# Managing Tree-Conductor Conflicts by Risk Assessment

**By**
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We might say, in round numbers, that utilities have had one hundred years to resolve the issue of tree-conductor conflicts. Why is it still an issue today? Quite possibly the answer is that without a quantifiable means of predicting the reliability benefit of maintenance actions, utility management has been loathe to invest the necessary resources and other stakeholders resistant to giving up their trees.

Trees are a major cause of power outages, particularly on distribution systems. Utility presentations[1] dealing with trees and reliability reveal that on distribution systems tree-related outages comprising 20% to 50% of all unplanned outages are common. While these percentages indicate trees are a major threat to reliability, the convention of excluding statistics arising from major storm events, means the extent of the problem is vastly understated.

In the last ten years we've had a firestorm in Washington, the burning of an historical town and two major western grid crashes attributed to tree-conductor contact. In the west, where summer forest conditions tend to be dry, tree-conductor contacts are a frequent cause of forest fires.

Utilities in the east face ice storms. In the south and southeast windstorms are relatively frequent events. 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.

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 will increase.[2] 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.[3]

A new trend emerging from Public Utility Commissions is to specify reliability targets that must be met. 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. 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 practises have not compounded the

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[1] Presentations made for the UAA section at annual ISA conferences.
[2] Watson, Robert T., M.C. Zinyowera, R.H. Moss, Intergovernmental Panel on Climate Change. *The Regional Impacts of Climate Change.* 8.3.9.3
[3] Hadden, Elaine. 2001. *Weather Lessons*. Transmission & Distribution World, Apr. 1, 2001.

extent of storm damage[4].

In a competitive electric services market, reliability is a customer service issue. With the advent of choice, reliability has gained in importance. D. Louis Peoples, CEO of Orange and Rockland Utilities, commenting on the results of 15 months of a customer choice pilot program September 1997 in Washington, DC said:

- Customers are concerned about "attributes beyond price, such as one-call service, reliability and recourse for problems"
- Large commercial and industrial customers, are anxious to participate in any program that reduces cost, as long as reliability is ensured by the local utility
- these concerns were preventing people from switching suppliers

With the shift to and expansion of the digital economy, reliability of the electric system takes on unheard of 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)[5].

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".

Changing customer and regulator expectations suggest an approach of classifying tree-related outages as non-preventable and in a sense, thereby minimizing or discounting the problem, will no longer be acceptable. The need for reliable service has increased dramatically. Due to costs, the digital economy is completely intolerant of outages. We might expect the most flexibility and tolerance with light load residential and small commercial customers. But how often will these customers dependent on electric service for security, comfort, productivity, convenience and recreation be forgiving for outages stemming from major storm events? Will not failure to address this issue drive customers to adopt the emerging distributed generation technologies to free themselves of the grid?

To reduce tree-related outages it's necessary to examine the origin of tree-related outages[6,7,8]. To do so, we turn to outage statistics. Tree-related outages can be classified into two groups: those attributable to tree growth; and, those attributable to tree failure. A visual assessment of a tree trimming program

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[4] Tomich, Jeffrey, 2001. *Arkansas Ice Storm Cruel to Poorly-Maintained Electric Lines*. Arkansas Democrat-Gazette, Little Rock, AR, Jan. 9, 2001.
[5] Lewis, Stuart M. 2001. *Utilities Cannot Afford to Become "Sometimes Power & Light"*. Transmission & Distribution World, Apr. 1, 2001.
[6] Simpson, P., R. Van Bossuyt. *Tree-Caused Electric Outages*. Journal of Arboriculture 22(3): May, 1996, p.117.
[7] Guggenmoos, S. *Outage Statistics - As a Basis for Determining Line Clearance Program Status*. UAA Quarterly, 5(1), Fall 1996.
[8] Rees, Jr. William T., Timothy C. Birx, Daniel L. Neal, Cory J. Summerson, Frank L. Tiburzi, Jr., and James A. Thurber, P.E. 1994. *Priority Trimming to Improve Reliability*. ISA Conference presentation, Halifax, Nova Scotia, 1994.

