Introduction to Aging Assets Analysis

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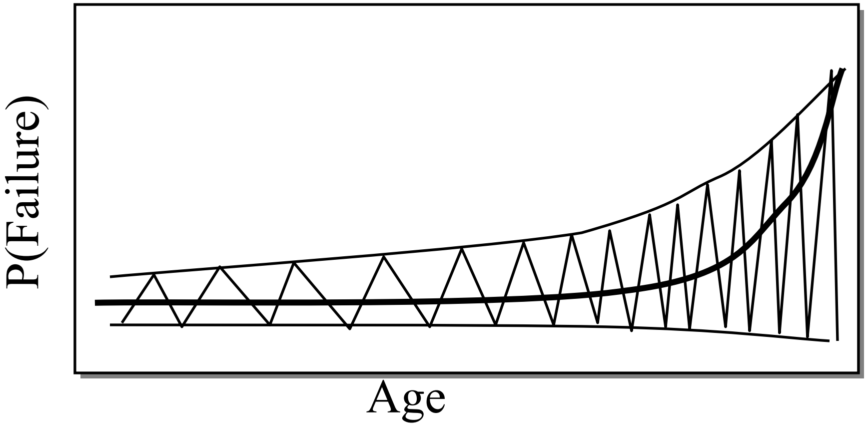
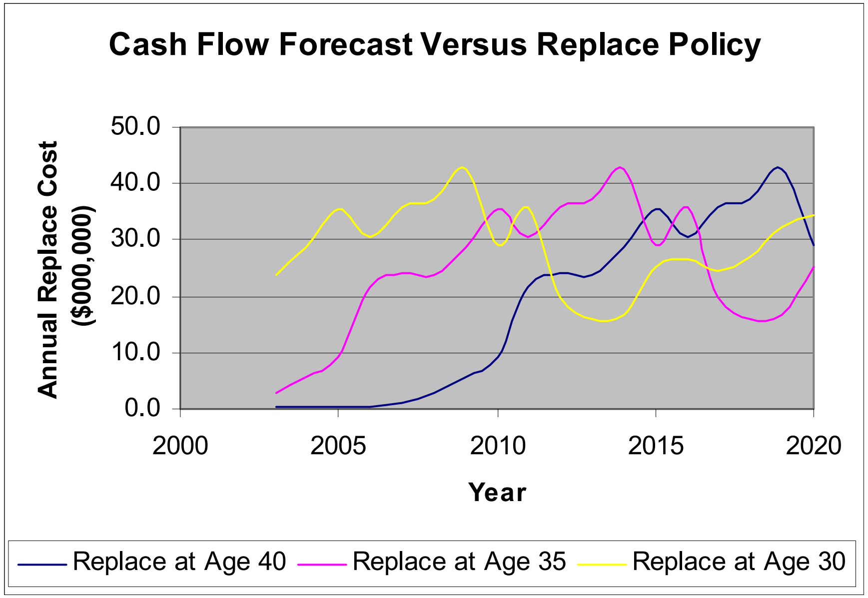
Outline

- ⇨ Introduction
- Analytical Method
- Aging Assets & RCM
- Breaker Study

Two Fundamental Problems

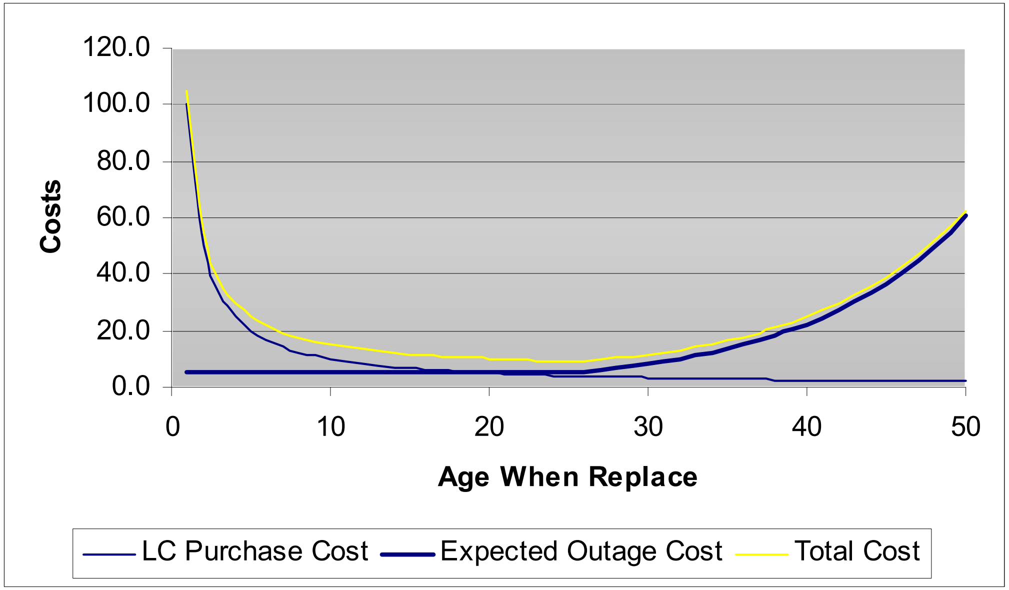
- Optimal maintenance and replacement policy
  - Varies by asset class
  - Based on age, performance, and condition information for individual assets
- Cash flow planning
  - Least cost replacement of infrastructure inventory
  - Long term financial planning
  - Policy based on maintenance and replacement policy for individual assets





