Application of Risk Analysis and Optimization to an Integrated Reliability Improvement Program

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Reliability Program Objectives

- Achieve a stated level of reliability improvement at minimum cost
- Given a stated level of funding achieve the maximum level of reliability improvement
- Defined as constraints , requirements and objectives

The "Issues"

- No methodology other than "gut feel" to determine how to allocate resources to reliability improvement programs
- How do we assure management we are making the most cost effective allocation of resources to achieve the required reliability improvements?
- An integrated approach is needed that evaluates all possible initiatives or programs for reliability improvement

The "Risks"

- Effectiveness of different programs varies
  - Nothing is 100%
  - Wildlife protection, lightning protection and other initiatives have varying degrees of effectiveness
- Unit Costs vary with the targeted devices
  - One branch line is 2 spans long
  - Another may be 2 miles long
- Repeatability – The "80-20 Rule"
  - 80% of outages are random and do not repeat in the next year
  - 20% are chronic repeaters

Integrated Reliability Improvement Program

- Requires an integrated approach which:
  - Recognizes all options for improvement
  - Estimates improvement for each option
  - Evaluates costs of each option
  - Optimizes the mix of improvement options
  - Evaluates risk and variability of each option

Program Guidelines

- Requirement = Item must be achieved
  - Given amount of reliability improvement
- Constraint = Limitation of budget or other resources
- Objective = Maximum improvement or Minimum Cost

Reliability Improvement Initiatives

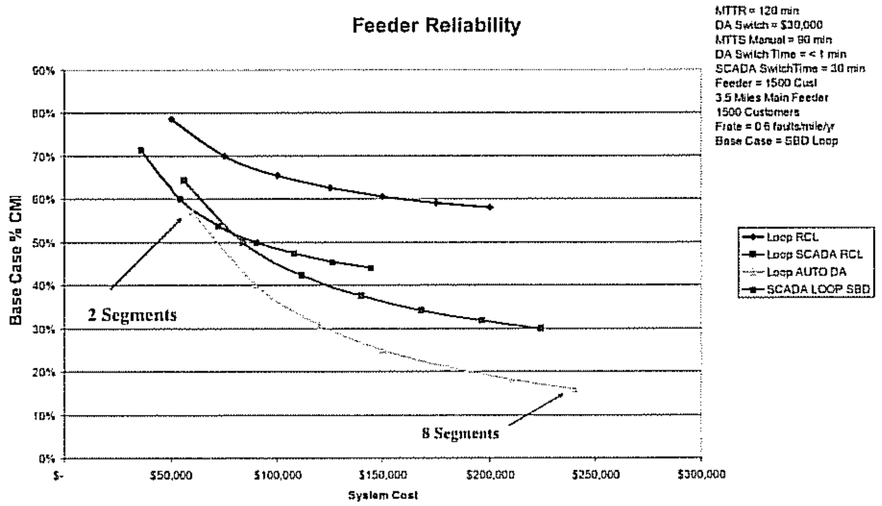
2 Types

Fault Prevention

Fault Mitigation

- Wildlife Protection
- Lightning Protection
- Infrared Inspection
- Tree Trimming
- Additional Sectionalizing
- Faulted Circuit Indicators (FCI's)
- Automation
- Others (Fuse Coordination,…)

Fault Mitigation by Design



Outage Database is Mandatory
Data Mining is Key

- For each initiative identify and quantify the reliability improvement expected
  - Extract information from outage database
  - Identify specific devices, line sections or feeders which have causes related to the initiative
  - quantify the CMI for the location
  - sort all locations/devices in Pareto fashion

Reliability Improvement Estimates

- Historical performance is base case
- Improvement will not exceed historical base case
- Use CMI and multiplicity as measures of future performance
- Evaluate effectiveness of improvement options

Effectiveness Definition

- Effectiveness = Post Improvement probability a device will not have another outage from the same cause
- IE: If only 20% of the devices treated for wildlife protection have wildlife caused outages in the next year then the wildlife protection program is 80% effective

Probable Reliability Improvement

Improvement is a function of:

Historical Annual CMI of the Device
Repeatability of the fault
Effectiveness of the repairs

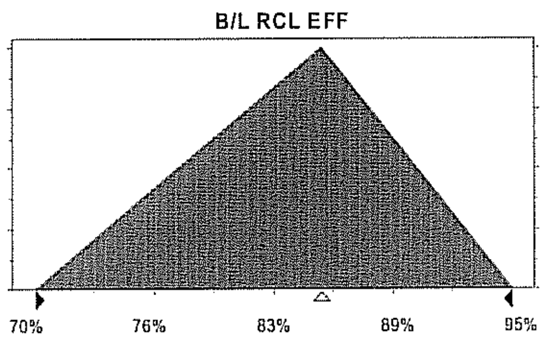
 # Devices Repaired

Net Effect of repeatability and effectiveness is to reduce the reliability improvement estimate

Estimating Effectiveness

- Defined as probability distribution based on historical performance
- Nothing is "100%"

