Electric Distribution Hazard Tree Risk Reduction Strategies

Technical Report

Electric Distribution Hazard Tree Risk Reduction Strategies

1008480

Final Report, November 2004

EPRI Project Manager
J. Goodrich-Mahoney

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Environmental Consultants, Inc.

ORDERING INFORMATION

Requests for copies of this report should be directed to EPRI Orders and Conferences, 1355 Willow Way, Suite 278, Concord, CA 94520, (800) 313-3774, press 2 or internally x5379, (925) 609-9169, (925) 609-1310 (fax).

CITATIONS

This report was prepared by

Environmental Consultants, Inc.
520 Business Park Circle
Stoughton, WI 53589

Principal Investigator
P. Appelt

This report describes research sponsored by EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Electric Distribution Hazard Tree Risk Reduction Strategies, EPRI, Palo Alto, CA: 2004. 1008480.

REPORT SUMMARY

Hazard trees pose a significant risk to electric distribution systems, and some utilities are taking the crucial first step in recognizing that distribution service interruptions caused by tree failures are, in part, predictable and preventable. EPRI has developed a process map for the purpose of identifying danger trees early in order to reduce service disruptions and their associated costs.

Background

The majority of utilities have not performed sufficient analysis of the risks posed by hazard or danger trees. The challenge of implementing a program to reduce these hazard tree outages is twofold: first, identifying tree populations that present the greatest risk, and second, designing and implementing an economical yet effective method for targeting these high-risk trees. Assessing the risk of hazard trees and taking the proper steps to reduce such risk is a daunting task. Several utilities, however, are accepting the challenge and are beginning to shed light on how to address this issue, what course of action to follow, and results following their implementation of various methods.

Objectives

- To assess three utilities in regards to how each approached the problem of service interruptions caused by hazardous trees along rights of way.
- To investigate and summarize the key components of the various strategies utilized by each utility.
- To prepare process maps for each utility and develop a suggested generic process map.

Approach

Investigators evaluated several approaches to reducing interruptions due to tree failure. Implementing the various approaches were three geographically dispersed utilities: BC Hydro, Vancouver, British Columbia, Canada; Central Hudson, Poughkeepsie, New York; and National Grid, Westborough, Massachusetts.

Results

All three companies cooperating in this research effort reported positive results from varied strategies for reducing hazard tree failure risks. Each utility depended on the process of interruption analysis, while two of the three also investigated the characteristics of trees that fail in order to guide development of tree rating systems or guidelines for ranking trees. While all three utilities measured risk reduction differently, each reduced risk by 26 to 67 percent.

EPRI Perspective

Service disruptions due to trees along and under a utility right of way can occur when trees come in proximity to the right of way. This EPRI process model reduces costs and enhances reliability by enabling early, cost-effective identification and removal of danger trees along transmission and distribution rights of way. With one utility experiencing avoided repair cost savings of $1283 per tree-caused service interruption, it is clear that a generalized process map will result in significant utility cost savings, both in terms of outages and their associated costs.

Keywords

Hazard/Danger Trees
Service Interruptions
Tree Failure
Tree Maintenance Programs
System Reliability
Utility Right of Way

CONTENTS

1 INTRODUCTION 1-1

Background 1-2

2 THREE UTILITY APPROACHES TO REDUCING INTERRUPTIONS FROM TREE FAILURE 2-1

Central Hudson Energy Group 2-2

Central Hudson Program Description 2-2

Central Hudson Results 2-3

National Grid (Niagara Mohawk) 2-3

Niagara Mohawk Program Description 2-3

Circuit Selection 2-5

Operations and Public Relations 2-7

Niagara Mohawk Results 2-7

BC Hydro 2-8

BC Hydro Program Description 2-8

BC Hydro Results 2-10

Conclusion 2-11

Objective Comparisons 2-11

Process Comparison 2-11

Measurement Comparison 2-12

A APPENDIX A A-1

Process Maps A-1

Tree Failure Report Example A-6

B REFERENCES CITED B-1

LIST OF FIGURES

Figure 1-1 Decayed Tree Trunk, Reducing Tree Strength..1-2
Figure 1-2 Hazard Tree Downed by Wind 1-3
Figure 2-1 Niagara Mohawk Distribution of Tree Failures by Type...2-4
Figure 2-2 Distribution of Common Tree Species that Failed Compared to Species Presence in the Population 2-5
Figure 2-3 Average Niagara Mohawk Customers Affected by Tree-Related Interruptions by Voltage Class 2-6
Figure 2-4 Reduction in Numbers of Customers Affected by Tree-Related Interruptions at Niagara Mohawk From 2000 to 2004 (12-Month Periods from September to August)..2-8
Figure 2-5 BC Hydro Historic Distribution of Tree-Related Interruptions by Cause..................2-9
Figure 2-6 BC Hydro Hazard Tree Program Cost and Estimated Repair Savings 1992 to 2000 2-10
Figure A-1 Central Hudson Enhanced Tree Maintenance Process A-1
Figure A-2 Niagara Mohawk TORO Process.. A-2
Figure A-3 BC Hydro Hazard Tree Process Map.. A-3
Figure A-4 Model Hazard Tree Risk Reduction Process A-4
Figure A-5 Tree Failure Report Form Used by BC Hydro, Page 1. .... A-6
Figure A-6 Tree Failure Report Form Used By BC Hydro, Page 2. .... A-7

LIST OF TABLES

Table 2-1 Comparison of Program Components by Utility..2-1
Table 2-2 Comparison of Costs and Results by Utility..2-2
Table 2-3 Three-phase versus Single-phase Interruptions – Impact on Customers..................2-6
Table 2-4 BC Hydro Failure Potential and Action Timing Definitions......................................2-10

1
INTRODUCTION

In recent years, many electric utility distribution companies have done a good job developing and implementing tree maintenance programs that have significantly reduced the number of tree-related outages resulting from tree growth into conductors. One study conducted in 1995 and 1996 in the U.S. and Canada on the subject of tree-related outages among 17 utilities indicated that less than 30 percent – and often less than 20 percent – of tree-related outages were caused by tree growth into conductors (EPRI, 1996). The other 70 percent to 80 percent or more of tree-related outages were generally categorized as tree failure or breakage outages. The traditional approach to these outages is to treat them as *non-preventable*, and not establish programs specifically addressing tree-failure outages. Some utilities, however, have recognized that tree failure is neither totally random nor totally unpredictable.

Tree hazards are generally defined as defective trees that threaten a particular target. In the context of electric distribution systems, the target is overhead power lines and equipment. Both the defect and the target must be present for a hazard to exist (Matheny and Clark, 1994). Matheny and Clark state: "All trees have the potential to fail, but only a relative few actually do so" (1994).

The science of arboriculture has made great progress in the past two decades defining tree conditions that cause trees to catastrophically fail. Research has been done on the mechanics of tree failure, and books have been written to guide arborists in the identification of high-risk trees. The economical application of this information to utility line clearance, however, has been challenging, and few companies have implemented programs to address outage risk caused by failure of hazard or danger trees.

Part of the challenge in implementing a program to reduce outages from hazard trees is defining the portion of the tree populations growing near distribution lines that represents the most significant risk to lines, and then designing programs to economically target those high-risk trees that will have the greatest impact on reliability. While maintaining wide rights of way might solve the problem, such a solution is not practical for most utilities operating with 10- to 30-foot wide distribution easements, often in developed residential neighborhoods. Not all trees are at high risk of failure, and a program that would target all trees would not be efficient. The question is:

How can hazard tree risk to electric distribution systems be assessed, and what steps can be taken to reduce this risk?