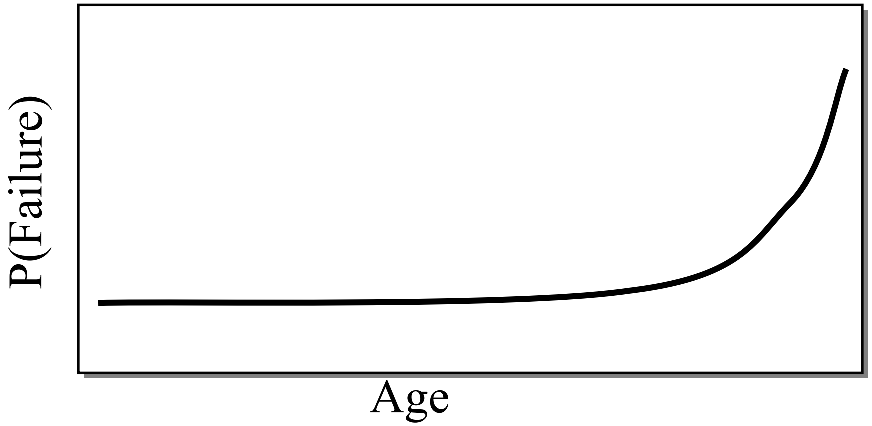
Start With Simple Model of Repair / Replace

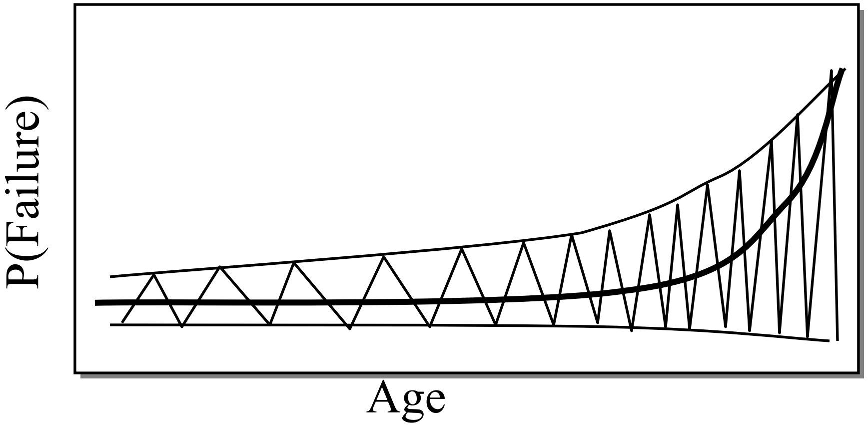
- Life cycle purchase cost = f(purchase cost / age when replace)
- Expected Outage Cost = f(p(failure) * cost failure)
- Assumes only variable for predicting true state of machine {p(failure)} is age
  - Age is only state variable
  - What about other state variables?
  - P(failure) = f(non-observables)



Key to Developing Replace Policy is Predicting failure

- Start with bathtub curve
- Add uncertainty
- Add non-age state variables (predictors)
  - Diagnostics
  - Inspections
  - Etcetera





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A3 System – Summary of Analytical Method

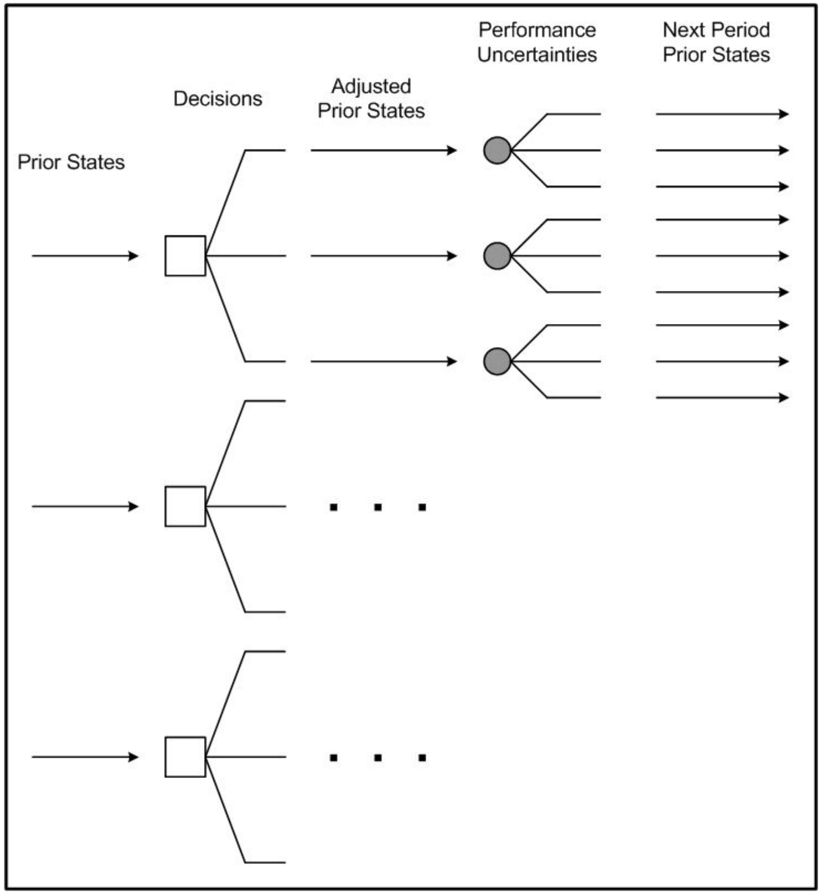
- Solving the repair / replace problem requires answering the following question:
  - given an asset type (e.g., transformers, cables, poles, etc.),
  - a set of asset characteristics (Age, Condition, Failure modes Uncertainties in future performance, Observables and Unobservables, Costs), and
  - a set of alternatives (Repair, Replace, Rebuild, Refurbish, Test, Maintain),
- what should we do, when, and under what conditions?