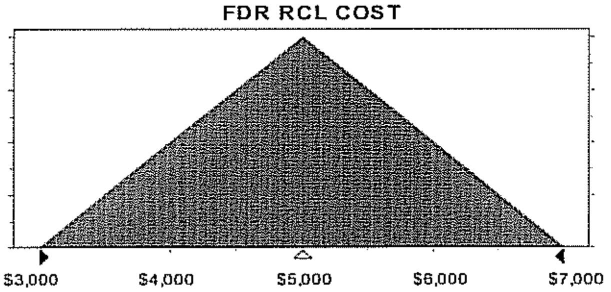
Effectiveness Probability Distributions



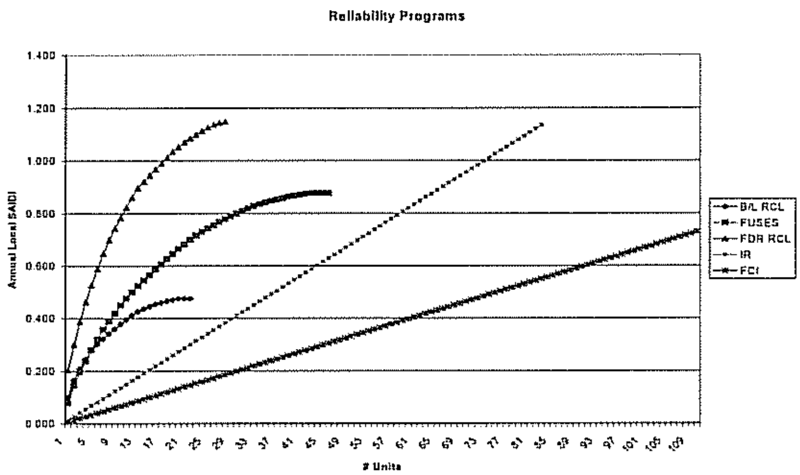
Cost Estimates for Options

- Branch Lines vary in length
- Costs will vary with length and other factors
- Define variability as a Median cost with a probability distribution
- Cost Estimate = unit cost X probability X Units Repaired

Cost Probability Distribution



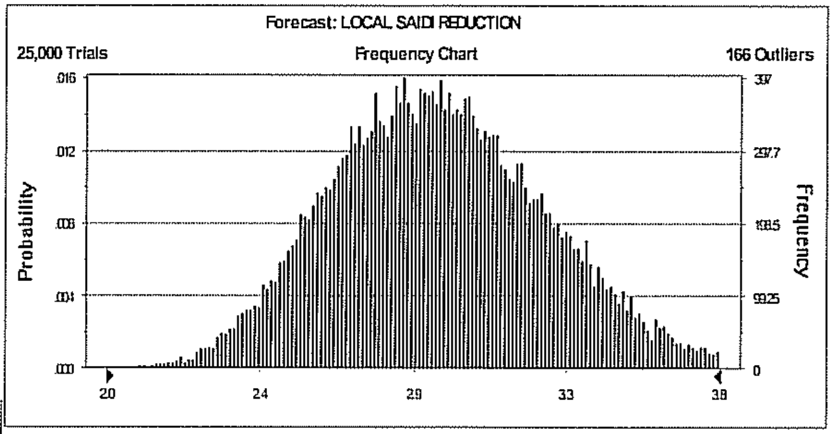
Historical Device CMI



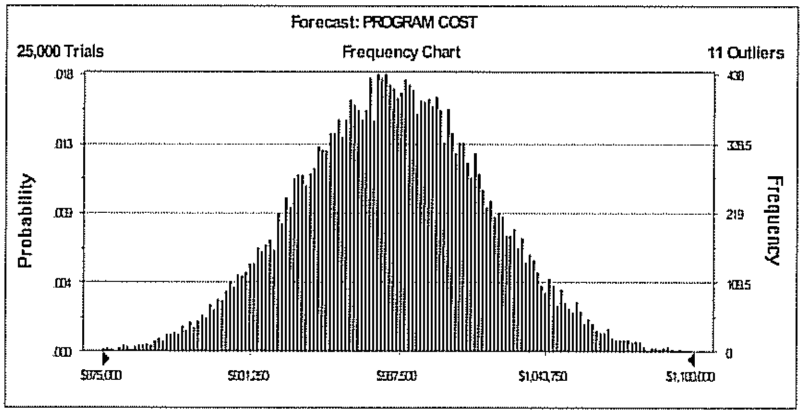
Risk Analysis

- Uses a statistical simulation (Monte Carlo or Latin Hypercube)
- Evaluates the equations for
  - Reliability Improvement
  - COST
- Allows quantification of the variability of the outcomes

Reliability Improvement Risk Analysis Results



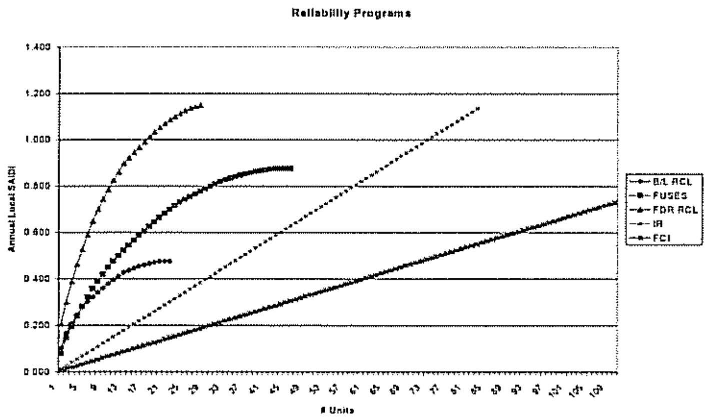
Cost Estimate Risk Analysis Results



Optimization

- How much of each option to optimize the objective?
- Determined by # Devices Repaired and Cost expended on each Option
- How much to invest in lightning Protection vs.. Infrared

Optimize # Units of each Option for Cost and Reliability Improvement



Optimization

- No direct Solution available
- Solved by Monte Carlo or Latin Hypercube Simulation
- Determines optimum # Units for each Option to achieve Objectives, meet Requirements and conform to Constraints