Background

Forest pathologists and arborists have studied tree structure, pathogens that affect wood strength, soil and site conditions, as well as maintenance practices that affect mechanical failures in trees. The history of arboriculture is replete with books and technical papers describing how best to preserve trees thought to be at risk of mechanical failure. Methods described have included cabling systems, steel bracing, cavity filling and even staking systems for newly transplanted trees. Forest product engineers and wood technologists have documented various characteristics of trees that affect wood strength of different commercially important tree species. Some of these mechanical properties of wood include: specific gravity, modulus of elasticity, modulus of rupture, compression and tension strengths (Forest Products Laboratory, 1974). In more recent years, as arborists have explored questions of how and why trees fail, new relevant measures have been produced for different tree species, such as Comparable Strength in Longitude and Aerodynamic Drag Factors (Brudi and van Wassenaer, 2001). Testing equipment has also been developed for arborists to measure decay presence and location, and evaluate tree strength.

Various formulae have been devised to establish numeric values of relative tree strength based on visual observation of the size and location of defects. Most measurement devices, however, are not yet practical for large-scale evaluations of tree hazards. Such evaluations generally rely on visual assessment, together with education and experience regarding tree failures.

Figure 1-1
Decayed Tree Trunk, Reducing Tree Strength

At least one effort undertaken to compare the accuracy of visual evaluations in predicting actual decay patterns in laurel oaks (Quercus hemisphaerica) found that visual assessment can be a reliable means of predicting internal decay and voids that may be hazardous (Kennard, et al 1996). Another study of western hemlock (Tsuga heterophylla) found that external indicators are not sufficient to judge the internal conditions of hemlocks (Dunster, 1996).

Several field guides have been published for arborists to assist in evaluation of hazard trees (Clark and Matheny, 1993). Not only has significant work been conducted on how to best evaluate hazard trees, but new research has begun to challenge commonly held beliefs about how, when and under what circumstances trees fail through field experiments (Smiley and Coder, 2001). One research effort has demonstrated ranges in forces necessary to cause branches to fail under measured, static loads in an effort to simulate snow or ice loading (Lilly and Sydnor, 1995). Work has also been done to quantify certain wind thresholds that result in widespread branch failure. A recently reported 8-year study on the relationships between wind gusts and branch failure concluded that wind gusts of 50 mph or greater cause most branch failures when trees are in leaf. Gusts up to even 75 mph resulted in little branch damage during the dormant, leafless seasons (Luley, et al 2002).

Figure 1-2
Hazard Tree Downed by Wind

The entire body of research related to hazard trees has enriched understanding of how to evaluate tree conditions commonly associated with tree failure, how trees fail, and under what circumstances trees are most likely to fail. There are continued voids, however, in the current understanding of how to practically evaluate tree failure risk and predict the timing of failures.

Utility managers would ideally like to know not only when a tree has symptoms that predispose it to failure, but also when it will fail and if it will strike power lines. Given enough time, the majority of trees affecting electric overhead distribution systems will fail. The answer to *when* a particular tree will most likely fail will allow utility managers to make rational decisions about if and when to allocate resources to the reduction of specific potential tree hazards.

Several utilities have begun to take steps to reduce exposure to service interruptions caused by tree failures. This report summarizes the steps three utilities have taken to address this issue, the processes used, and the individual results.

2

THREE UTILITY APPROACHES TO REDUCING INTERRUPTIONS FROM TREE FAILURE

This section presents results from three utility approaches to the problem of service interruptions caused by failure of hazardous trees. Each utility implemented somewhat different strategies to achieve reductions in interruptions caused by tree failure. Table 2-1 summarizes the key components of each program, while Table 2-2 summarizes the costs and results.

Table 2-1
Comparison of Program Components by Utility

Component	BC Hydro	Central Hudson	National Grid
Objective	Reduce percent of system interruptions caused by trees from initial 56% and reduce associated repair costs	Reduce total system average interruption frequency index (SAIFI) by 25%	Reduce total SAIFI
Implementation Time Period	7 years	2 years (February 2002 to December 2003)	Ongoing, since 1999 pilot
Program Development	Studied tree-related outage characteristics	Evaluation of customers affected by tree-related disruptions; projection of customer outages avoided (COA)	Studied tree-related outage characteristics and interruption statistics
Circuit Prioritization	All circuits	Cost Benefit analysis estimated cost per COA by Circuit	Rank circuits with high customer counts, higher voltage
System Protection Relationship	All lines	All three-phase mainline	Three-phase to first protective device
Tree Selection	Professional arborists	Professional arborists	Professional arborists
Integrated with Routine Maintenance or Special Stand-alone Program	Ongoing (separate recording and budget), operationally integrated into cyclic vegetation maintenance	Special stand-alone program 2-year effort	Ongoing stand-alone program

Table 2-2
Comparison of Costs and Results by Utility

Component	BC Hydro	Central Hudson	National Grid
Cost of Program	C$18 million (total)	$9.6 million (total)	$2.4 million per year
Results	Trees now 10-30% of all interruptions, including storms, compared to 56% previously	26 % reduction in annualized SAIFI (all causes, including storms) through 6/30/04 on 51 circuits completed	67% reduction in number of customers experiencing interruptions on 92% of treated circuits
Savings per Outage Avoided	Avoided repair costs of C$1,283 per tree-caused interruption avoided.	N/A	N/A

Central Hudson Energy Group

Central Hudson Program Description

Central Hudson established an Enhanced Reliability Program, in 2002, to improve overall system reliability. Circuits were analyzed using 3-year interruption data to identify potential opportunities. A key component of the program was to develop an evaluation methodology to facilitate ranking based on cost/benefit metrics. The metric utilized for this analysis was cost per Customer Outage Avoided (COA). The COA for each proposed project was calculated using estimated project costs and projected reliability improvements of each project. Typically, when ranked by lowest cost per COA, enhanced tree maintenance projects had the lowest cost to potential improvement ratios. Other projects included in the program were reconductoring, enhanced lightning protection, reclosers and sectionalizers, and automatic load transfer schemes. In calculating estimated cost per COA for enhanced tree maintenance projects, Central Hudson assumed a 50 percent reduction in the number of customers affected by tree-related interruptions following maintenance on the entire three-phase portions of designated circuits, as compared to the 3-year average before enhanced tree maintenance. Circuits with the most customers affected by tree-related interruptions per exposure mile ranked near the top of the list. Cost per COA for capital improvements designed to improve reliability were, in many cases, orders of magnitude higher than cost per COA projected for enhanced tree maintenance.

Tree maintenance practices at Central Hudson have included a regular cyclic program of line clearance, but not removal of overhanging limbs or significant removal of hazardous trees outside of the normal clearance zone, as a general practice. The primary objectives of the Enhanced Tree Maintenance Program were to achieve removal of overhanging limbs and removal or crown reduction of dead, dying, decayed or leaning trees along the edge of the right of way. Immature, tall-growing trees (brush) were also removed or trimmed, as part of the work. Trees to be either pruned or removed were designated by professional vegetation management work planners who prepared work plans for each property in advance of job assignments to the line clearance contractors who performed the tree work.