Analytic Method – Model Structure

- The user must specify the asset type, asset characteristics and decision alternatives
- Based on user inputs, creates a decision tree
- The tree is defined by a series of decision stages. Each stage has three decision components:
    - possible conditions immediately prior to a decision,
    - a set of decision alternatives,
    - the conditions immediately following the decision.
    - These components occur at the beginning of a decision stage

Analytic Method – Model Structure

- A decision stage is defined by a period of time of one or more years.
- After the decision is made time passes and conditions change (age and technology performance).
- The three decision components are labeled prior state, decision and adjusted prior state



Model Mechanics

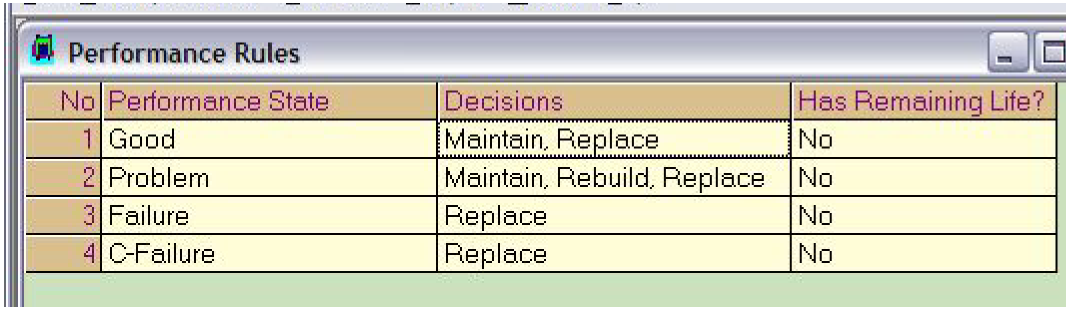
- States in the system are defined by technology type, effective age and performance
- Typical decision alternatives are rebuild, maintain and replace.
- Prior State might be technology A, age 10 years, performing badly.
- The model requires that the user define technology types, performance states and decision alternatives.

Model Mechanics – cont.

- Given a set of prior conditions (Prior State), a decision is made
- Based on this decision, using a set of user specified rules, the Prior State is modified to produce the Adjusted Prior State
    - For example, a decision to maintain might have no effect on effective age, technology or technology performance.
    - However, replacing a poorly performing technology would change effective age, performance and perhaps even technology type.
- After the adjustments to state, the model calculates a Prior State for the next stage and jumps to that stage.

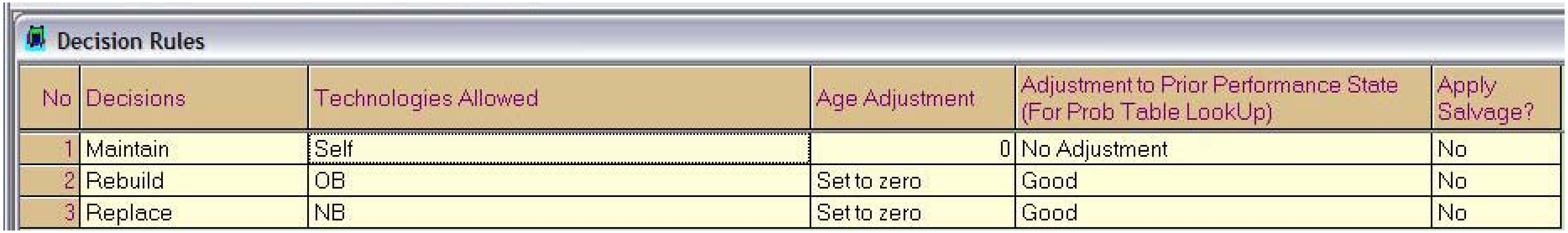
Model Mechanics cont.

- Model specification requires that the user define technologies, technology performance states and decision alternatives.
- Specification also requires defining rules associated with
  - performance states
  - decisions



Performance Rules

No	Performance State	Decisions	Has Remaining Life?
1	Good	Maintain, Replace	No
2	Problem	Maintain, Rebuild, Replace	No
3	Failure	Replace	No
4	C-Failure	Replace	No

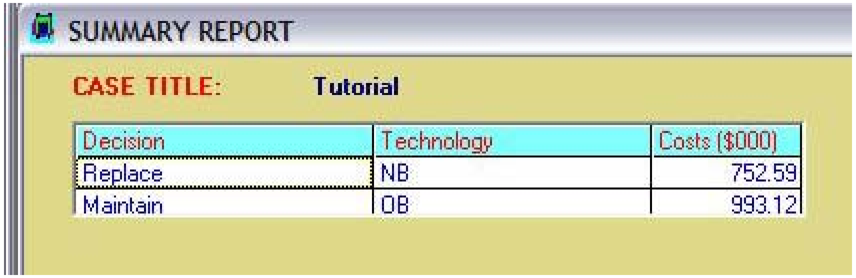


Decision Rules

No	Decisions	Technologies Allowed	Age Adjustment	Adjustment to Prior Performance State (For Prob Table LookUp)	Apply Salvage?
1	Maintain	Self	0	No Adjustment	No
2	Rebuild	OB	Set to zero	Good	No
3	Replace	NB	Set to zero	Good	No

Model Outputs – a least cost policy

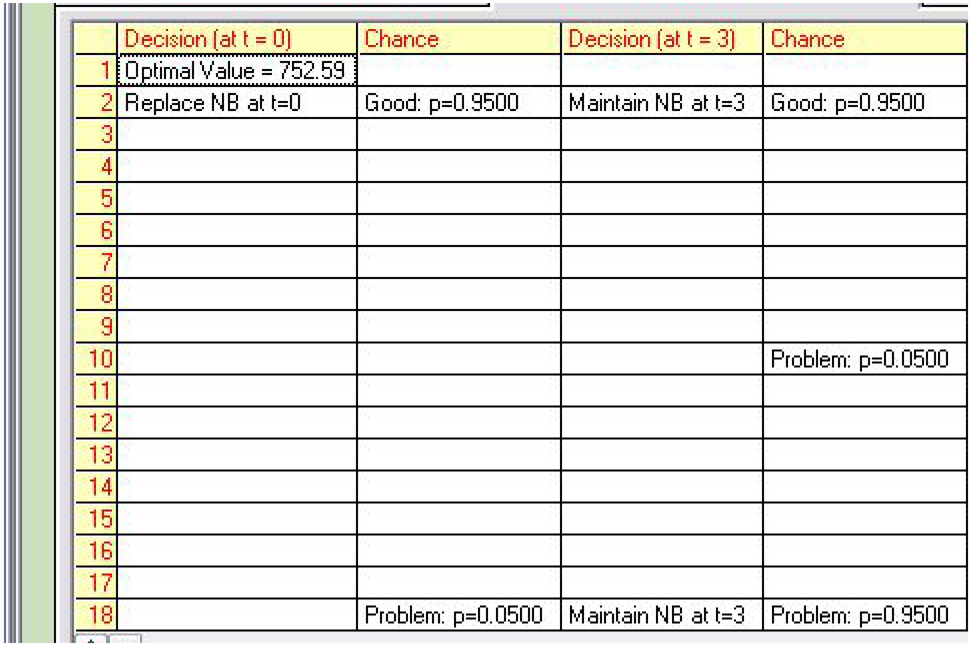
- A set of decisions conditional on asset age and condition