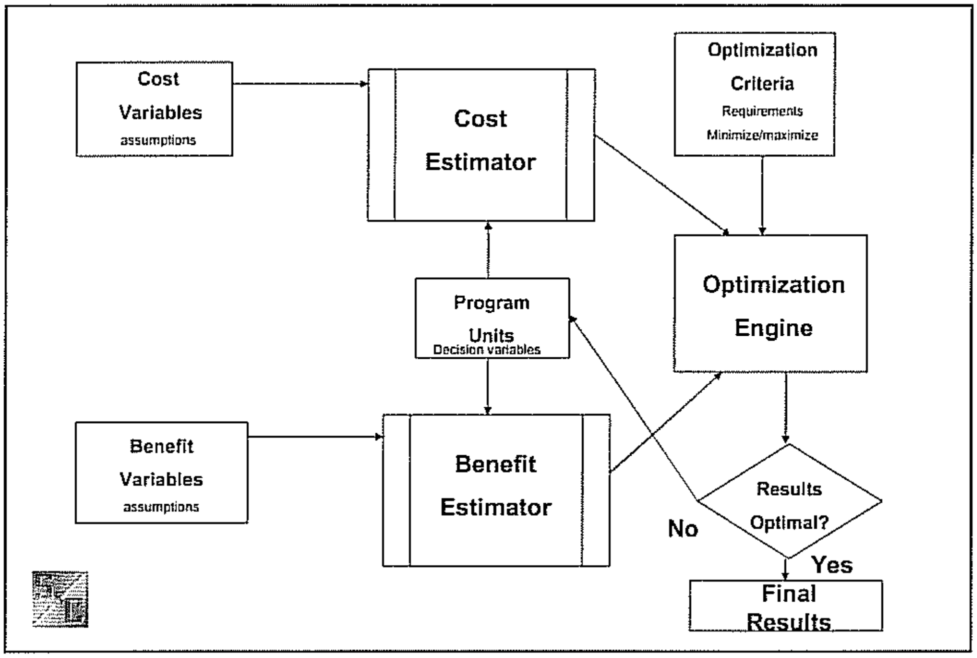
Strategic Reliability Plan

Optimization Analysis

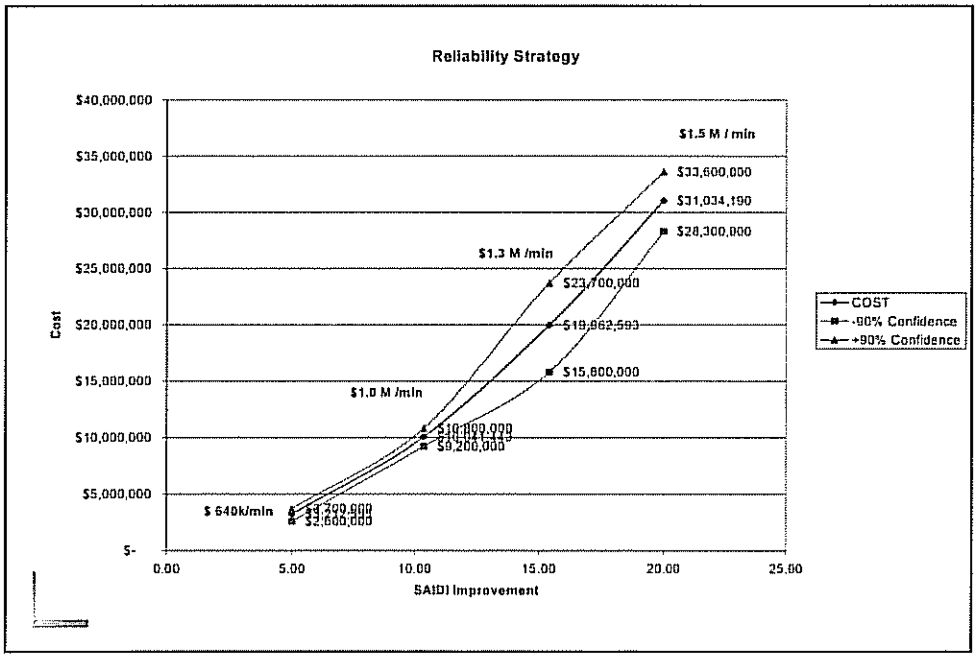
Initiative	Type Units	# Units	MAX Units	Min Units	CMI	Unit Cost	Total Cost	Total CMI Benefit	NET SAIDI Benefit
FDR Reclosers	Feeders	233	762	1	4,967,786	$ 22,667	$ 5,281,333	4,719,397	3.37
Fuse Coord	Feeders	236	968	1	11,584,151	$ 15,433	$ 3,642,261	5,792,076	4.14
FCI's	Feeders	257	600	1	1,533,368	$ 2,400	$ 616,800	1,022,245	0.73
FDR LA's	Feeders	422	952	1	12,790,314	$ 6,552	$ 2,765,120	3,197,578	2.28
B/L LA's	Feeders	248	952	1	9,641,904	$ 18,533	$ 4,596,222	2,410,476	1.72
Added Sectionalizing	DEV LOC	426	820	1	1,273,740	$ 3,333	$ 1,420,000	1,019,572	0.73
Loop Sectionalizing	Feeders	233	762	1	4,967,786	$ 12,500	$ 2,912,500	4,471,008	3.19
Small Wire Reconductor	DEV	31	655	1	1,163,300	$ 35,806	$ 1,110,000	756,145	0.54
Vegatation Mitigation	Feeders	2	100	1	546,922	$ 130,000	$ 260,000	218,769	0.16
Additional Automation	Feeders	86	762	1	2,521,236	$ 32,000	$ 2,752,000	2,269,112	1.62
							$ 25,356,237	25,876,378	18.5
							Objective		Requirement

