considered to be 100% or 1. When clear width is so large that trees cannot contact the line on failure (about 18 m in this example) the risk is 0.

regardless of condition. It reflects differences in mortality based on species only indirectly through tree density (See Figure 3). The ability to withstand wind and ice or snow loading, species specific patterns of decay and failure and the probability of weather events of specified severity are not incorporated when producing the Line Strike Probability Chart. The Risk Factor in the Line Strike Probability Chart is not a stand alone probability of tree failure. Rather, the Risk Factor is used to compare two or more construction or maintenance options for a specific area.

The Line Strike Probability Chart (**Figure 8**) shows that at a 0 m clear width the Risk Factor is 1. The Risk Factor reaches 0 when the clear width is so great that no falling tree can strike the line.

To determine the effects of clear width (clear width and clear distance are used interchangeably) on line security, tree canopy height, tree density and the line height can be used in a mathematical derivation (Optimal Clear Width Calculator, Guggenmoos 2000) of risk exposure. The graphic output, the Line Strike Probability Chart (**Figure 8**), shows how the risk of line strike changes with the clear width. The derivation of risk shown in the Line Strike Probability Chart assumes all possible directions of tree fall have an equal probability. All trees capable of striking the line are considered equal

In this example the Risk Factor reaches 0 at an 18 m clear width. A point of particular interest evident in the Line Strike Probability Chart (**Figure 8**) is that there is a point of diminishing return in line security for the dollar invested in increasing clear width. In this example that point is at a clear width of 6m to 7m. At a clear width of 6m to 7m the Risk Factor passes through the value of 0.2. Stating it in another way, assuming the variables in this example, a 6m to 7m clear width reduces the risk of trees striking the line by 80%. The percentage of trees removed to attain the 0.2 Risk Factor is 39% ($7\text{m}/18\text{m} \times 100$).

The point where clear width provides a diminishing return in line security can provide guidance for the extent of easement required on new lines where an optimal balance between cost and reliability is desired.

The data produced by the Line Strike Probability Chart can be used in a number of ways. To illustrate, three examples are provided.

Examples

1. A section of distribution line running through a forested area is identified as problematic. Under windy conditions trees fail and take the line out. The hazard tree removal program has had limited success. Perhaps widening the right of way is the solution? But it is difficult to justify making a major investment without a means of forecasting the benefit, the impact on reliability.

To produce a Line Strike Probability Chart certain field data are required. Assume the following conditions:

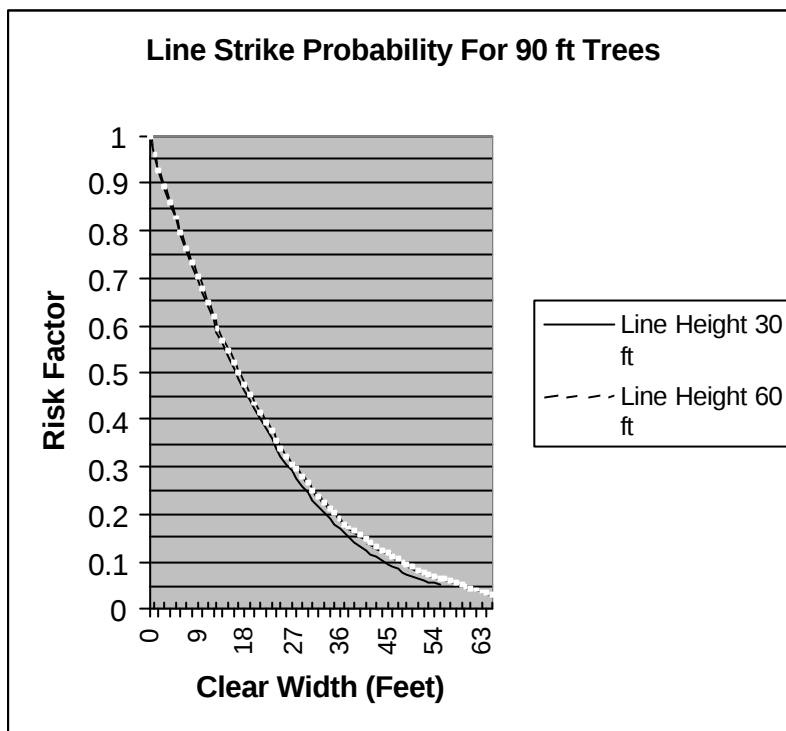
Line height – 9.1 m (30 feet)
 Tree height – 27.3 m (90 feet)
 Trees/ha – 298 (120 trees/Ac)
 Current clear width – 3 m (10 feet)

What would be the benefit of increasing the clear width to 6.1 m (20 feet)?