SUMMARY REPORT

CASE TITLE: **Tutorial**

Decision	Technology	Costs ($000)
Replace	NB	752.59
Maintain	OB	993.12



	Decision (at t = 0)	Chance	Decision (at t = 3)	Chance
1	Optimal Value = 752.59			
2	Replace NB at t=0	Good: p=0.9500	Maintain NB at t=3	Good: p=0.9500
3				
4				
5				
6				
7				
8				
9				
10				Problem: p=0.0500
11				
12				
13				
14				
15				
16				
17				
18		Problem: p=0.0500	Maintain NB at t=3	Problem: p=0.9500

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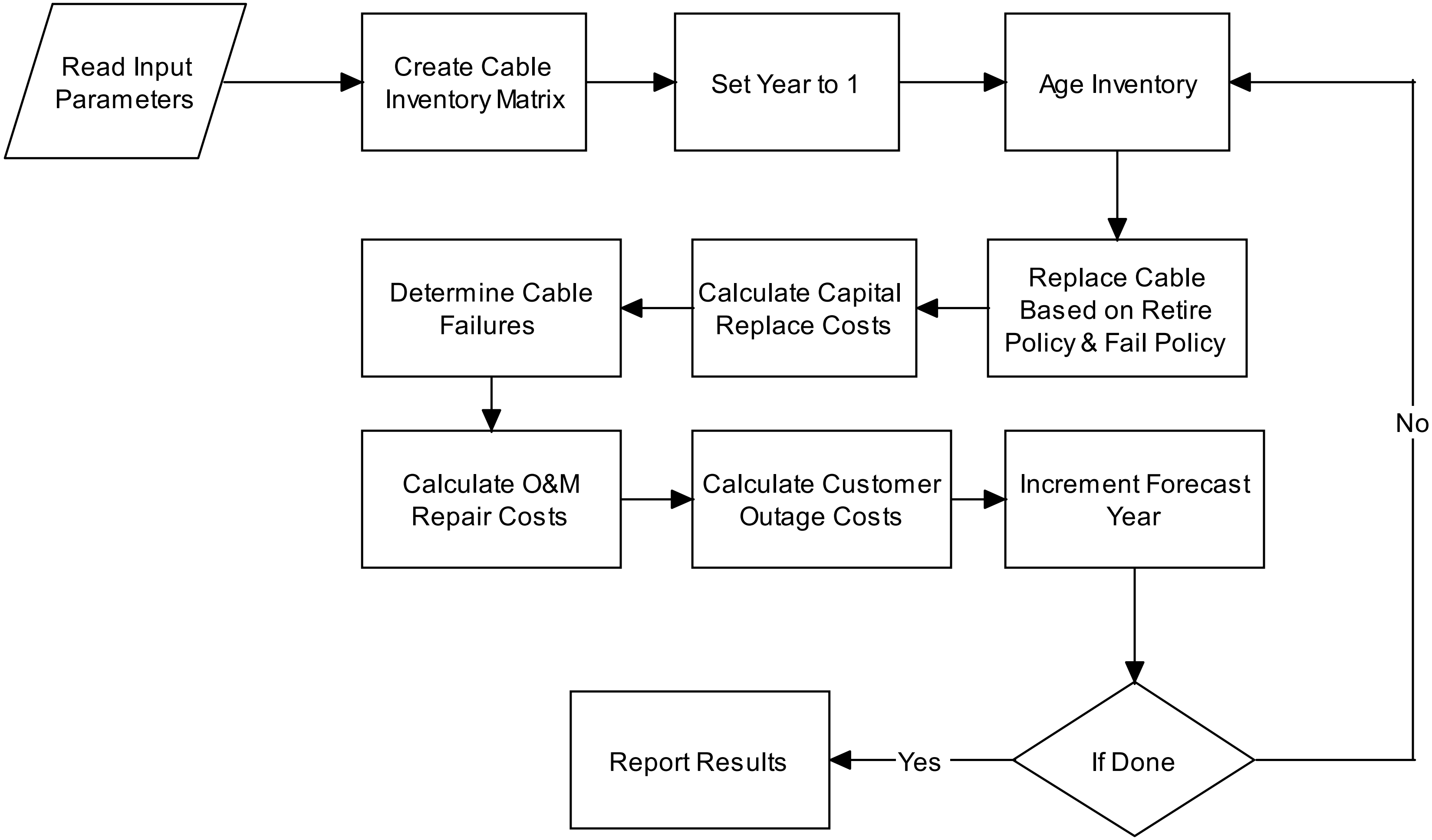
Optimal Population Management – Cash Flow Modeling

- Compare optimal policy (replacement interval plus allowable failure history)

and

- Non-replacement (continued repair)
- Variation by type
- Variation by capital cost, o&m, customer values

Asset Inventory Management Model Logic



Population Hazard Function -- Example

- A1: Failures:

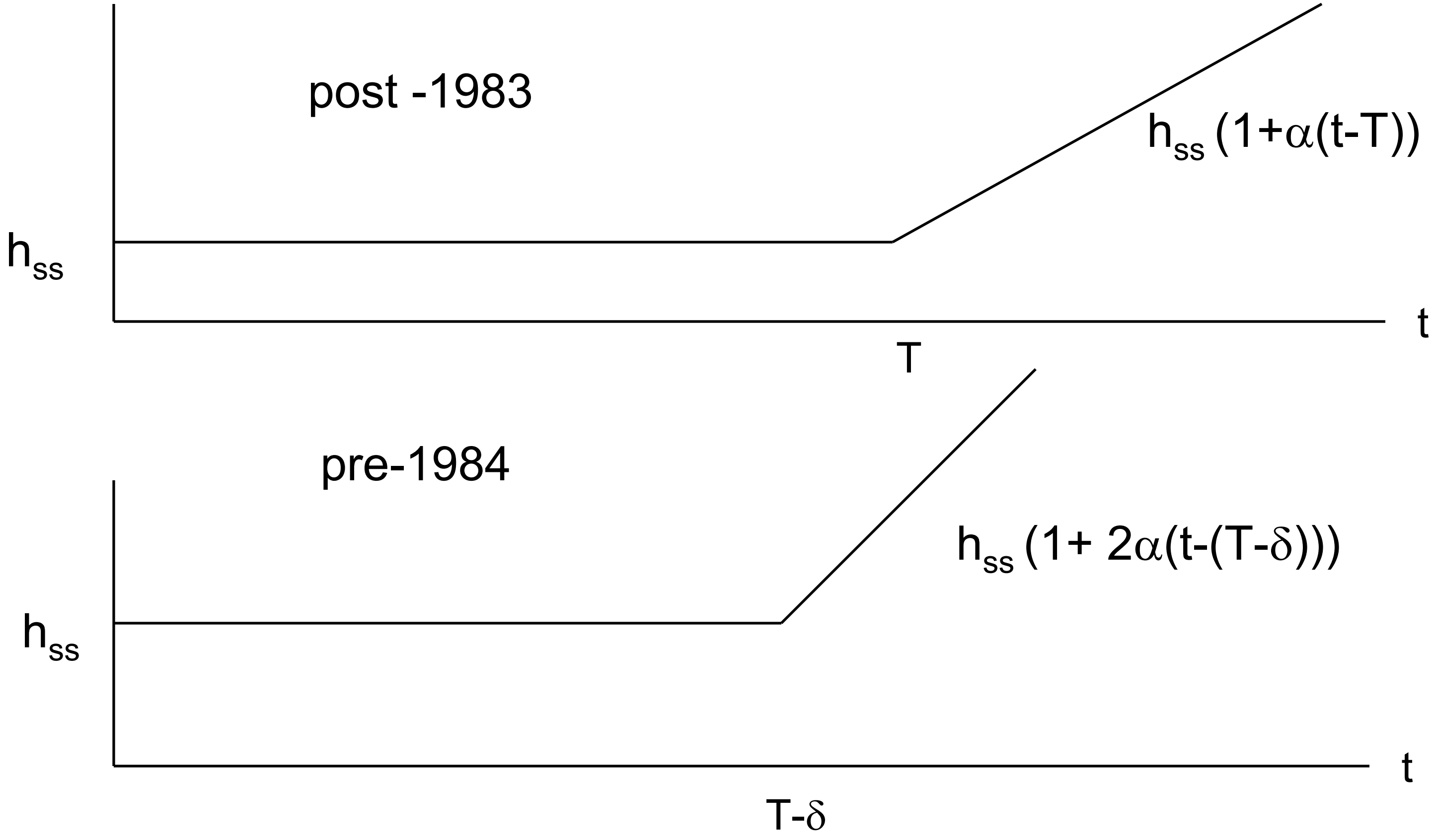
2AWG	1/0	2/0	4/0	500	750	
394		152	61	24	*	28

- A2: 85% of failures occur in cable installed prior to 1983 (non-tree retardant)
- A3: 16% of failed segments experience additional failure in the same year

* 500 assumed to fail as 750

Hazard Function (cont'd)