Risk Analysis

Initiative	Unit Cost	$/FDR	Cost/LOC	Cost Variability			Benefit Variability		Effectivness
FDR Reclosers	$ 22,667	$/FDR	$ 22,667	Cost/RCL	1	RCL/FDR		% SAIDI IMPROV	95%
Fuse Coord	$ 15,433	$/FDR	$ 300	COST/LOC	51	AVG FUSE/FDR			50%
FCI's	$ 2,400	$/FDR	$ 600	cost/loc	4	Loc/FDR	8.0	Min/Outage	67%
FDR LA's	$ 6,552	$/FDR	$ 350	cost/loc	1,975	Total miles	4	LA LOC/Mile	25%
B/L LA's	$ 18,533	$/LOC	$ 175	cost/loc	6,566	Total miles	4	LA LOC/Mile	25%
Added Sectionalizing	$ 3,333	$/FDR	$ 3,333	cost/loc	$ 3,333	cost/loc	2990	cmi/dev	80%
Loop Sectionalizing	$ 12,500		$ 25,000	cost/loc	25000	Cost/RCL	0.15	% SAIDI IMPROV	90%
		$/DEV					0.5	RCL/FDR	
Small Wire Reconductor	35,806	$/fdr	35,806						65%
Vegatation Mitigation	$ 130,000	$/FDR	1	miles/fdr	130000	cost/mile		CMI/FDR	40%
Additional Automation	$ 32,000		$ 12,000	Cost/loc	2.67	LOC/FEEDER		% Total FDR CMI	90%



Cost
Variables
assumptions
Cost
Estimator
Optimization
Criteria
Requirements
Minimize/maximize
Optimization
Engine
Program
Units
Decision variables
Benefit
Variables
assumptions
Benefit
Estimator
Results
Optimal?
No
Yes
Final
Results



Reliability Strategy
$40,000,000
$35,000,000
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
$-
Cost
$1.5 M / min
$33,600,000
$31,034,190
$28,300,000
$1.3 M /min
$23,700,000
$19,962,593
$15,800,000
$1.0 M /min
$10,800,000
$9,200,000
$ 640k/min
$2,600,000
0.00
5.00
10.00
15.00
20.00
25.00
SAIDI Improvement
COST
-90% Confidence
+90% Confidence

Targeting Reliability Initiatives

- Not Just "WORST Performing Feeders"
- Target by interrupting device
  - Includes RCL, FUS and STA devices
- Address Repeat Outages
  - Multiples on a device
  - Multiples to customers
  - Future Repeatability

Targeting Improvements & Repairs

- Must Understand how faults REALLY work!
- Induced Lightning Flashovers vs. Direct
  - Issues are:
    - Low BIL/CFO
    - Open points
    - Arrester Spacing
    - Failed arresters
    - Grounding on Static Wire Line Designs
- Tree faults require sustained wire to wire contact
  - Lateral limb contact doesn't cause faults
- Animal Contact Points ABOVE the transformer fuse

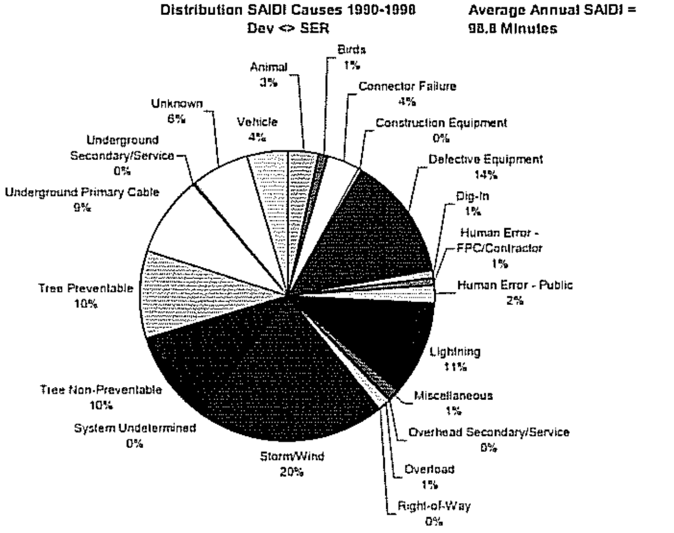
Targeting Reliability Initiatives

- Requires "Data Mining" of outage database
- Looks at specific outaged devices (Fuse, Rcl, Fdr, etc) based on causes
- Considers repeatability of outages
- Majority of outages have low repeatability (10% - 25%)

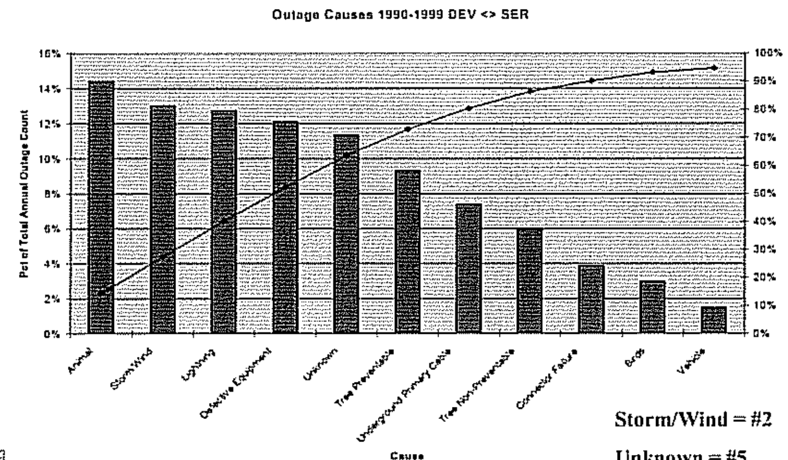
	Outage History	
2003	2004	2005
1	1	1
	2	2
		3
Pattern has 80% probability of Repeat outage in 2006		