Central Hudson Results

Central Hudson completed enhanced tree maintenance on a total of 51 circuits. Partial work was completed on additional circuits. Total cost of the project was approximately $9.6 million. Nine hundred three-phase miles were completed over the course of almost two years (February, 2002 to December 2003). Additional partial circuits were completed in late 2003. Reliability data from the date of completion of each circuit was compared to the 1999-2001 3-year system average interruption frequency index (SAIFI) for each respective circuit. At the same time, the enhanced tree maintenance work was completed, Central Hudson also installed a new outage management system that allowed more complete reporting of interruptions than had previously been reported in the old system. When adjusted for changes in the reporting system, average annualized SAIFI (for all causes, including storms) was reduced by 41 percent for the 51 circuits for which enhanced tree maintenance had been completed. The SAIFI reduction without this adjustment was 26 percent.

National Grid (Niagara Mohawk)

Niagara Mohawk, a National Grid company in New York, has a long history of effective vegetation management on its 36,000-mile distribution system. This right-of-way management work historically focused on maintenance of clear space around conductors to prevent interruptions associated with the growth of tree limbs into conductors. Niagara Mohawk participated in a multi-utility study (ECI, 1996) that highlighted the importance of tree failures on overall tree-related outages. Approximately 85 percent of tree-related interruptions were a result of uprooted trees, or failures of tree branches or trunks. By 1998, Niagara Mohawk had begun to develop a strategy to reduce the reliability impact of tree failures. Additional studies were undertaken to help the utility focus resources on those portions of the distribution system that would benefit most from a reduction in interruptions caused by tree failures. Additional work was done to determine how to identify the trees on the system that have the highest potential for failure. These three efforts, together with the corporate need to improve overall reliability, led to the implementation of the Tree Outage Reduction Operation (TORO) beginning with a pilot project on two circuits in the summer of 1999. This program is in addition to a consistently implemented cyclic tree maintenance program.

Niagara Mohawk Program Description

Investigation into the root causes of tree-related interruptions at Niagara Mohawk revealed a number of telling facts about the nature of trees that failed on the system. Among living tree limbs that failed, approximately two-thirds exhibited no obvious visible sign of defect. For trunk failure, the number was lower at about 40 percent. This particular finding was consistent with the experiences of other utilities that participated in the 1995-1996 study (ECI, 1996). Also, as illustrated in Figure 2-1, analysis of tree-caused interruptions in 1999 indicated that tree and limb failures were about equal on the system. Approximately 86 percent of tree-related outages involved trees that were outside the right of way.

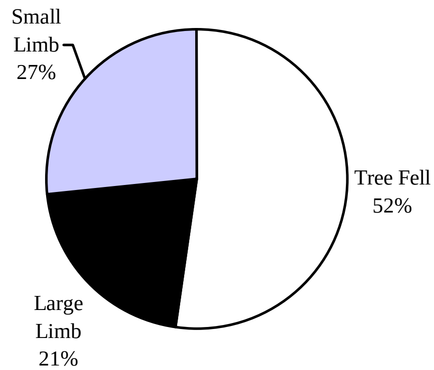

Figure 2-1
Niagara Mohawk Distribution of Tree Failures by Type

These studies also shed light on species that were the most problematic. Figure 2-2 summarizes one analysis of tree failures by species, along with the relative position of that species within the overall tree population. Note that sugar maple (Acer saccharum), black locust (Robinia pseudoacacia) and aspen (Populus tremuloides) not only represented relatively high percentages of species that failed and caused interruptions, but were failing at rates much higher than their presence in the population. Twenty percent of the outages were from sugar maple, yet sugar maple makes up only 12 percent of the tree population. In addition, sugar maples are generally thought of as fairly strong trees and less subject to failure. A closer look revealed that most sugar maple failures were the large, old roadside maples — in serious decline with multiple co-dominant leads, included bark, extensive decay and visible fungal fruiting bodies (conks). This information led Niagara Mohawk to make removal or pruning of these tree species a higher priority – during both the TORO effort and routine cyclic maintenance activities – than those species whose failure rates merely reflected their position in the overall population. Failures in black locust were often related to the shedding of small branches over three-phase lines, during light misting rains. Added weight of water exceeded the strength of the small limbs. Aspen failures were often related to weakness created by Hypoxelon canker, or uprooting in the early spring or late fall when the trees were in leaf in advance of other trees that later protect aspen from wind-throw in saturated soils.

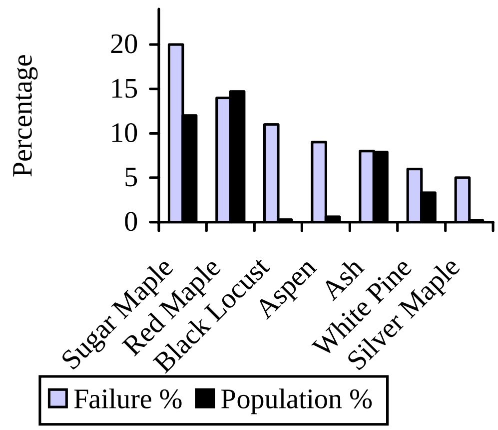

Figure 2-2
Distribution of Common Tree Species that Failed Compared to Species Presence in the Population

Circuit Selection

Not only has tree selection been an important consideration for TORO, but selection of where to apply the program on the system has been key to maximizing the reliability benefits of the program within a narrow budget. Consequently, a circuit analysis model was developed to assist in prioritizing circuits that would most benefit from the removal of overhanging limbs and/or tree removal, to the first protective device. One of the first screens was selection of circuits where 1,000 or more customers had been interrupted by failed trees, during the previous year. This was then evaluated against recent cyclical maintenance requirements to determine the need for routine maintenance, TORO, or both programs. This screening process resulted in identification of those circuits that represented more than approximately:

- 50 percent of all customers affected by trees within the past year
- 50 percent of customer hours interrupted by trees within the past year
- 50 percent of all tree-related interruptions within the past year

This screening process also limited the scope of work to a relatively small portion of the distribution system. Niagara Mohawk's goal was to reduce both the number of customers interrupted and outage duration. Consequently, special attention was given to circuits that suffer from either high numbers of customers interrupted or long restoration times associated with their remote locations, and time required for repair crews to respond to those locations. The ranking system that was developed applied higher values to these situations.

When tree-caused interruptions were separated by voltage (see Figure 2-3), it was apparent that targeting the highest distribution voltage would provide the greatest reliability improvement for the most customers.

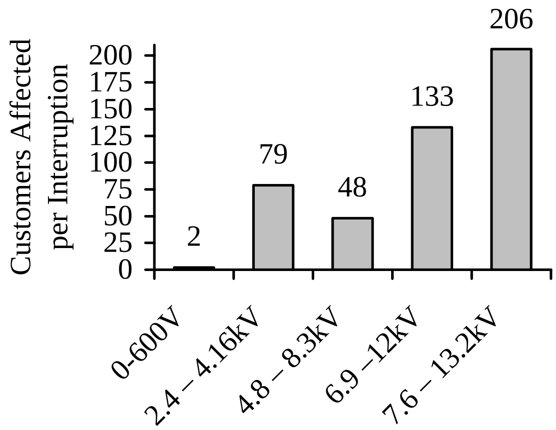

Figure 2-3
Average Niagara Mohawk Customers Affected by Tree-Related Interruptions by Voltage Class

System interruptions were also analyzed by construction type and, not surprisingly, it was found that more customers are affected by three-phase interruptions than single-phase interruptions. Table 2-3 illustrates this relationship using typical data from Niagara Mohawk's system.