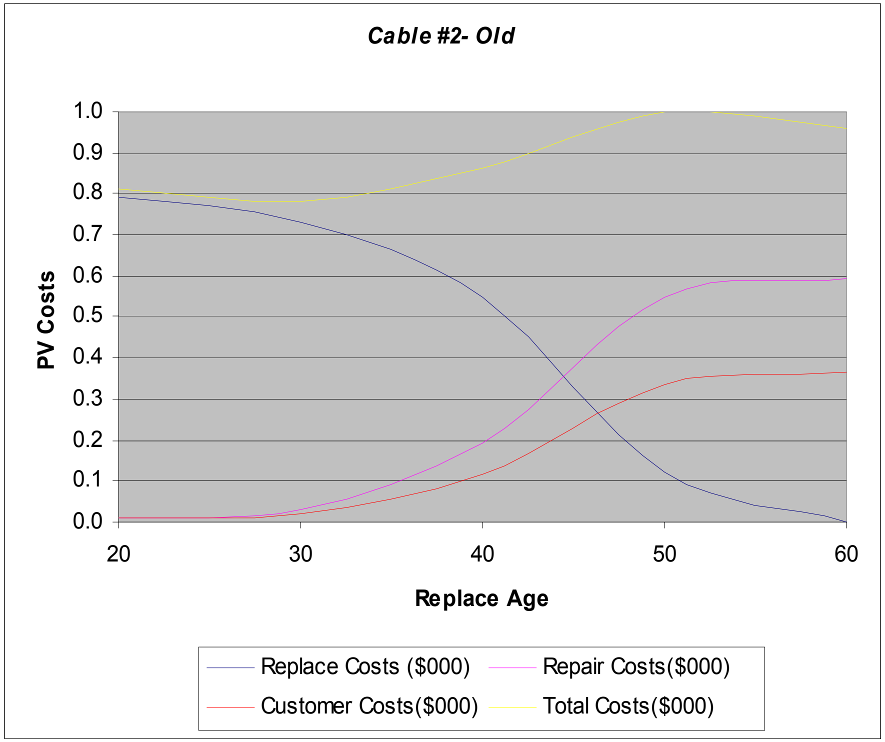
- A4: Two functional forms

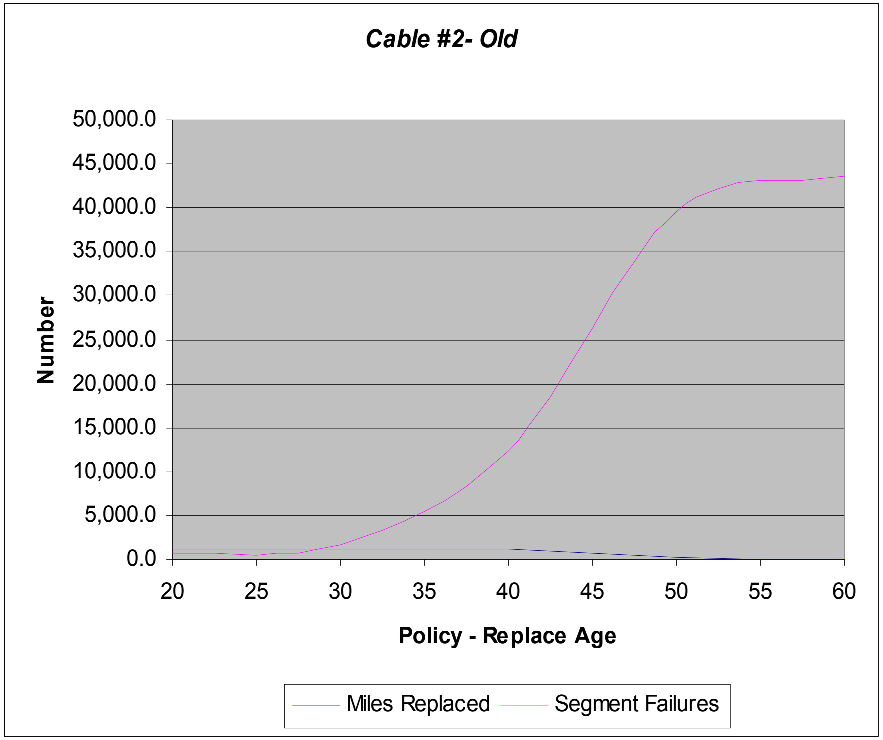


Sample Results Summary – Optimal Management of Cable Inventory

Cable Type	Optimal Policy	PV Costs
#2 Old	40 Years, 2 Fails	1.0
#2 New	50+ Years, 3 Fails	.02
750 Old	30 Years, 3 Fails	.29
750 New	50+ Years, 3 Fails	.01