Outage Causes

Storm/Wind & Unknown account for 26% of all Outages



Outage Cause Pareto Analysis



Storm/Wind = #2

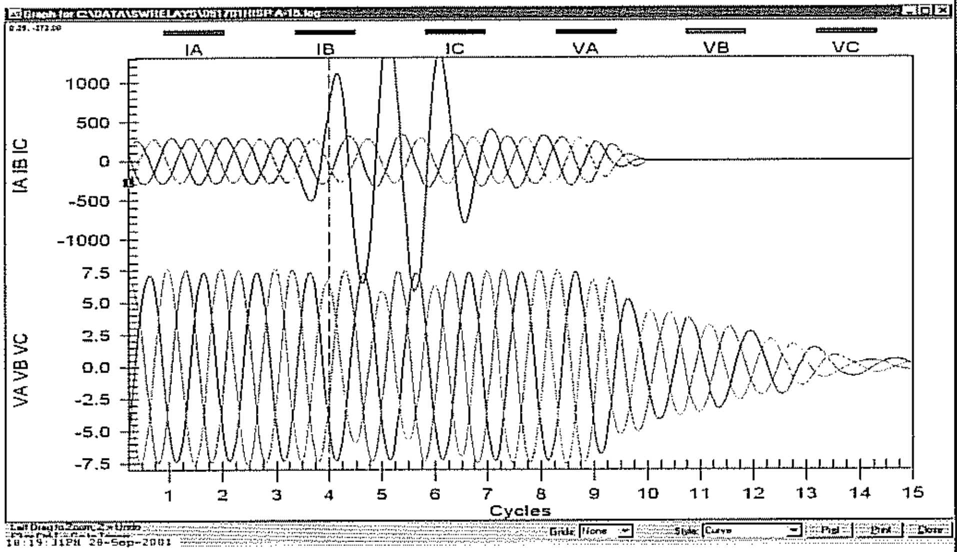
Unknown = #5

90% of Outages = 8 Causes

Unknown or STORM Caused Outages?

- Storm or Unknown are not REAL causes
- They are the result of not finding an identifiable cause
- Many are the result of failures of Fuse Save schemes

Failure of Fuse Save



The "Unknown" Problem

- Unknown caused outages cannot be targeted by a specific program
- Use a Maximum Likelihood Analysis to convert unknowns to a probable cause
- Assumption:
- Requires cause pattern analysis

Outage Cause Analysis

- Unknown or Storm caused outages are difficult to target fixes
- Apply Maximum Likelihood Analysis
  - Causes of unknowns are similar to knowns
  - Actual cause was not found or reported

Maximum Likelihood Analysis

- Uses key characteristics of known causes to develop probable cause tables for unknown cause outages
- Allows determination of probable cause for all unknown or storm/wind outages

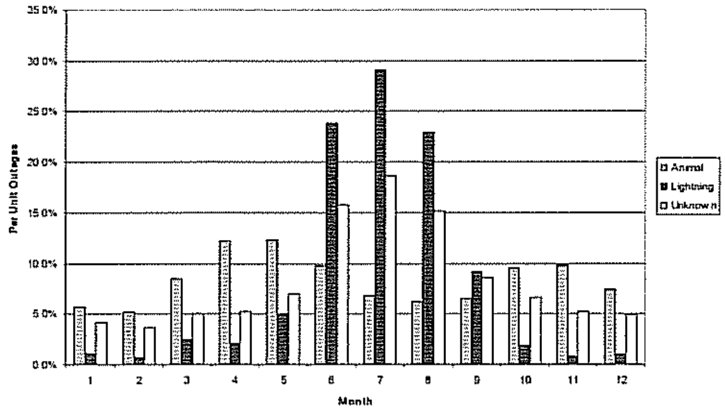
Maximum Likelihood Analysis

- Assumes unknown outages are similar in cause to known outages
- Uses characteristics of known cause outages to estimate causes of unknown outages
- 4 key characteristics used
  - **Month**
  - **Hour**
  - **Device Type (FUS, RCL, etc)**
  - **Weather**

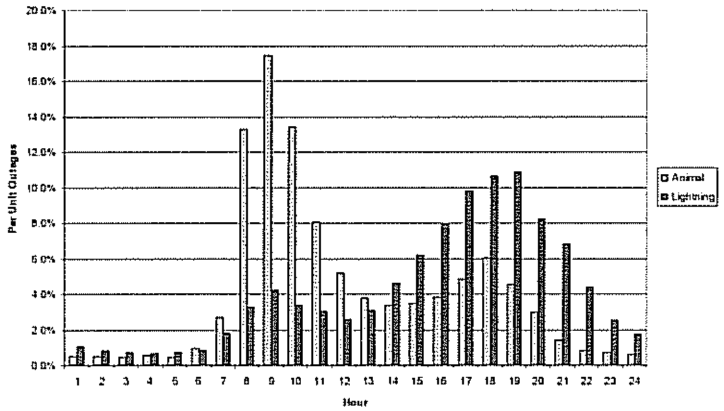
Outage Pattern Analysis

- 3 distinct patterns exist
  - **1. Summer Peakers - Lightning, Trees**
  - **2. Constant Level -Composite (Car hit pole, defective equipment, others)**
  - **3. Spring and Fall Peakers - Animal & Bird**