Table 2-3
Three-phase versus Single-phase Interruptions – Impact on Customers

Phases	No. of Interruptions	No. of Customers Interrupted	Avg. No. of Customers per Interruption
Single	1,092	51,096	47
Three	795	165,596	208
TOTAL	1,887	216,692	115

With more than four times the average number of customers affected per three-phase interruption compared to an average single-phase interruption, Niagara Mohawk recognized that more resources should be directed toward three-phase lines. Location selection was further refined to include only those three-phase line segments extending from the substation to the first protective device, since the average lockout affected about 18 times more customers than the average interruption. The plan developed by Niagara Mohawk included the following components:

- Identification of the worst performing circuits utilizing specific tree-caused indices.
- Voltage – Target work toward 13.2kV circuits for biggest improvement.
- Number of Phases – Target work toward three-phase portions of the circuit to prevent interruptions for the largest number of customers.

- Lockout Potential – Target work from the station to first protective device to minimize worst case tree-related interruptions.
- Removal of overhanging limbs from trees located from the substation to the first protective device wherever possible.
- Removal of trees evaluated as most likely to fail, located on targeted circuit segments.
- Identify opportunities for system protection improvements, and coordinate closely with System Engineering groups.

Operations and Public Relations

Ten specialized crews are devoted to TORO on an annual basis, in addition to five certified arborists who evaluate tree conditions and plan work in advance of the assignment to the tree crews. Trees selected for TORO pruning or removal could be as much as 50 feet from power lines, if the arborist determines that a tree is a significant risk. During calendar years 2002 through 2003, approximately 56,000 trees were removed. New additions to TORO include inspections for presence of single-phase tap fuses, installation of absent fuses or repair of open or non-functional fuses.

One issue for most utilities is the impact on customer relations when trees are removed that, to the general public, may appear green and healthy. Niagara Mohawk carefully addressed this issue with affected property owners, and also implemented a tree-planting effort called the *10,000 Trees and Growing Program.* This program has helped maintain good public relations, as Niagara Mohawk seeks property owner and municipal permission to remove trees. The cost of the program has been modest, but has resulted in the planting of thousands of low-growing trees under distribution lines in residential neighborhoods.

Niagara Mohawk Results

Customers affected by tree-related interruptions across the Niagara Mohawk system have been trending down since implementation of the TORO program, which started as a pilot program in 1999. Through 2002, Niagara Mohawk reported a 62 percent reduction in the number of customers affected by tree-related outages on 92 percent of the circuits treated through their TORO program. More recent data documents the improvement in overall system customers affected. Figure 2-4 demonstrates the trend in customers affected annually by tree-related outages on the distribution system. This is a strong downward trend indicative of the cumulative effect of hazard tree risk reduction over time.

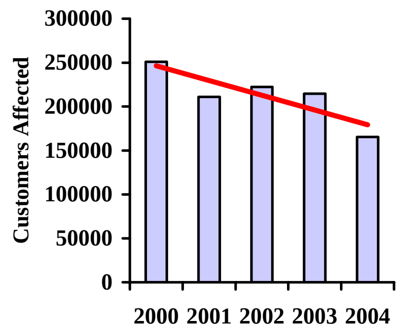

Figure 2-4
Reduction in Numbers of Customers Affected by Tree-Related Interruptions at Niagara Mohawk From 2000 to 2004 (12-Month Periods from September to August)

Niagara Mohawk learned through research conducted in 2001 that trees of similar defect and potential risk in practically the same locations don't fail at the same time. Time of failure is not possible to predict; only the predisposition to failure can be assessed through evaluation. Trees that were observed to be hazardous in the early years of the TORO program may not have contributed to reductions in customers affected by tree-related interruptions in the first, second or even third year of the program. It is likely, however, that the impact of this risk reduction program is cumulative and becomes more evident over time.

The focus of TORO primarily has been to reduce the number of customers affected by tree-related interruptions, and to reduce interruption frequency. This is reflected by reductions of 9 percent in the number of interruptions, but a corresponding 20 percent reduction in customers affected.

BC Hydro

BC Hydro Program Description

The tree population affecting the BC Hydro distribution system is denser than tree populations affecting many utilities (100 trees per mile within the ROW, and more than 300 trees per mile, if the trees along the edge of the ROW that can fall on the lines are included). Additionally, conifers represent nearly 50 percent of the tree population at BC Hydro, and those trees tend to be taller than trees in most parts of North America. Consequently, the exposure level to tree-related interruptions at BC Hydro is relatively high.

Throughout the 1980s and early 1990s, tree-related outages were categorized as either *preventable* or *non-preventable*. Preventable tree-related outages were generally those resulting from tree branches that were within the normal clearance zone around conductors. From 1986 through 1990, non-preventable tree-related outages ranged from 64 percent to 81 percent of all tree-related outages. During this period, all recorded tree-related interruptions represented about 16 percent of total interruptions, excluding all major storms. From 1991-1992, with all storms included, 56 percent of all interruptions were attributed to trees.

Before implementing a hazard tree reduction program, BC Hydro adopted a significant change in how they categorized tree-related outages. These changes began with the premise that all tree-related interruptions are preventable. Much of the industry views outages caused by uprooted or broken trees outside the normal right of way as beyond the scope of traditional maintenance, and therefore, non-preventable. In reality, all of those outages are — at least theoretically — preventable if sufficient resources and public support are available to address the interruption causes. From this position that tree-related outages are preventable, BC Hydro began to categorize tree-related outages in more useful groups: tree failure, branch failure and tree growth. Analysis of the cause categories indicated that 88 percent of outages were caused by either tree or branch failure, as illustrated in Figure 2-5.

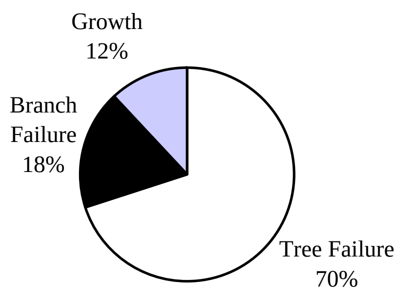

Figure 2-5
BC Hydro Historic Distribution of Tree-Related Interruptions by Cause

In 1995-1996, BC Hydro participated in a multi-utility effort to gather data on the field attributes of trees that were identified as having caused distribution system interruptions (ECI, 1996). This work helped BC Hydro identify the type of tree conditions that most commonly result in structural failure and become an interruption cause. It also identified tree failure causes by species, distance of failed trees from conductors, site conditions, tree height and diameter of the failed branch, previous maintenance and maintenance interval. Information from this study was used by BC Hydro to help refine their approach to identification of trees representing the greatest failure risk. For example, western hemlock (*Tsuga Heterophylla*), which makes up only 5 percent of the total tree population adjacent to distribution lines, represented a disproportionate percent of failures at 18 percent. Consequently, guidelines for hazard tree rating designated western hemlock as a species that is at high risk of failure — particularly whole tree failure.

Based on information about trees that fail on their system, together with arboricultural guides for evaluation of tree defects and structural weaknesses, BC Hydro developed a hazard tree priority system for rating trees. This system assigns points to three general factors, as follows:

- Condition of the tree
- Species hazard rating

- Outage potential

Possible points range from 5 to 42. Point ranges translate into priority classifications for failure potential, and guide the decisions about if and when some hazard reduction action should be scheduled for a particular tree. Failure potentials are based on the evaluated point totals according to the definitions included in Table 2-4.

Table 2-4
BC Hydro Failure Potential and Action Timing Definitions

Failure Potential	Action Timing
High	Immediate or as soon as possible: 90 days maximum.
Moderate	Within 15 months: 90 days to 15 months.
Low	Within 3 years: (optional) do in next cycle or leave (customer request) and continue to monitor for decline.
Minor	Optional, but monitor: request removal when appropriate; remove in next block cycle or review next cycle. Remove on request when economically viable.