that is somewhat behind shows that the majority of trees growing into an energized line are burned off, likely from momentary contact. Very rarely would we expect a fault to occur. Rees et al of Baltimore Gas & Electric attributed only 2% of all tree-related outages to trees growing up into a line.[9] Guggenmoos showed tree growth to account for 2% to 10% of tree-related outages on TransAlta Utilities' system.[10] Ken Finch reporting on Niagara Mohawk's tree-caused outages indicates tree growth accounts for 14% of outages,[11] while Beth Rogers explains part of the reasoning behind Puget Sound Energy's Tree Watch program is that only 13.5% of tree-related outages were attributable to tree growth.[12] From these geographically, ecologically diverse utility systems a common thread emerges. Tree growth accounts for less than 15% of all tree-related outages. A marked increase in outages is not likely to occur until the trimming program is so far behind that tree branches are of a more substantial diameter and in contact with two phases.[13,14]

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; by bringing phases into contact with each other; or by making a substantive bridge between phases allowing a carbon path to develop, leading to a short.[15,16] Where maintenance practise does not remove overhangs some outages caused by tree failure will arise from trees on the right of way. However, the number of trees capable of striking the line from outside the right of way completely overwhelms the number of trees on it and these will be the major source of outages, particularly under severe weather conditions. Finch reports 86% of tree-caused outages result from trees outside the right of way.[17] Similarly, on the west coast, Rogers reports that 66% of PSE's outages are caused by trees greater than 15 feet from the nearest conductor.[18] To substantially decrease tree-related outages, off right of way trees need to be addressed.

On any system where the majority of tree-related outages are attributable to tree growth the trim 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

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[9] Rees, et al. 1994. *Priority Trimming to Improve Reliability*.
[10] Guggenmoos, S. *Outage Statistics - As a Basis for Determining Line Clearance Program Status*. UAA Quarterly, 5(1), Fall 1996.
[11] Finch, K.E., C. Allen 2001. *Understanding Tree Caused Outages*. EEI Natural Resource Conference, Palm Springs, CA, Apr. 2001.
[12] Rogers, Beth, I. 2001. *Puget Sound Energy Tree Watch Program*. EEI Natural Resource Conference, Palm Springs, CA, Apr. 2001.
[13] Rees, et al. 1994. *Priority Trimming to Improve Reliability*.
[14] Finch, K.E., C. Allen 2001. *Understanding Tree Caused Outages*. EEI Natural Resource Conference, Palm Springs, CA, Apr. 2001.
[15] Rees, et al. 1994. *Priority Trimming to Improve Reliability*.
[16] Finch, K.E., C. Allen 2001. *Understanding Tree Caused Outages*. EEI Natural Resource Conference, Palm Springs, CA, Apr. 2001.
[17] Finch, K.E., C. Allen 2001. *Understanding Tree Caused Outages*. EEI Natural Resource Conference, Palm Springs, CA, Apr. 2001.
[18] Rogers, Beth, I. 2001. *Puget Sound Energy Tree Watch Program*. EEI Natural Resource Conference, Palm Springs, CA, Apr. 2001.

tree failure is the major source of tree-related outages, resolution of the problem is more complex and certainly not as apparent.

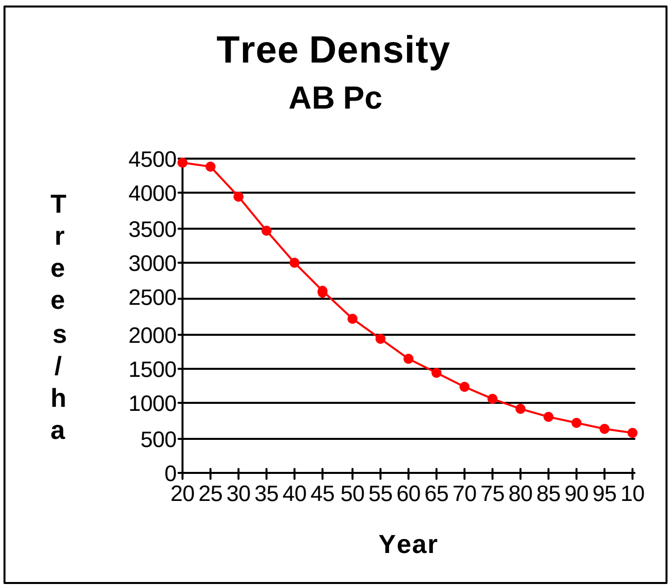
What are the factors affecting tree-related outages? They are[19]:

- tree density (number of trees per mile of line)
- clear distance (horizontal distance 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

Examining these factors, there is only one we control, the clear distance[20]. The maintenance cycle isn't included in this list since it would be determined by tree species characteristics, climatic factors and clear distance.