Reading from the Line Strike Probability Chart (**Figure 9**), at a 3 m (10 ft) clear width the Risk Factor is about 0.68 while at a 6.1 m (20 ft) clear width the Risk Factor is about 0.42. That information can then be put into a simple spreadsheet (**Figure 10**), which shows increasing the clear width another 3 m (10 ft) would result in a 37% improvement in line security.

Adding unit costs to the spreadsheet facilitates a quick assessment of the cost versus the benefit in increased line security. In this way the cost for improvement in reliability gained through right of way widening can be compared to alternatives such as increasing line height, differing construction, undergrounding or use of protective devices.

2. Your utility company plans to build another transmission line. Due to siting

Figure 9

difficulties, the most expedient approvals are likely if the line is added to an existing right of way. Applying to increase the current easement may also result in delays so the company is favouring using the existing right of way. Before finalizing this decision, management would like an assessment of the impact this action will have on line security.

Assume the following conditions:

Seventy percent of the line runs through forest. The clear width will be reduced to 9.1 m (30 feet).
 Line height – 18.2 m (60 feet)
 Tree height – 27.3 m (90 feet)
 Trees/ha – 298 (120 trees/Ac)
 Current clear width – 19.7 m (65 feet)

Figure 10

Cost: Benefit Analysis					
Line Segment Specific:		Ac/mi	Trees/mi	Cost/mi	Line Security Improvement
Line Height	30				
Tree Height	90				
Trees/Ac	120				
Current Clear Width	10				
Current Risk Factor	0.67				
Increase Width	10	1.21	145		
New Risk Factor	0.42				37%
Removal Cost/tree *	\$8			\$1,164	
Removal Cost/tree **	\$60			\$8,727	
* Using feller buncher					
** Chainsaw removals					

A Line Strike Probability Chart is produced (Figure 9).

From the Line Strike Probability chart (Figure 9) we see that at a 19.7 m (65 ft) clear width the Risk Factor is about .03 while at a

Figure 11

9.1 m (30 ft)

Cost: Benefit Analysis					
Line Segment Specific:		Ac/mi	Trees/mi	Cost/mi	Line Security Improvement
Line Height	60				
Tree Height	90				
Trees/Ac	120				
Current Clear Width	65				
Current Risk Factor	0.03				
Increase Width	0	0.00	0		
New Risk Factor	0.26				-767%
Removal Cost/tree *	\$0			\$0	
Removal Cost/tree **	\$0			\$0	

clear width the Risk Factor is about .26. Entering this information into spreadsheet (Figure 11) shows the impact of decreasing the clear width by 10.6 m (35 ft)

is a 767% drop in line security. In other words, one should expect about 8 times the current number of tree-related outages.

3. A 48 km (30 mi) segment of a 240 km (150 mi) 25 kV circuit is being rebuilt. A new 69 kV line is being constructed and for the portion of the overlap the 25 kV circuit will be understrung on the taller 69 kV structures. There have been a significant number of tree problems on the 25 kV line. The records indicate that over the length of the line there were 7 tree-caused outages in the last year. Management has indicated that this level of reliability is unacceptable for a 69 kV line. They have asked what would be required to reduce the tree incidents to no more than one in three years. Engineering has told you that they plan to build the 69 kV line on 3 m (10 ft) cross arms and the average line height would be 12.2 m (40 ft).

Assume you find the following field conditions:

The current 25 kV line is built on 2.4 m (8 foot) cross arms and the average conductor height is 8.5 m (28 feet). Sixty percent of the line runs adjacent to a forest edge. The poles are situated at the edge of a 20 m (66 foot) road allowance.