BC Hydro Results

Following a 7-year implementation period, tree-related interruptions range from 10 percent to 30 percent of all interruptions on the system, depending on weather-related events in a particular year. This compares to more than 50 percent of total interruptions prior to implementing a hazard tree removal program. Figure 2-6 summarizes the program costs and benefits in reduced repair costs estimated by BC Hydro from 1992 to 2000.

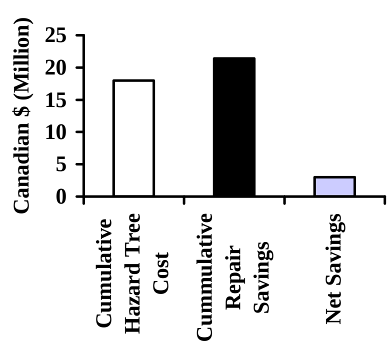

Figure 2-6
BC Hydro Hazard Tree Program Cost and Estimated Repair Savings 1992 to 2000

Savings in repair costs are based on a conservative estimate of cost to repair a tree-failure interruption (slightly more than two times the cost of the average repair). By 2002, BC Hydro estimates that the net savings from the program has been about C$3 million. Savings are cumulative, so the utility continues to benefit in later years from work completed several years earlier. When normalized for wind, BC Hydro calculated even greater cumulative net savings of up to C$25 million through 2002. More than 250,000 trees were removed, at a cost of about C$18 million. Since 1999, the hazard tree removal portion of the vegetation management budget has remained steady at C$3.0 million per year, which is about 21 percent of their total vegetation management program cost. New focus is being directed toward trees killed by a pine beetles epidemic in British Columbia.

Conclusion

The three approaches utilized by Central Hudson, BC Hydro and Niagara Mohawk have elements in common, as well as some important differences in objectives, processes and measures. While only two of these companies have chosen to make hazard tree risk reduction ongoing programs, they have all reported positive and encouraging results from their efforts to date. This adds credence to the idea that practical approaches can be devised to reduce tree failure risks that affect overhead distribution systems. Following is a brief summary of key differences in approach:

Objective Comparisons

- Central Hudson set a short-term objective to improve system SAIFI by 25 percent through enhanced tree maintenance and system improvements.
- Niagara Mohawk's objective focuses on reductions in the number of customers affected by interruptions and outage duration.
- BC Hydro's focus has been on reduction in the number of tree-related interruptions and the associated savings in restoration/repair costs.

Process Comparison

- Central Hudson began its process with an analysis of interruption data and estimated cost per outage avoided by circuit for various options expected to improve system SAIFI. Hazard tree risk reduction was confined to the three-phase portions of target circuits. Professional arborists who are experienced in work planning and hazard tree assessment were relied on to select trees for pruning or removal. This special program was implemented separately from the routine, scheduled tree maintenance program.
- Niagara Mohawk carried out more extensive analysis over several years to determine how best to reduce risk from tree failure to benefit the most customers for the least cost. Guidelines were created based on research and experience on tree failure to guide the Certified Arborists in the selection of trees to include in the hazard tree risk reduction program. Niagara Mohawk's TORO program is distinct from the cyclic tree maintenance program, with separate priorities, separate budgets and targets separate circuits.

- BC Hydro also began with analysis of tree failure trends on its system and developed a rating system for evaluation of hazard trees. Specially trained professionals are relied upon to evaluate trees and make hazard ratings that include tree conditions, as well as target risk. Based on the rating, worst trees are worked first. BC Hydro's program is integrated operationally within the cyclic vegetation maintenance program, but budgeted and tracked separately.

Measurement Comparison

- Central Hudson measured effectiveness by reduction in SAIFI on circuits included in their enhanced tree maintenance program.
- Niagara Mohawk evaluates reduction in customers affected by tree-related interruptions on circuits included in their TORO program.
- BC Hydro measures reduction in the percent of system interruptions related to trees and estimates reductions in the cost of restoration and repair of tree-related interruptions.

A

APPENDIX A

Process Maps

Process maps were created to describe the high-level process flows for each of the approaches to improvement in system performance through hazard tree risk reduction. Based on the successes of each program, and the attributes that appear to cause this success, a suggested model process map for hazard tree risk reduction is also presented in Figure A-4.