Clear distance becomes particularly important where power lines run adjacent to or through natural tree stands. **Figure 1** shows trees per hectare for lodgepole pine in Alberta over time[21]. Between age 20 and 100 years there are about 4000 trees that die. Putting that into a utility context, a hectare is about one mile by twenty feet wide. For a line running through forest there are about 4000 trees that die over an 80-year period within a 10 foot strip on each side of the line. Subtracting the trees that on dying are below typical distribution line height of 30 feet the number of trees is reduced to about 3500 over 70 years. If we take, for the sake of simplicity, a straight line average, that amounts to an annual average of 50 trees per mile that become susceptible to failure.

**Figure 1**




Source: Johnstone, W.D. 1976

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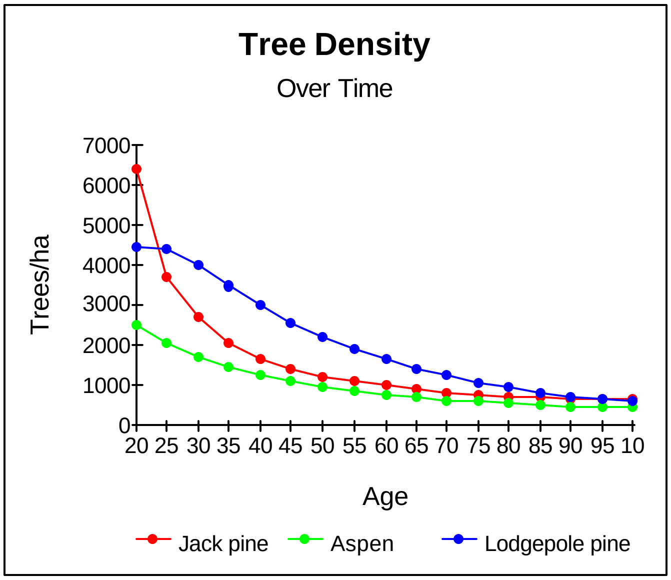
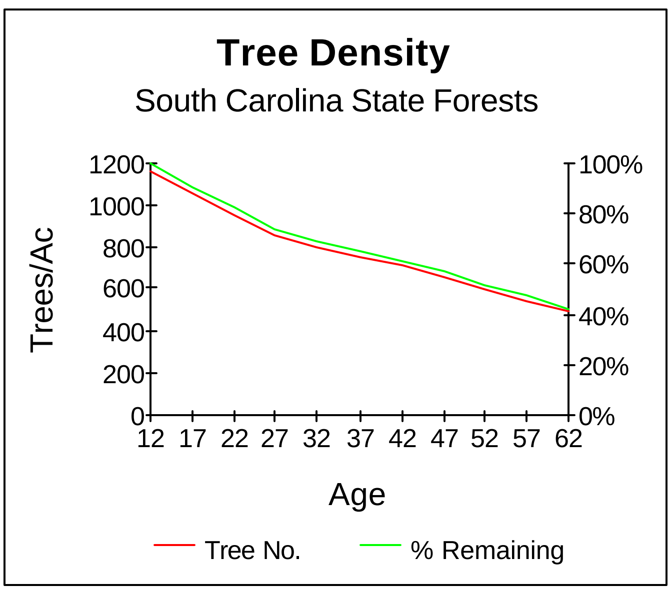
[19] Guggenmoos, S. *Outage Statistics - As a Basis for Determining Line Clearance Program Status.* UAA Quarterly, 5(1), Fall 1996.
[20] Guggenmoos, S. 1996. *Outage Statistics - As a Basis for Determining Line Clearance Program Status.*
[21] Johnstone, W.D. 1976. Variable-density yield tables for natural stands of lodgepole pine in Alberta. Can. For. Serv., Dept. Fish. Envir., For. Tech. Rep. 20: p.110.