Current 25 kV conditions:

Line height – 8.5 m (28 feet)

Tree height – 25.8 m (85 feet)

Trees/ha – 620 (250 trees/Ac)

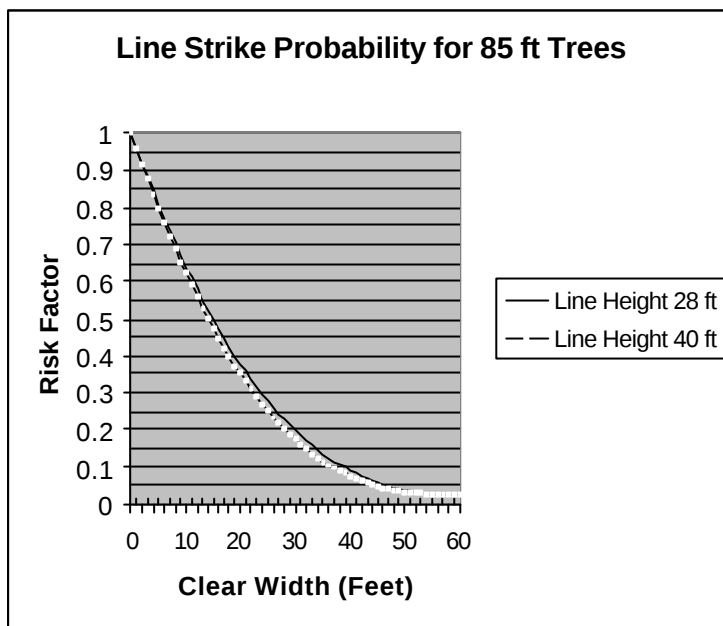
Current clear width – 4.5 m (15 feet)

69 kV conditions as proposed:

Line height – 12.2 m (40 ft)

Current clear width – 4.2 m (14 feet)

Two Line Strike Probability Charts need to be produced: one for a 8.5 m (28 ft) line height (Figure 12) and the second for a 12.2 m (40 ft) line height (Figure 12). The tree Risk Factor for the current situation (28 ft height & 15 ft clear width) is 0.50. The

Figure 12

yr⁻¹.

You calculate the required increase in line security to be 76%:
 $(1 - (.33 \text{ outages yr}^{-1} / (.50/.50 \times 7 \text{ outages yr}^{-1} / 150 \text{ mi.} \times 30 \text{ mi})) \times 100)$

Using a spreadsheet (**Figure 13**) you enter the tree and line data and the starting tree Risk Factor of 0.50 (derived from the chart **Figure 12**). Then by iterations of decreasing the New Risk Factor value you determine the Risk Factor value that brings the Line Security Improvement as close as possible to 76%. That value is 0.12.

Figure 13

Cost: Benefit Analysis					
Line Segment Specific:		Ac/mi	Trees/mi	Cost/mi	Line Security Improvement
Line Height	40				
Tree Height	85				
Trees/Ac	250				
Current Clear Width	14				
Current Risk Factor	0.5				
Increase Width	21	2.55	636		
New Risk Factor	0.12				76%
Removal Cost/tree *	\$8			\$5,091	
Removal Cost/tree **	\$60			\$38,182	
* Using feller buncher					
** Chainsaw removals					

tree Risk Factor for the 69 kV line on the same ROW (40 ft height & 14 ft clear width) would be 0.50.

Hence, the number of tree-conductor incidents on the 69 kV line would be 0.50/0.50 of those experienced on the current 25 kV line.

Then you need to determine the amount of improvement required in line security to achieve the management objective of no more than 1 tree-caused outage over three years. This could be expressed as 0.33 outages

Returning to **Figure 12** we see that a Risk Factor of 0.12 occurs at a 10.6 m (35 foot) clear width. The distance from the tree line to centre-line needs to be 35 ft + 10 ft/2 (cross

arm) or 40 feet. Given the line runs along a road allowance, the road side portion has more than adequate clearance.