Sample Results - #2 Cable Old





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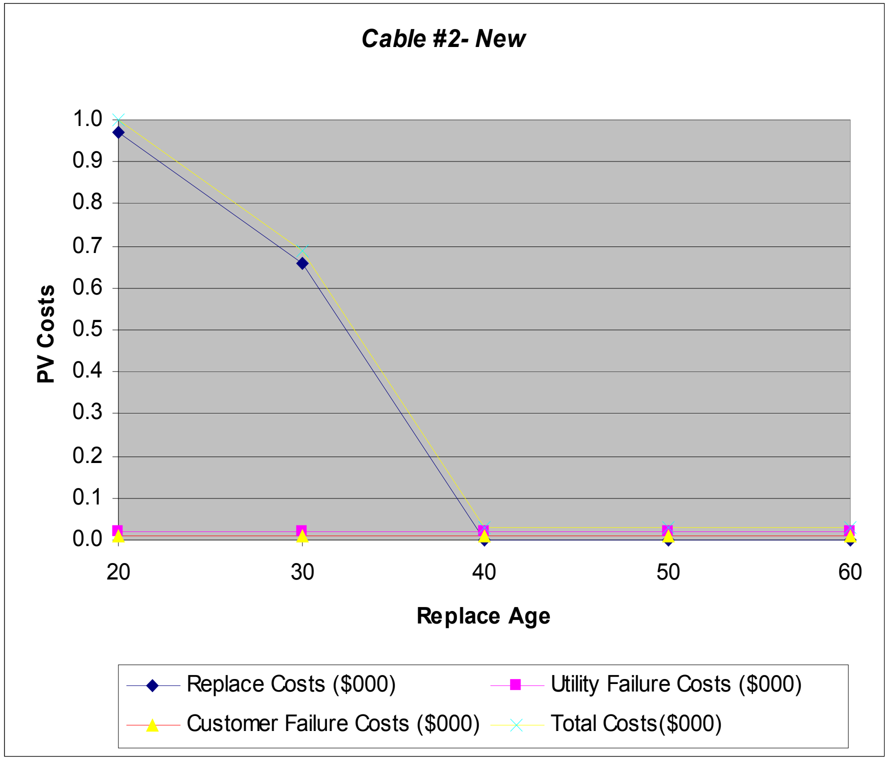
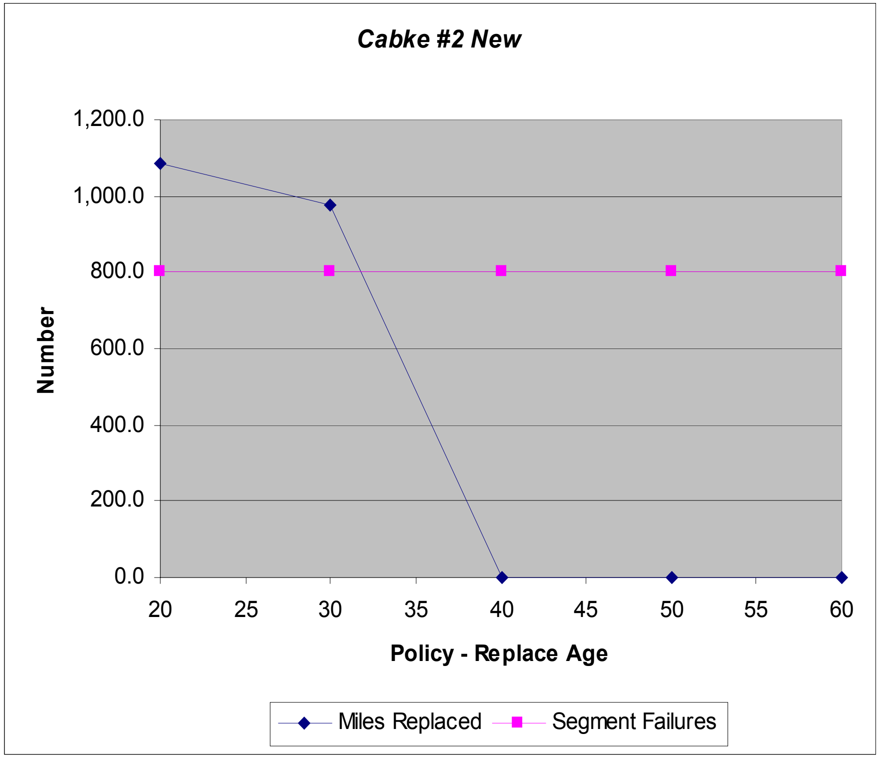
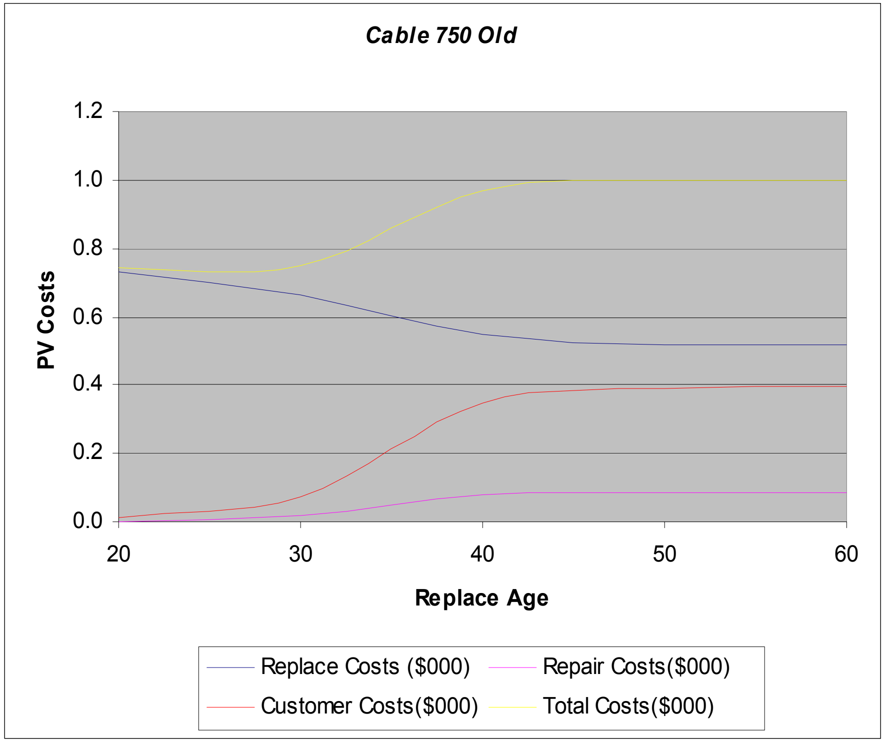
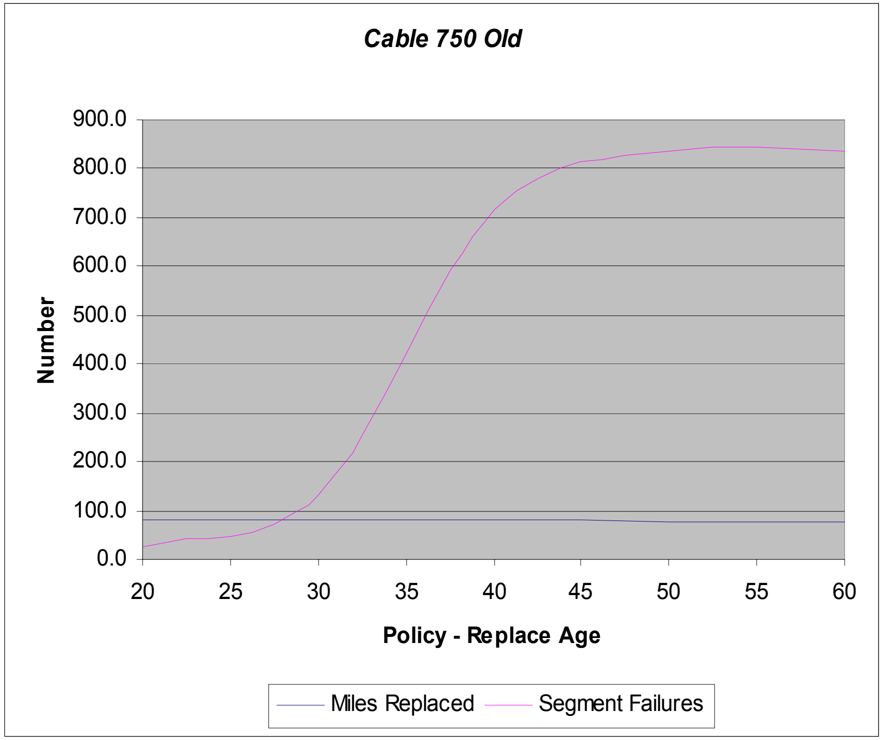