**Figure 2**




Source: Johnstone, W.D. 1976 & Plonski's Yield Tables

**Figure 3**



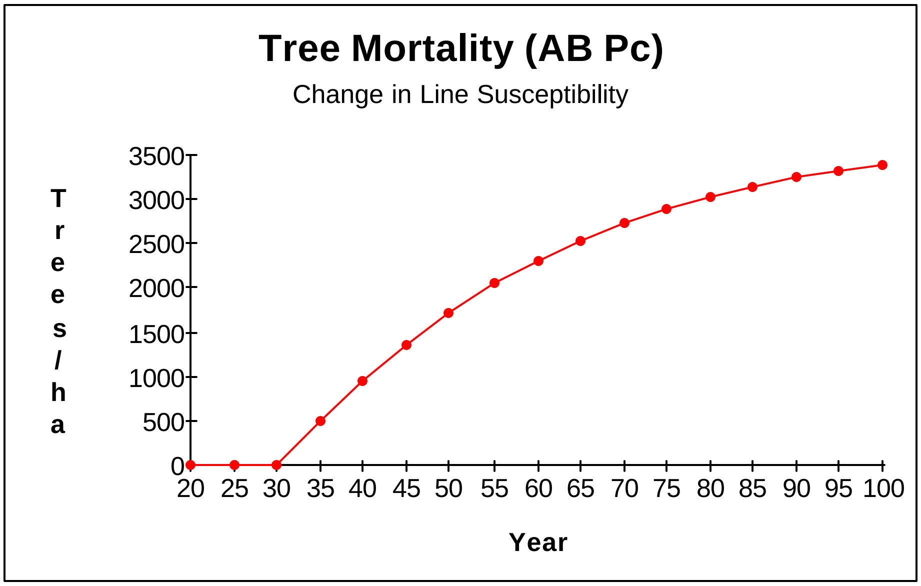

Source: Crookston, Nicholas L. 1997. Suppose: An Interface to the Forest Vegetation Simulator.

**Figures 2** and **3** show the changing tree density for various species distributed over several geographic areas. **Figure 2** shows the density change for jack pine is even greater than is the case presented for lodgepole pine. Figure 2 shows a 70% decline in stand density over 50 years. The main species represented in **Figure 3** for South Carolina forests are pines, oaks, maples, poplar and blackgum[22]. Figure 3 shows the stand density declines 60% over 50 years. **Figures 2** and **3** show that while the total number of trees and the rate of mortality varies by species, the trend of a declining viable tree population over time, is common. Hardwood mortality appears to follow more of a straight line. Nonetheless, the risk to power lines is substantial. Tree mortality for the forest stands represented in **Figure 3** amounts to 36 trees per mile per year over just a 20-foot width. When tree height is considered, a conservative estimate of tree mortality would be 36 trees/mi X 60ft/20ft = 108 trees $mi^{-1}yr^{-1}$ per ROW side.

It is principally the competition for light, water and nutrients that drives the decline in the tree population. Periods of stress caused by drought or pests will accelerate the rate of mortality. To understand the implications of the declining tree density on power line security the data in Figure 1 has been re-arranged to highlight the number of dead and decadent trees (**Figure 4**). The data has also been altered to exclude trees

[22] Source: Crookston, Nicholas L. 1997. Suppose: An Interface to the Forest Vegetation Simulator. In: Teck, Richard; Moeur, Melinda; Adams, Judy. 1997. Proceeding: Forest vegetation simulator conference. 1997 February 3-7, Fort Collins, CO. Gen. Teck. Rpt. INT-GTR-373. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

**Figure 4**




Source: Adapted from Johnstone, W.D. 1976

that die before achieving 30 feet in height (typical distribution line height).

Figures 1-4 illustrate the common condition of decreasing viable tree density over time for forests. This natural phenomenon represents an enormous risk to line security. It is, however, a largely ignored and unquantified risk due to the fact that the trees comprising this risk are usually outside the right of way. These trees give rise to tree-related outages that are classified as unpreventable.