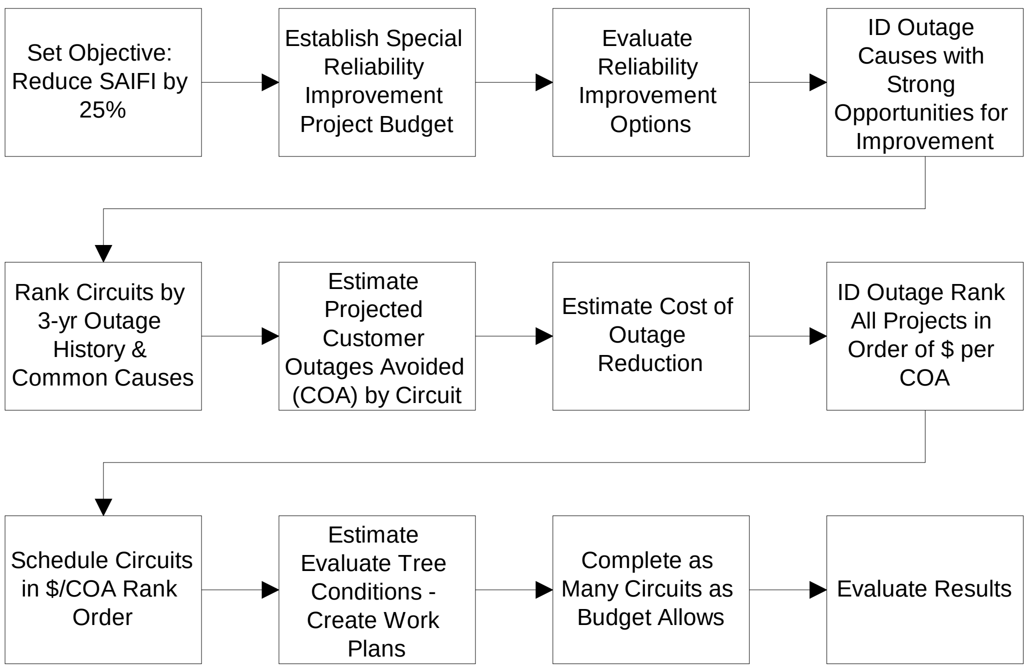

Figure A-1
Central Hudson Enhanced Tree Maintenance Process

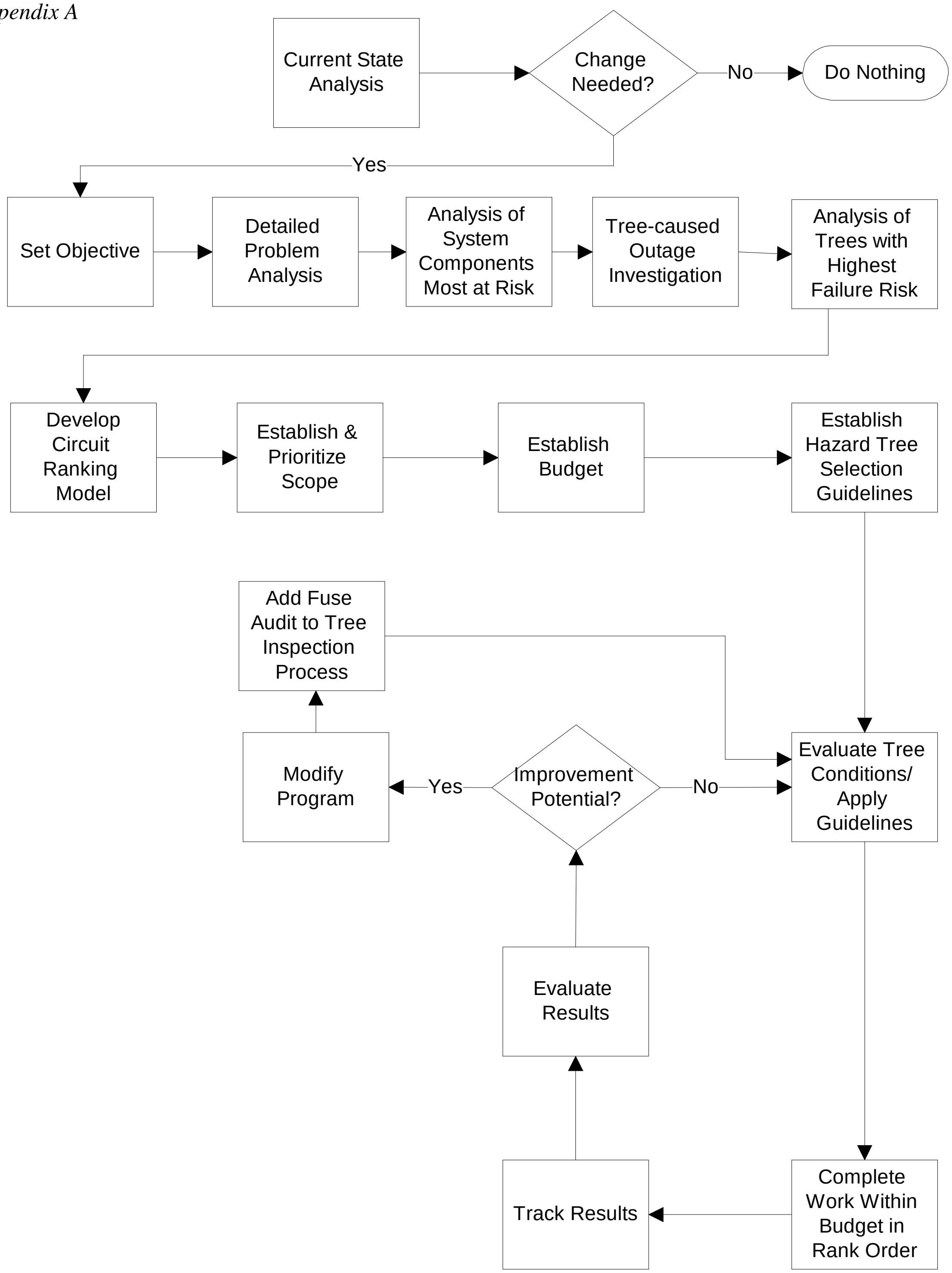

Figure A-2
Niagara Mohawk TORO Process

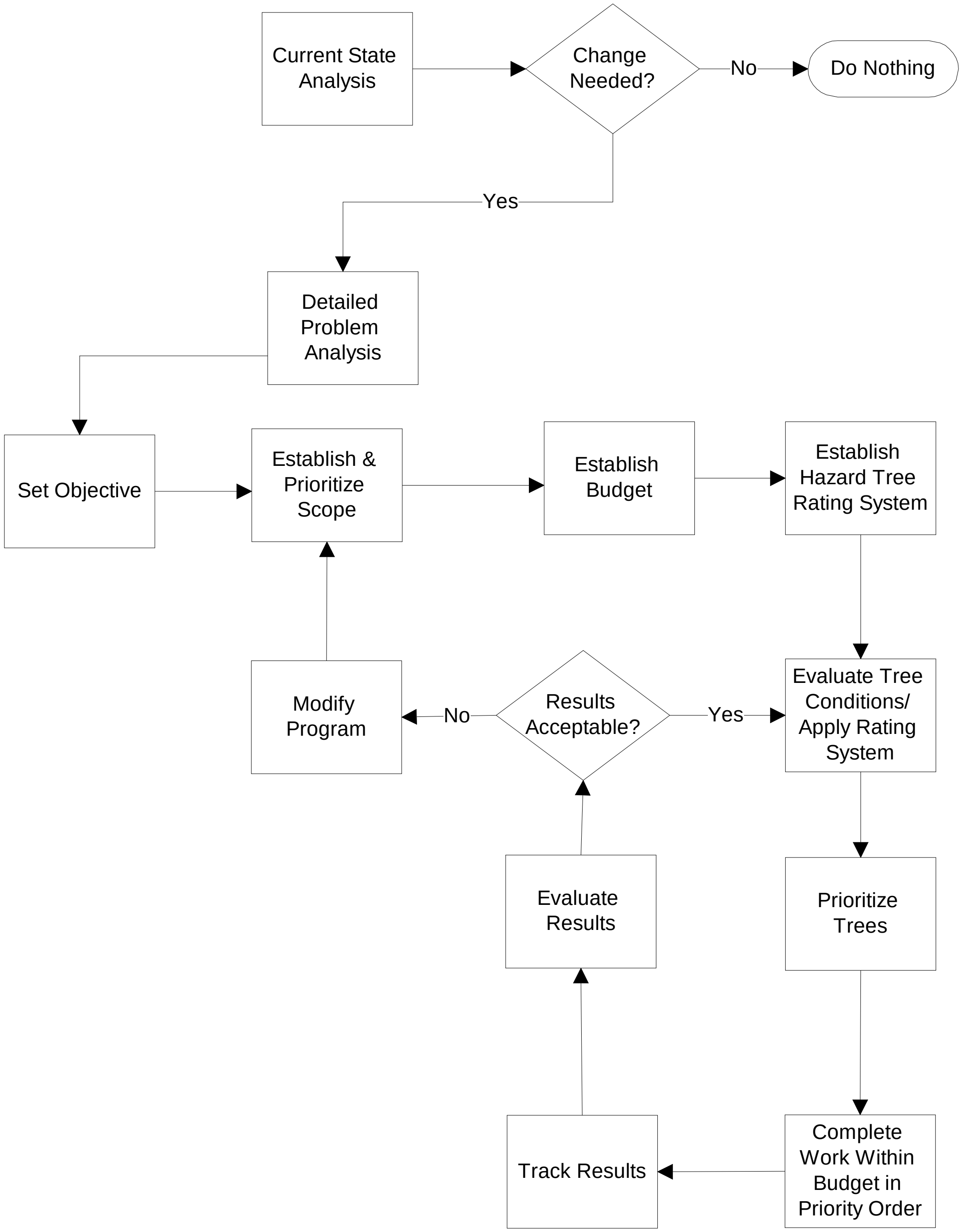

Figure A-3
BC Hydro Hazard Tree Process Map

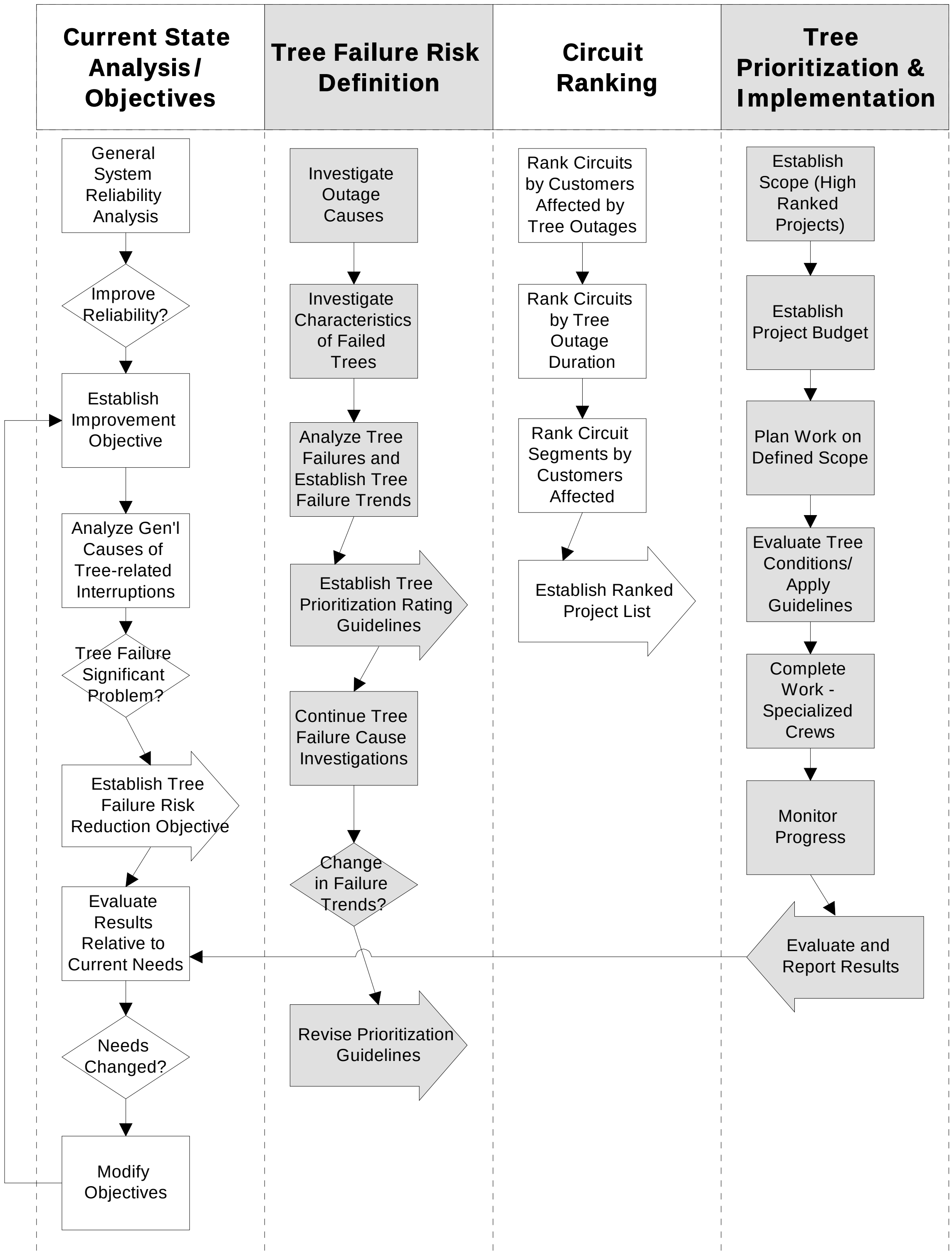

Figure A-4
Model Hazard Tree Risk Reduction Process

Figure A-4 illustrates a process flow derived from features of each of the three hazard tree reduction programs studied. This model process includes four main sub-processes, as follows:

1. Current state analysis and objective setting.

2. Definition of tree failure risk and development of risk evaluation guidelines.

3. Circuit prioritization.

4. Tree evaluation, prioritization and hazard risk reduction implementation.

The current state analysis begins with a system reliability analysis determining that reliability associated with tree-related interruptions should be improved. Tree failure risk reduction objectives are established after choosing improvement objectives and determining that interruptions caused by tree failure represent the best opportunity for tree-related interruption reduction.

The second process step is to gather data about the characteristics of trees that fail, resulting in interruptions. This data is gathered through root cause investigations of tree-related interruptions and the specific tree conditions associated with tree failures. Analysis of this data will point to failure trends among specific tree species and the most common conditions associated with failed trees. Initial tree hazard evaluation and prioritization guidelines for evaluators should be developed based on analysis of the failure trends. As more data is gathered, changes in the initial tree hazard evaluation guidelines may require modification.

The third step focuses on identification of circuits and/or circuit segments that would benefit the most from reductions in hazard tree risks. Ranking circuits by customers affected, as a result of tree failure interruptions and by outage duration, will provide a list of circuits and/or circuit segments for inclusion in an initial hazard tree reduction program.