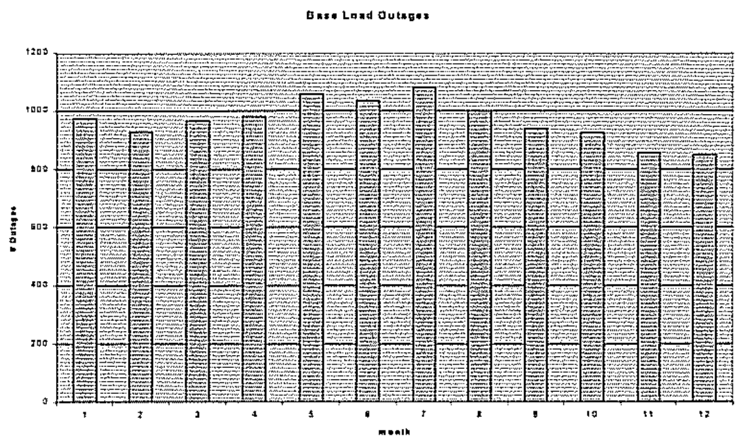
Monthly Outages



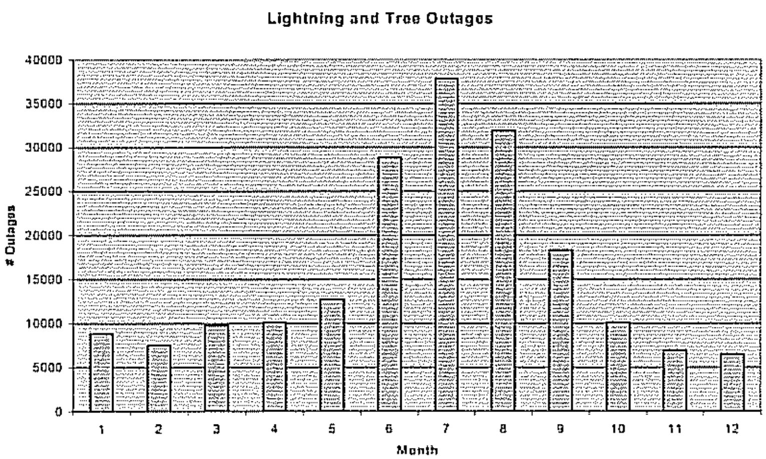
Hourly Outage Patterns



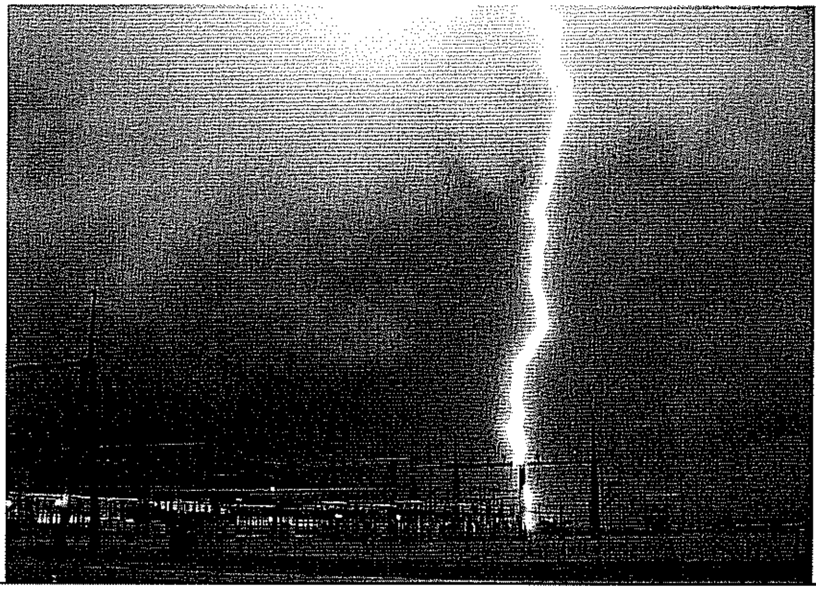
Base Load "Constant" Outages



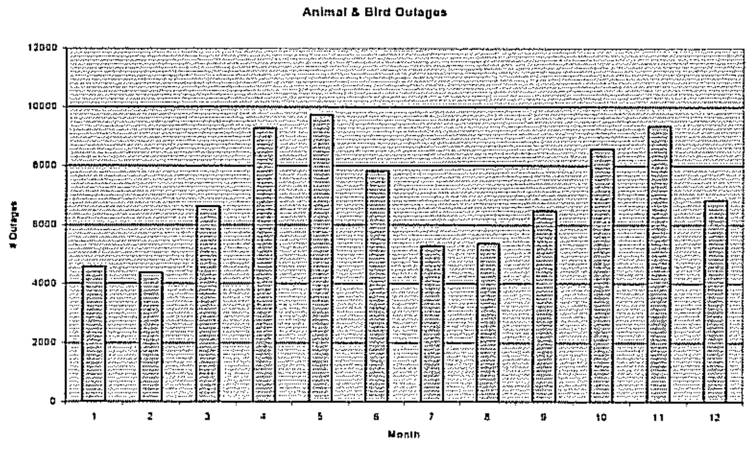
Summer Peaking Outages

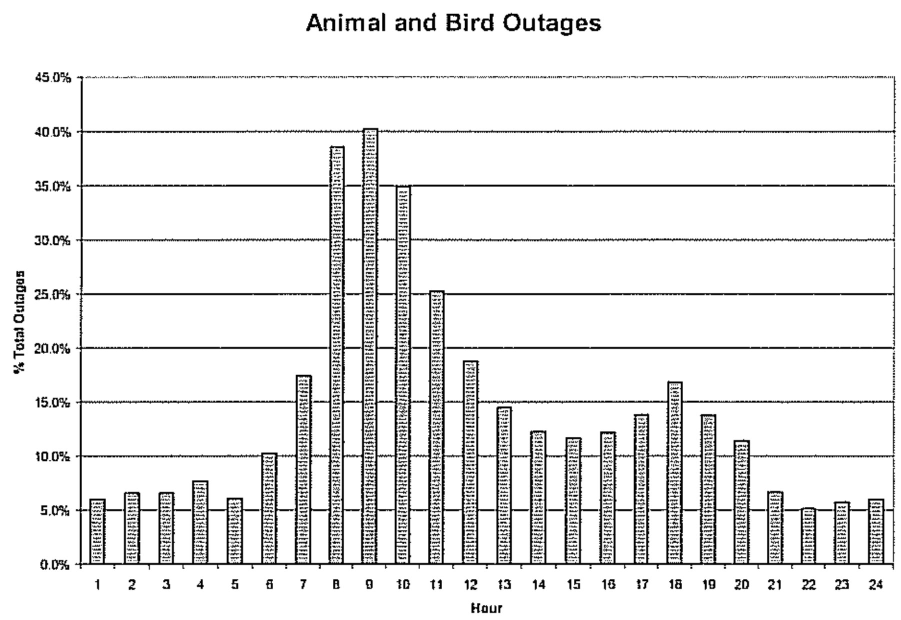


Direct Strike

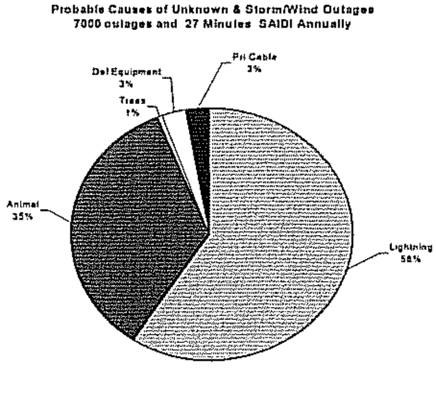


Animal & Bird Outages

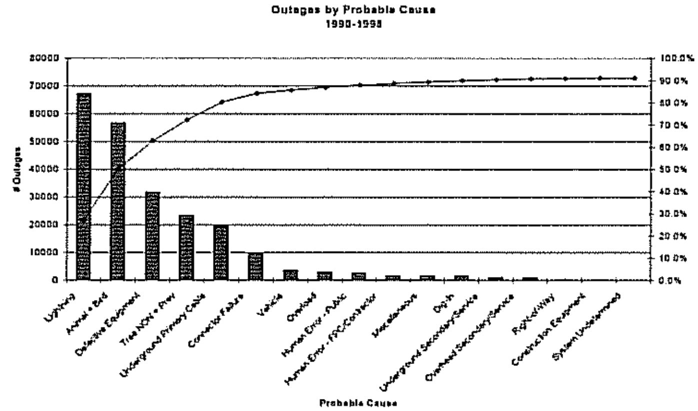


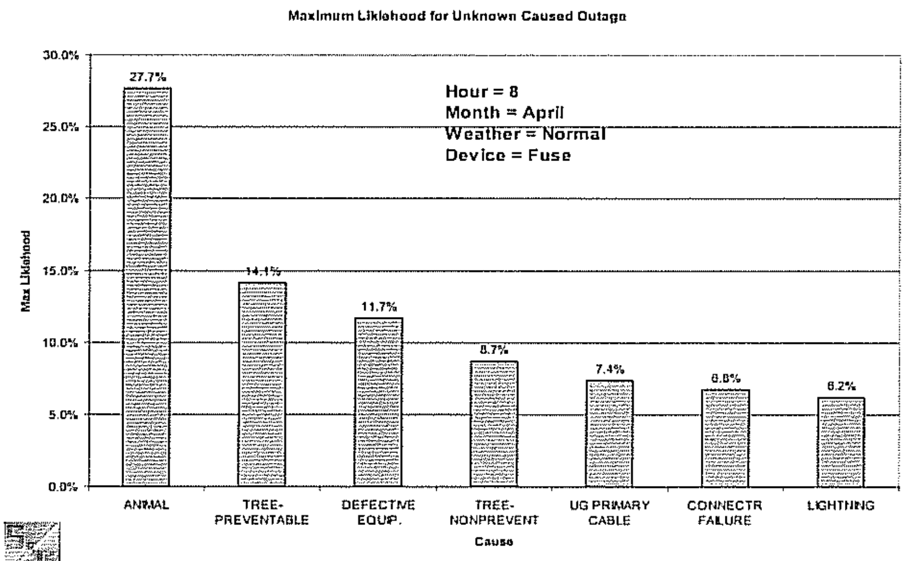


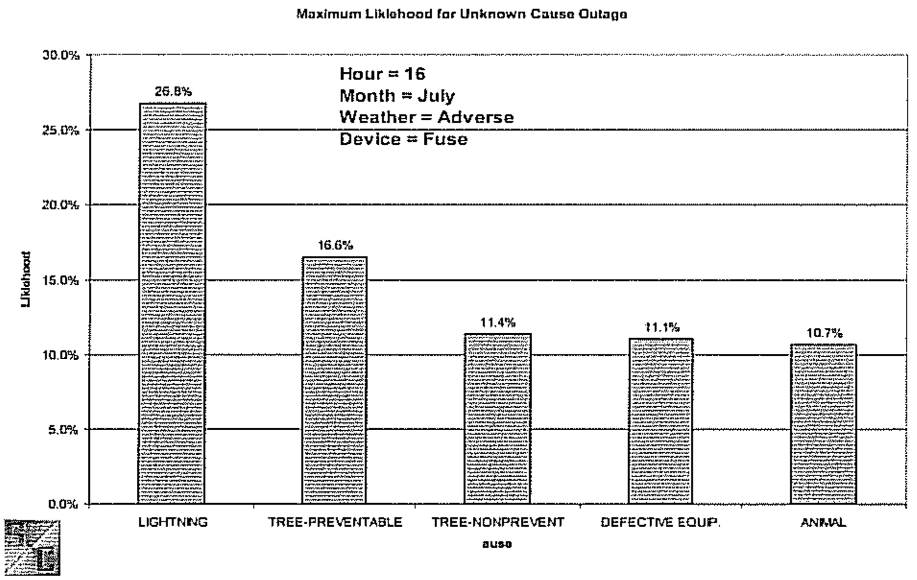
Maximum Likelihood Analysis Results



Outage Probable Cause Pareto

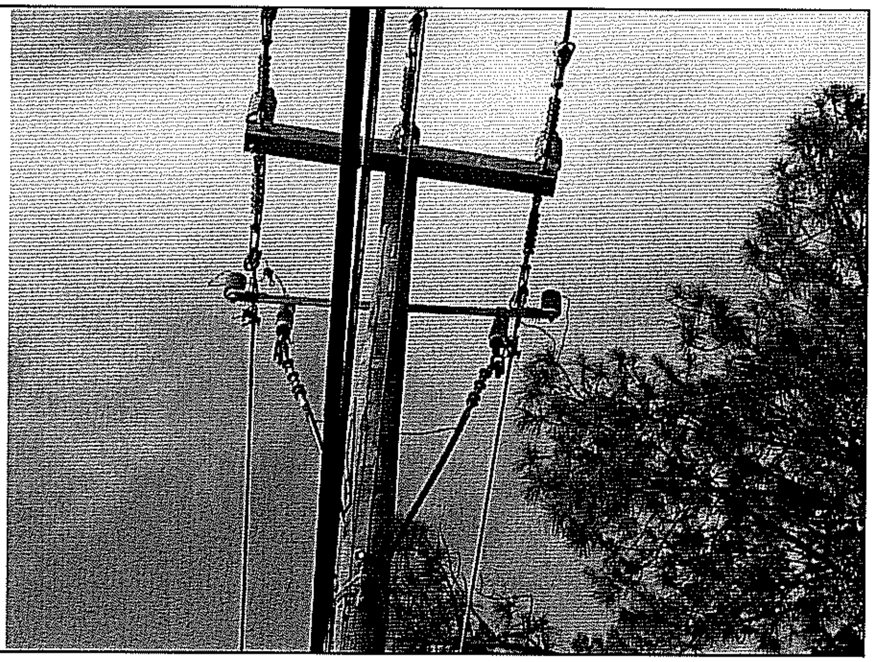


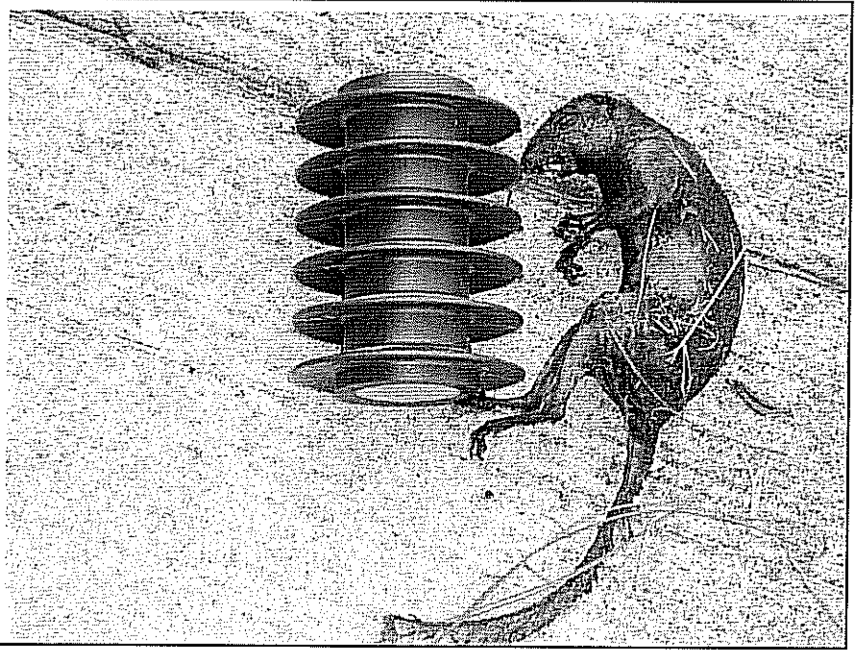