**Figure 4** illustrates the fact that power lines running adjacent to or through forests or natural tree stands are at risk. The risk is directly related to the number of trees within striking distance of the line. Tree mortality rates will depend on local tree species and conditions. 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.[23] A cursory review of various stand data suggests mortality rates ranging from 50 to 150 trees $mi^{-1}yr^{-1}$ per 60 feet of ROW side will be quite common. The risk is enormous and far outweighs the risk arising from trees considered part of the normal maintenance regimen, which places the emphasis on trees requiring pruning. How might we mitigate this risk? Is a hazard tree program a reasonable approach? The risk can be quantitatively mitigated by decreasing the number of trees capable of striking the line either by increasing the clear distance or the line height[24].

To determine the effects of clear width[25] on line security, tree canopy height, tree density and the line height can be used in a mathematical derivation of risk exposure[26]. The Line Strike Probability Chart

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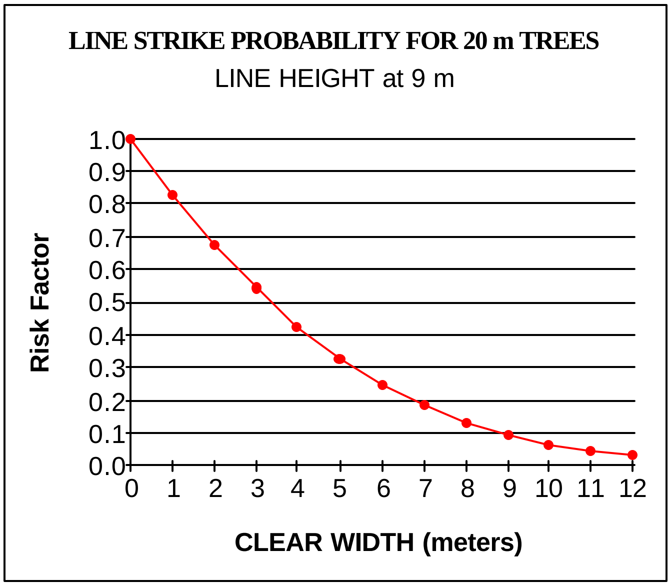
[23] Curtis, R.O., G.W. Clendenen, J.A. Henderson, 2000. *True Fir-Hemlock Spacing Trials: Design and First Results.* USDA, Forest Service, Pacific Nortwest Research Station. General Technical Report PNW-GTR-492, May 2000.
[24] The risk factor is far less sensitive to changes in line height. Thus, it may not be practical or economic to try to obtain significant risk reductions through increasing line height.
[25] Clear width and clear distance are used interchangeably. Clear width is the horizontal distance on the ground from the treeline to the nearest conductor.
[26] The mathematical derivation of risk exposure is commercially available as the Optimal Clear Width Calculator

**Figure 5**




Source: Ecosync 1998

(**Figure 5)** 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. It reflects differences in mortality based on species only indirectly through tree density (See Figure 2). A point of particular interest evident in the Line Strike Probability Chart is the fact 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 point where clear width provides a diminishing return in line security can provide guidance for the extent of easement required on new lines if 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, two examples are provided.

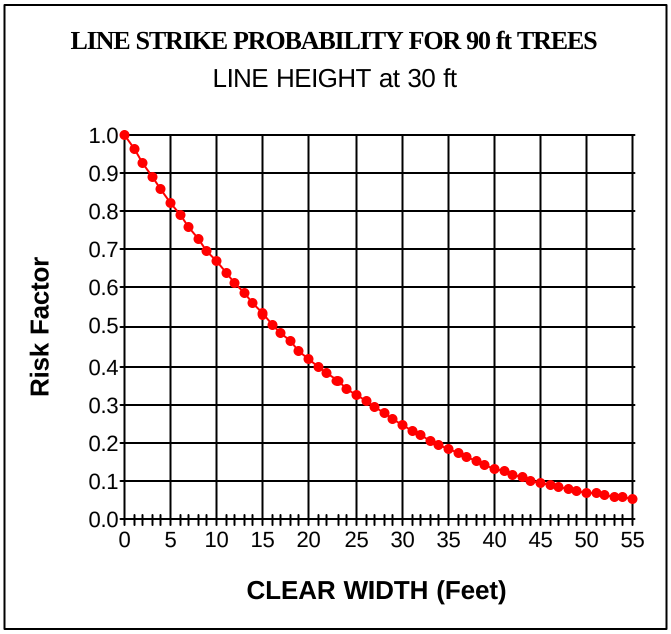
<u>Examples</u>

1. A section of distribution line running through a forested area is identified as problematic. Every time there's a stiff wind, 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's 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 we find the following:

   Line height – 30 feet
   Tree height – 90 feet
   Trees/Acre – 120
   Current clear width – 10 feet

**Figure 6**




Source: S. Guggenmoos 2001

What would be the benefit of increasing the clear width to 20 feet?