You advise management that you can meet the objective of no more than one outage in three years provided the easement is increased by 20 feet on the off road side and that you receive increased funding of \$91,638 ($\$5091 \text{ mi}^{-1} \times 30 \text{ mi} \times 0.6 \text{ tree covered}$) to widen the right of way.

These examples illustrate the utility of forecasting the impact of actions on line security. While risk is quantified in percentage terms, where the history of tree incidents is known, a simple calculation can convert the data to the number of tree incidents to expect in the future (as in Example 3.). In doing so, it need be recognized that it is an estimate that assumes the same tree and weather conditions from one year to the next.

The approach used in arriving at the Risk Factor assumes all trees are susceptible to failure and as such, all trees capable of striking the line represent a liability. While this represents a worst case scenario, it recognizes that we cannot predict which healthy trees in a stand will next succumb to the stresses of competition. Thus, while varying tree mortality rates influence the scope and intensity of the hazard tree program that should be applied to the residual trees, mortality rates do not alter the Risk Factor.

One Risk Factor rating, taken in isolation, provides no information about the number of tree-caused outages experienced on or projected for a line segment. It is only when the Risk Factor is used on a comparative basis that it becomes a tool that informs the process of selecting between maintenance or construction options. The three examples illustrate that the changes in Risk Factor arose from changes in the variables of line height and/or clear width. Tree species failure and decay characteristics that either contribute to or decrease the likelihood of line outages are the same for each possible option. These tree species failure and decay characteristics are also reflected in the tree-related outage experience. Hence, the Risk Factor can be used to derive a percentage change in reliability without the need to identify the specific tree failure modes.

IMPORTANCE OF TARGET CLEARANCE - A CASE STUDY

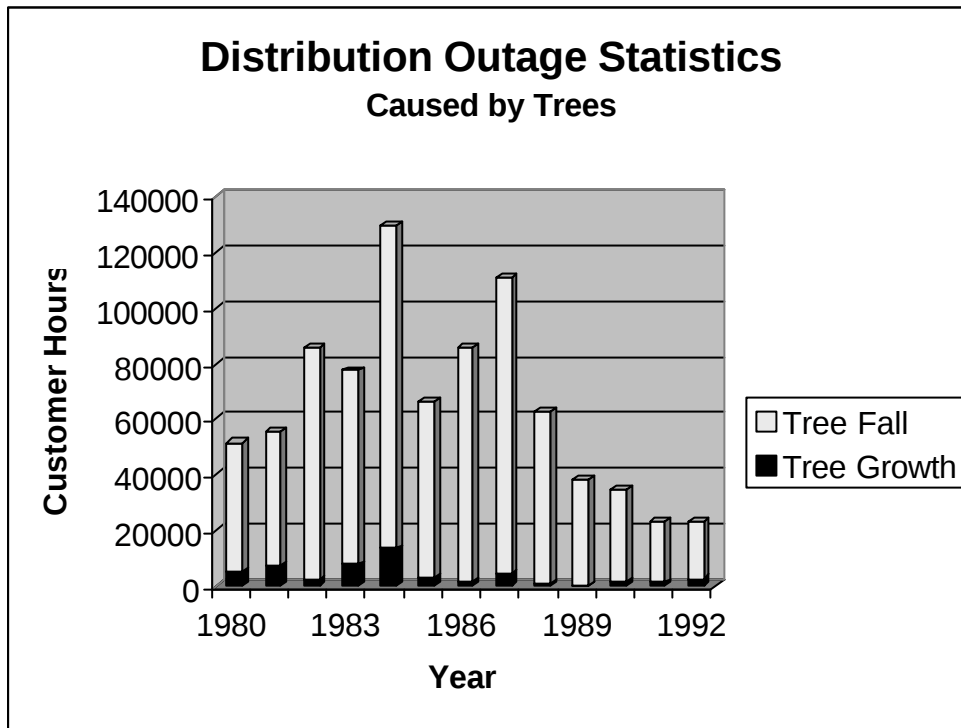
To this point, tree risk quantification has been examined in the context of applying it to new construction and problematic line segments. However, in a sense, utilities have set their tree risk exposure on a system wide basis by the clearance standards adopted.