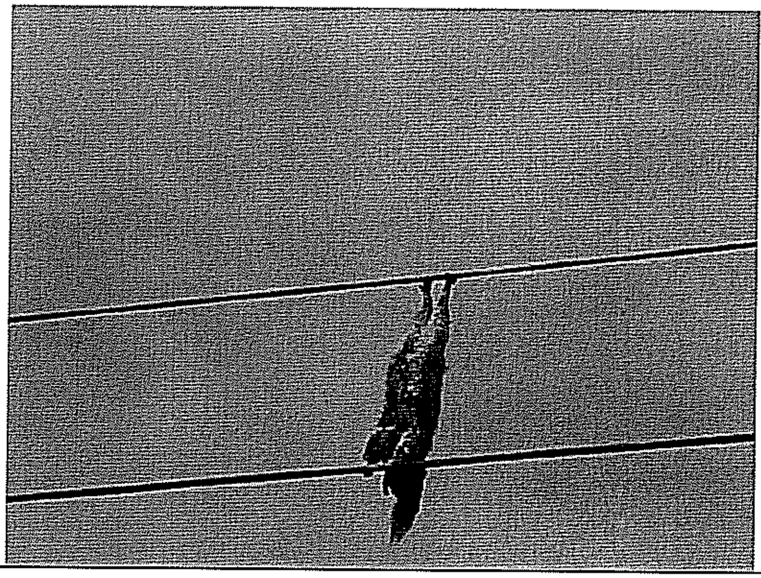
How Faults Happen

- Knowing and understanding how faults happen is essential to targeting reliability improvements
- Field personnel (engineers & line personnel) must be trained in how faults work
- This can make or break fault prevention initiatives





Permanent Animal Fault



"Effective"

Tree Trimming

Training is a Must

- Engineers and Line Personnel MUST understand HOW FAULTS WORK to effectively implement programs
- Beware of common perceptions about this!
- System wide training is required
- Videos and Photos are helpful

Improved Targeting of Programs

- Use Probable Cause for :
  - "Unknown"
  - " Storm" or Weather
  - Other Undefined Cause Outages
- Optimize the funds spent on all programs as an integrated effort
- Achieve the most cost effective mix of programs

Results

- Reliability Program Cost effectiveness was doubled when compared to initial "gut feel" approach
- Management presented with probability estimates of costs and benefits of an integrated program.
- This approach results in an integrated reliability improvement program that optimizes the cost effectiveness of the improvements by allocating appropriate $ to each initiative
- This technique was applied to a 3 year reliability improvement program that drove SAIDI from 123 to 78 for a major electric utility