Reading from the chart (**Figure 6**), at a 10 foot clear width the Risk Factor is about 0.68 while at a 20 foot clear width the Risk Factor is about 0.42. That information can then be put into a simple spreadsheet (**Figure 7**) that shows increasing the clear width another 10 feet would result in a 37% improvement in line security. Unit costs have been added to the spreadsheet to facilitate a quick assessment of the cost versus the benefit in increased line security.

**Figure 7**

| **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 | | | | | |

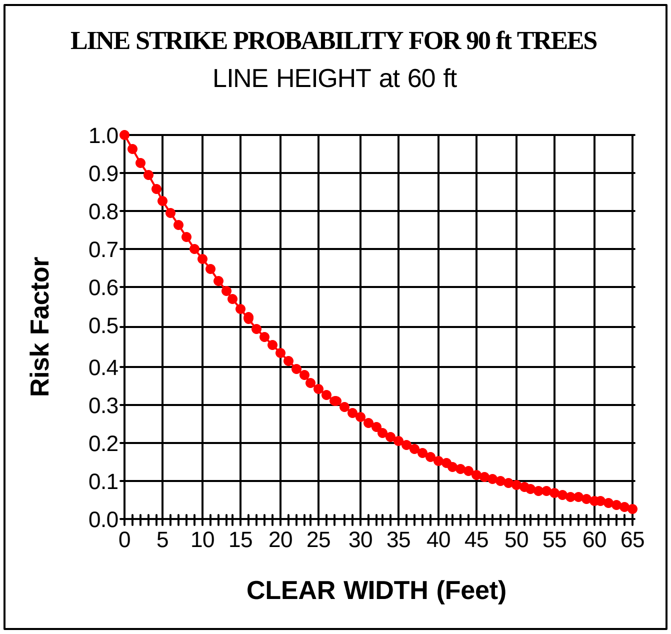
Source: S. Guggenmoos 2001

2. Your utility company is building another transmission line. Due to siting 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 we find the following:

**Figure 8**




Source: S. Guggenmoos 2001

Much of the line runs through forest. The clear width will be reduced to 30 feet.
Line height – 60 feet
Tree height – 90 feet
Trees/Acre – 120
Current clear width – 65 feet

The Line Strike Probability Chart produces **Figure 8**.

From the chart we see that at a 65 foot clear width the Risk Factor is about .03 while at a 30 foot clear width the Risk Factor is about .26.

Entering this information into a simple spreadsheet (**Figure 9**) shows the impact of decreasing the clear width by 35 feet is a 767% drop in line security. In other words you should expect about 8 times the current number of tree-related outages.

**Figure 9**

| **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 | |

Source: S. Guggenmoos 2001

These examples illustrate the possibility and 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. In doing so, it need be recognized that it is an estimate. Figures 1 - 4 show the decreasing tree density over time. We recognize, 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 fall when conditions arise that place them under unbearable stress.

The approach used assumes all trees are susceptible to failure and as such, all trees capable of striking the line represent a liability. Changes in tree mortality rates do not alter the Risk Factor. Line security, however, will be impacted by the condition of residual trees.

The use of Line Strike Probability Charts could be very 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 trees may be salvaged. In widening, the width of the 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.

Outage statistics are the most meaningful measure of the success or failure of a vegetation management program. If these statistics reveal the majority of tree-related outages are the result of tree failure, a hazard tree identification and removal program will help. However, given common annual mortality rates ranging from 1% to 3%, it is probable that this effort will be swamped by the sheer magnitude of natural tree mortality and hence, do little to appreciably improve reliability. 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. The quantitative approach reduces but does not eliminate the need for a hazard tree program. Most importantly it provides a means to progressively achieve unprecedented levels of reliability.

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