The final process step involves tree prioritization and hazard tree risk reduction through tree removal or tree pruning. Following establishment of a budget for completion of work on a substantial number of ranked circuits, field evaluation of trees is carried out on circuits in order of ranking. As work is planned, tree prioritization guidelines are applied in the evaluation of trees that have potential to negatively affect electrical facilities, including trees outside the normal maintenance zone. Following identification of hazardous trees, appropriate line clearance crews are assigned planned work for completion. Results are monitored and compared to current needs, as part of a return to step one reliability analysis.

Tree Failure Report Example

PACIFIC NORTHWEST TREE FAILURE REPORT

Available online at: http://w3/td/ma/vegetationnew/tdcorridor/doc/pacific_northwest_tree_failure_report_form.doc *To request a Users Guide please contact:* mailto:brian.fisher@bchydro.com

TREE INFORMATION

Genus ______
Species ______
Cultivar ______
Common Name ______
Dbh (inches) ______ Height (ft) ______
Spread (ft) ______ Age ______
Condition ☐1-dead ☐2-poor ☐3-fair ☐4-good ☐5-specimen
Crown Class ☐1-dominant ☐2-codominant ☐3-intermediate ☐4-suppressed

TREE FAILURE DETAILS:

1. Date of Failure (mm/dd/yyyy) ______
2. Time of Failure (24:00) ______
3. Location of failure on tree (choose 1)
   - ☐ 1-Trunk _____ ft above ground _____ inches diameter
   - ☐ 2-Branch _____ ft from attachment _____ inches diameter
     - Height of attachment _____ ft
     - Branch angle at point of failure _____ Degrees
     - End weighted branch ☐ Yes ☐ No
   - ☐ 3-Root failure
4. Site use (explain on page 2)
   - ☐ 1-undeveloped
   - ☐ 2-low (intermittent vehicles / people
   - ☐ 3-medium (permanent structures, intermittent vehicles/people
   - ☐ 4-high (permanent structures, frequent vehicles/people)
5. Stand Type
   - ☐ 1-natural ☐ 2-planted ☐ 3-mixed
6. Tree occurring (choose 1)
   - ☐ 1-alone (at least one crown diameter apart)
   - ☐ 2-grove (less than one crown diameter apart)
   - ☐ 3-altered stand (new forest edge)

TREE STRUCTURAL DEFECTS:

7. Choose up to 3 in order of importance 1st:___ 2nd:___ 3rd:___
   - 1-failed portion dead
   - 2-multi trunks/codom stems
   - 3-dense crown
   - 4-heavy lateral limb
   - 5-asymmetrical (side heavy)
   - 6-asymmetrical (top heavy)
   - 7-multibranching at 1 point
   - 8-embedded bark in crotch
   - 9-crook or sweep
   - 10-leaning trunk
   - 11-crack or split
   - 12-kinked/girdling roots
   - 13-none apparent
   - 14-other

TREE STRUCTURAL DEFECTS:

8. Type of decay at failure (choose 1)
   - ☐ 1-root rot ☐ 2-heart rot
   - ☐ 3-sap rot ☐ 4-heart rot and sap rot
   - ☐ 5-no decay noted
9. Extent of decay % cross sectional area
   (for root failure estimate % roots decayed)
   - ☐ 1-25% or less ☐ 2-26-50%
   - ☐ 3-51-75% ☐ 4-76-100%
   - ☐ 5-unknown
10. Fungal conks, etc near failure ☐ Yes ☐ No
11. Other injury at failure location (choose 3) 1st:___ 2nd:___ 3rd:___
    - 1-mechanical
    - 2-lightning
    - 3-insect
    - 4-animal
    - 5-chemical
    - 6-vehicle
    - 7-fire
    - 8-none
    - 9-other (explain on page 2)
12. Other injury, entire tree 1st:___ 2nd:___ 3rd:___
    (choose up to 3 in order of importance -- same options as 11)

Reference # __________ Report Date: __________

TREE LOCATION

Owner ______
Street Number ______
Street ______
City ______
Province / State ______

Site Category: ☐1-Residential - ☐SF or ☐MF ☐2-Street ☐3-Park ☐4-School ☐5-Highway ☐6-Parking Lot ☐7-Mall ☐8-ROW ☐9-Other

MAINTENANCE HISTORY:

13. Pruning - at failure location 1st:___ 2nd:___ 3rd:___
    (choose up to 3 in order of importance)
    - 1- heading cut (moderate) diameter ______ "
    - 2- heading cut (severe) diameter ______ "
    - 3-thinning cuts
    - 4-lion tailing
    - 5-flush cuts
    - 6-root pruning
    - 7-no pruning
    - 8-other (explain page 2)
14. Pruning - entire tree 1st:___ 2nd:___ 3rd:___
    (choose up to 3 in order of importance -- same option 13)
15. Other maintenance (choose up to 2) 1st:___ 2nd:___
    - 1-cable/hardware
    - 2-staking/props
    - 3-girdling wire/rope/etc.
    - 4-cavity treatment
    - 5-not applicable
    - 6-other (explain page 2)

SOIL AND ROOT CONDITIONS AT SITE:

16. Restricted roots (choose up to 2) 1st:___ 2nd:___
    - 1-raised planter or bed
    - 2-container or boxed tree
    - 3-root barriers
    - 4-root cutting/trenching
    - 5-not applicable
    - 6-other (explain page 2)
17. Irrigation
    - ☐ 1-none ☐ 2-less than 1x per month
    - ☐ 3-more than 1x per month ☐ 4-more than 3x per month
18. Ground cover under tree (choose 2) 1st:___ 2nd:___
    - 1-bare soil
    - 2-mulch
    - 3-turf
    - 4-native cover
    - 6-shrubs
    - 7-mixed planting
    - 8-paving
    - 9-other

Figure A-5
Tree Failure Report Form Used by BC Hydro, Page 1.

5-herbaceous plants

19. Soil in tree vicinity
    - ☐ 1-good condition ☐ 2-compacted
    - ☐ 3-saturated ☐ 4-dry
    - ☐ 5-shallow ☐ 6-other (explain page 2)

20. Site topography changes (choose 2) 1st:___ 2nd:___
    - 1-excavation depth ___ ft distance from trunk ____ ft
    - 2-grade change - cut
    - 3-grade change - fill
    - 4-slope erosion
    - 5-streambank erosion
    - 6-not applicable

WEATHER AT TIME OF FAILURE

21. Wind Speed
    - ☐ 1-low (less than 5 mph) ☐ 2-moderate (5 to 25 mph)
    - ☐ 3-high (more than 25 mph)

22. Wind
    - ☐ 1-gusty ☐ 2-steady

23. Wind in prevailing direction for season select direction

24. Wind direction related to branch
    - ☐ 1-parallel ☐ 2-perpendicular

25. Temperature (degrees Fahrenheit) ____ ◦F

26. Precipitation
    - ☐ 1-rain ☐ 2-snow ☐ 3-ice ☐ 4-fog ☐ 5-none

Please submit photographs.

Briefly describe why you believe the failure occurred:

Results of the tree failure (i.e. property damage, personal injury, etc.):

Damage estimate (cost of clean-up, other costs if known):

Additional information and comments:

Prepared by:

Certification #			
Name		Title	
Company / Agency		Phone	

This completed form may be forwarded by Brian Fisher to:
PNW TREE FAILURE REPORTING PROGRAM
c/o PACIFIC NORTHWEST CHAPTER ISA
PO Box 811
Silverton, OR 97381

In CANADA mail to: or fax to (604) 275-9554
PNW TREE FAILURE REPORTING PROGRAM
c/o ARBORTECH CONSULTING LTD
4700 Windjammer Drive
Richmond BC V7E 4L6

This form may only be completed by an authorized assessor. For more information please contact Brian Fisher at (604) 543-4152, Norman HOL at (604) 275-3484, or Paul Ries at the PNW ISA Chapter office at (503) 874-8263. This form may be photocopied.

The information in this report will remain confidential, and will only be used to develop statistical and general information about tree failures by species and type of failure.

This document is adapted by Norman Hol, with permission from the California Tree Failure Reporting program as developed by A.M. Berry, L.R. Costello, and R.W. Harris.

Figure A-6
Tree Failure Report Form Used By BC Hydro, Page 2.

B
REFERENCES CITED

Brudi, E. and P. van Wassenaer. 2001. Trees and Statics: Nondestructive Failure Analysis. pp. 53-69. *In* E.T. Smiley and K.D. Coder (eds.) Tree Structure and Mechanics Conference Proceedings, October, 2001. Savannah, Georgia. International Society of Arboriculture. Champaign, IL.

Clark, J.R. and N.P. Matheny. 1993. A Handbook of Hazard Tree Evaluation for Utility Arborists. International Society of Arboriculture. Savoy (Champaign), IL.

Dunster, J.A. 1996. Hazard Tree Assessments: Developing a Species Profile for Western Hemlock. *Journal of Arboriculture* 22(1): 51-57.

Environmental Consultants, Inc. 1996. Tree-caused Interruptions: A 17 Utility Study.

Forest Products Laboratory, Forest Service. 1974. Wood handbook: Wood as an engineering material. U.S. Dept. Agric., Agric. Handbook 72, rev.

Kennard, D.K., F.E. Putz, and M. Niederhofer. 1996. The Predictability of Tree Decay Based on Visual Assessments. *Journal of Arboriculture* 22(6): 249-254.

Lilly, S. and T.D. Sydnor. 1995. Comparison of Branch Failure During Static Loading of Silver and Norway Maples. *Journal of Arboriculture* 21(6):302-305.

Luley, C.J., A. Pleninger, and S. Sisinni. 2002. The Effect of Wind Gusts on Branch Failures in the City of Rochester, New York. U.S. pp. 103-109. *In* E.T. Smiley and K.D. Coder (eds.) Tree Structure and Mechanics Conference Proceedings, October, 2001 Savannah, Georgia. International Society of Arboriculture. Champaign, IL.

Matheny, N.P. and J.R. Clark. 1994. A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas. International Society of Arboriculture. Savoy (Champaign), IL.

Smiley, E.T. and K.D. Coder (eds.) 2001.Tree Structure and Mechanics Conference Proceedings. Savannah, Georgia. International Society of Arboriculture. Champaign, IL.

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

EPRI. Electrify the World

Program: 1008480

Rights-of-Way Environmental Issues in Siting, Development, and Management

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com