Considering the factors affecting tree-related outages we find they are:

- tree density (number of trees per mile of line)
- clear distance (horizontal distance, measured on the ground, from tree edge to nearest conductor)
- tree species (based on specific characteristics such as mature height, propensity to shed branches, break, bend or uproot)
- soil characteristics
- disease and insect pests
- weather events such as wind, ice and wet snow

- landscape characteristics such as slope (Guggenmoos 1996)

Figure 14



Source: Guggenmoos 1995

The 80% tree-caused outage reduction between 1987 and 1991 is attributed to the chosen clearance standards.

Examining these factors, there is only one utilities control: the clear distance (Guggenmoos 1996). The maintenance cycle is not included in this list since it would be determined by tree species characteristics, climatic factors and clear distance. That is, the maintenance cycle and clear distance are totally interdependent. If the clear

distance is set, then the maintenance cycle is determined by the time it takes for growth to span the clear distance or reach the limit of approach. If the maintenance cycle is set, then the clear distance must be adjusted to reflect the amount of growth over the cycle.

When a line clearance program is under review, both the clear distance and maintenance cycle may be reviewed and adjusted, as was the case when TransAlta Utilities' program came under review in 1985. In spite of line clearance budget increases averaging 32% between 1980 and 1985, tree-related outages were expanding exponentially (Guggenmoos 1995) (**Figure 14**). At the time of the review, pruning clearances averaged 3 metres (10 ft). To increase the cycle length, the target pruning clearance was increased to 4.5 metres (15 ft). It was decided that trees over-hanging lines would not be acceptable. All overhangs would be removed. Side clearance, which was initially 6 m back in the 1950's when rural lines were built, had experienced some in-growth to average 5 m. Just before the new line clearance program based on a tree inventory and local growth rates was launched in 1986, a decision was taken to measure the target 6 m side clearance at line height to the nearest tree part, rather than along the ground (clear width). The result of this decision was that the clear width, as measured to the trunks of adjacent trees, was increased on average by 4 m. This decision had a profound impact on tree-related outages.

Tree-related outages increased from 1985 through 1987 but then began a steady decrease. In fact, by 1991 tree-related outages dropped 80% from the 1987 levels (**Figure 14**). A 70% reduction can be explained by the increased clear width (**Figure 15**) using averages for tree height, tree density and line height. The remainder of the reliability gain is attributed to the removal of overhangs (only 0.3% of total trims) and appropriate pruning cycles.

Figure 15

Line Segment Specific:		Ha/mi	Trees/mi	Cost/mi	Line Security Improvement
Line Height	9				
Tree Height	20				
Trees/Ha	1000				
Current Clear Width	5				
Current Risk Factor	0.33				
Increase Width	4	0.64		640	
New Risk Factor	0.1				70%

TransAlta's experience illustrates the clear distance standard selected is a key determinant of the number of tree-related outages.

That 85% of the tree-caused outages arise from off right of way trees is problematic, as it brings the utility into conflict with property rights.

While that would appear to rule out any increases in clear width without legally increasing the easement, it need not be so. In fact, TransAlta distribution lines had no easements except on crown land, which comprised less than 15% of the line miles. Increasing the clear width could only be achieved through the willing cooperation of the landowners.

CONCLUSION

Considering tree and typical line heights, common maintained right of way widths eliminate tall growing and potentially conflicting trees from only a fraction of the area along power lines. For both transmission and distribution lines, the major source of tree conflicts is from off right of way trees.

The clear widths used by North American utilities are fairly standard and not greatly variable. However, the exposure of power lines to possible tree-conductor conflicts is highly variable due to variable amounts of forest cover. In many states and provinces of North America, forests cover over 50% of the land base (Smith and Sheffield 2000, Forest Service 2000, Forestinformation.com).

The available information suggests that for North American utilities having both urban and rural lines, tree failure will be responsible for about 85% of all tree-caused outages, regardless of the number of trees per mile of line. While pruning trees on the right of way is essential for public safety, to make significant improvements in electric system reliability, the risks arising from adjacent, off right of way trees must be identified and addressed. Typically these risks are addressed through a hazard tree identification and removal program. There has been an industry focus on improving the science of hazard tree assessments and increasing staff and contractor competencies in the identification of these hazards. However, a gap in utility arboriculture literature regarding natural tree mortality rates and their implications for achieving reliability improvements suggests an area deserving of consideration.

Common annual tree stand mortality rates ranging from 0.5% to 3% reveal the rate of hazard tree formation or additions is substantially higher than removal rates through hazard tree programs. Given that natural tree mortality adds 21 to 150 trees $\text{mi}^{-1}\text{yr}^{-1}$ per treed ROW side it is probable that most hazard tree programs will do little to appreciably improve reliability for more than a few years. Where a hazard tree program does substantially improve reliability, over time the majority of the gains will be eroded by tree mortality.

Tree-conductor conflict risks are not limited to dead and decadent trees. High winds, ice, wet snow and lightening can cause healthy, structurally sound trees to fail. Hence, all trees capable of interfering with power lines constitute a risk to the safe, reliable transmission of electricity.

Tree height, line height, tree density and clear width are variables that can be altered to improve line security. A mathematical derivation of tree risk using these variables was used to produce Line Strike Probability charts. The Line Strike Probability chart reveals there is a point of diminishing return in line security as clear width increases. In most cases tree freeing a power line would not be financially prudent. The nature of the Line Strike Probability curve presents a visual that both clarifies and simplifies the understanding of the risk of trees in proximity of power lines. As such, it may serve as a useful communication tool between utilities and stakeholders such as federal and state foresters, community groups and regulators.

The variables used in the quantification of the tree risk facilitate the derivation of the cost of specified reliability improvements. The cost of benefits can be readily compared to alternatives, such as increasing conductor height, installing tree wire or undergrounding. Being able to calculate the cost of benefits opens an avenue to balancing the liability associated with incurring an outage with an acceptable degree of risk.

An examination of North American forest stand data shows a common trait, that of decreasing tree density over time. It is recognized, however, that for trees, death is a process not an event at one specific point in time. Dead or decadent trees retain a certain structural strength and fail when conditions arise that place them under unbearable stress. The occurrences of such conditions of stress are weather related. Thus, while this quantitative approach to managing tree-conductor conflicts offers benefits under relatively normal weather conditions, the larger opportunity lies in the avoidance of wind/storm-related tree outages.

The use of Line Strike Probability Charts could be particularly advantageous when there is a major pest infestation that significantly increases tree mortality. The usual maintenance approach would be to make numerous passes identifying and removing hazard trees. It may prove more economical to drastically reduce the number of trees capable of striking the line by widening the right of way to the point where clear width provides a diminishing return in line security. Under these circumstances this approach may appeal to forestry staff as the tree numbers may be high enough to justify salvage rather than simply dropping the trees into the forest. In widening, the residual area requiring hazard tree identification is reduced, correspondingly avoiding costs. Further, by concentrating a major tree volume to one maintenance event, the feasibility of more economical, mechanized removal methods is enhanced.

The derivation of tree risk that has been outlined views all trees capable of interfering with power lines as a risk. While a quantitative tree Risk Factor can be comparatively applied, it does not provide a measure of risk under variable weather conditions. A logical extension of this approach would include a study of tree failure rates, by species, under various wind intensities; the frequency of destructive ice/snow and wind storms; and, the direction of severe storms. These factors would serve to both to reduce the tree risk rating and move towards predictive measures of the probability of experiencing tree-caused outages and the severity of system damage.

The mathematical quantification of tree risk applied to priority areas as identified by outage statistics provides an opportunity to manage so called unpreventable tree-caused outages for real and lasting gains in reliability. Increasing conductor height and the clear width will improve reliability. However, unless a line is completely tree free, a hazard tree program remains an integral part of the maintenance process. The number and condition of residual trees will impact line security. The success of the hazard tree program will be improved as it need only be applied to a reduced tree population or residual risk. Most importantly, a quantitative approach to managing the risk of tree-conductor conflicts provides a means to progressively improve electric system reliability.

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