Sample Results - 750 Cable Old





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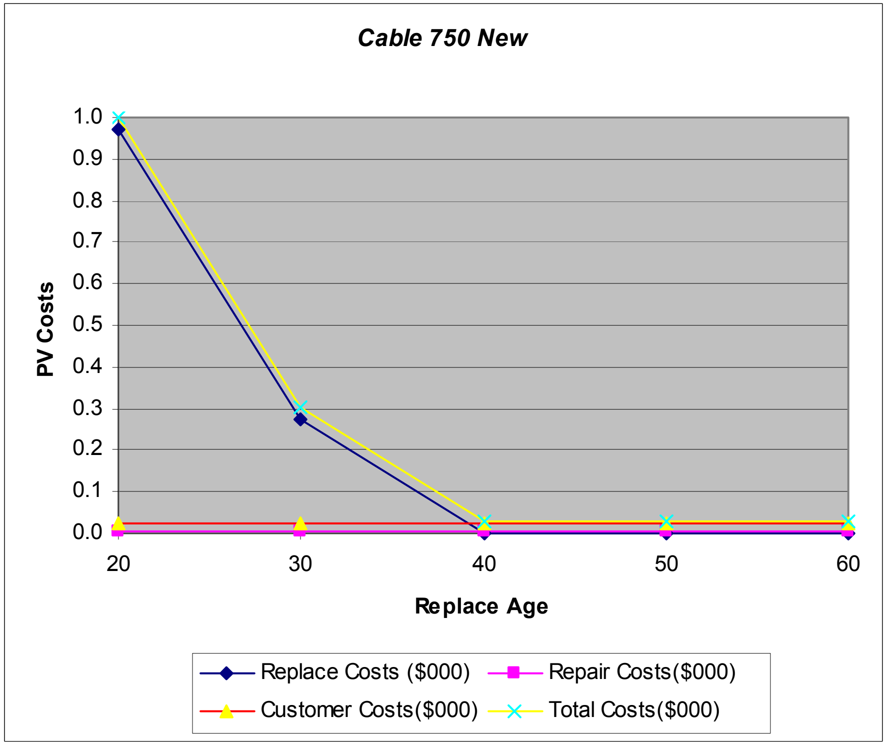
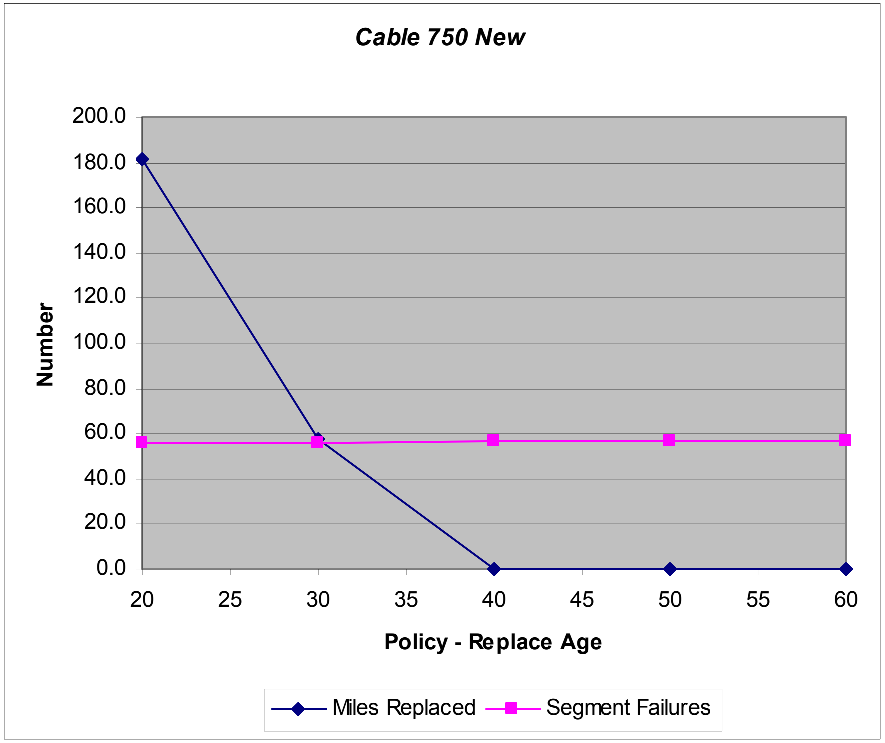
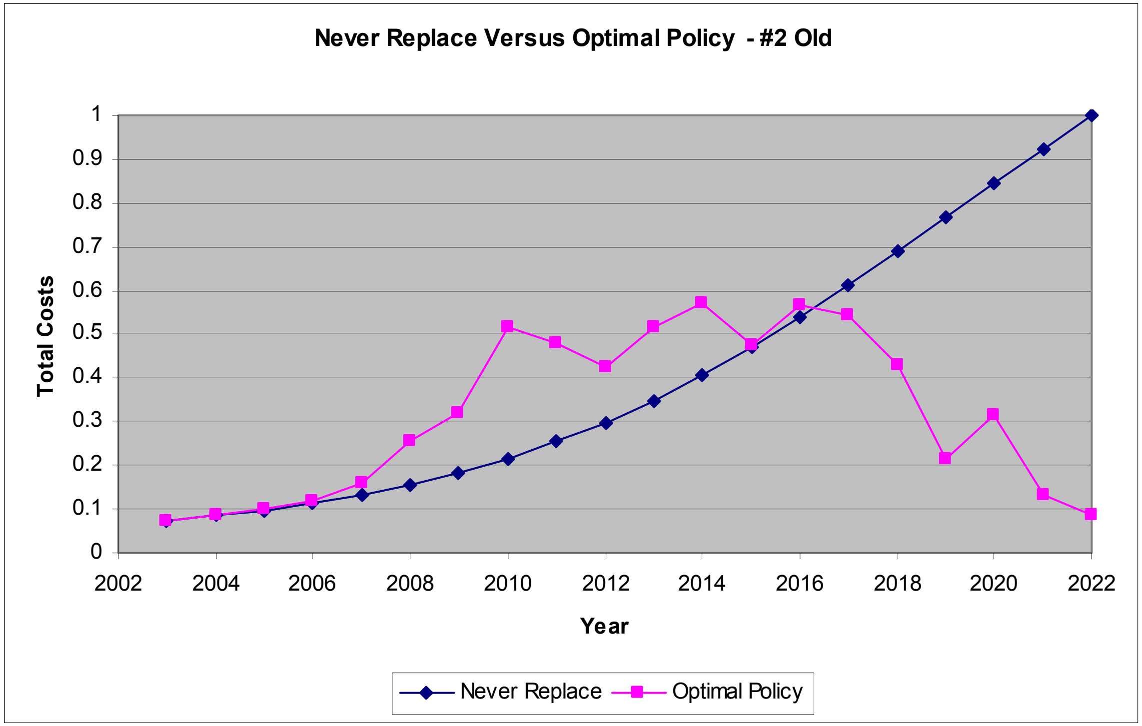




Sample Results - Total Costs - Continued Repair & Optimal Replace – #2 Old



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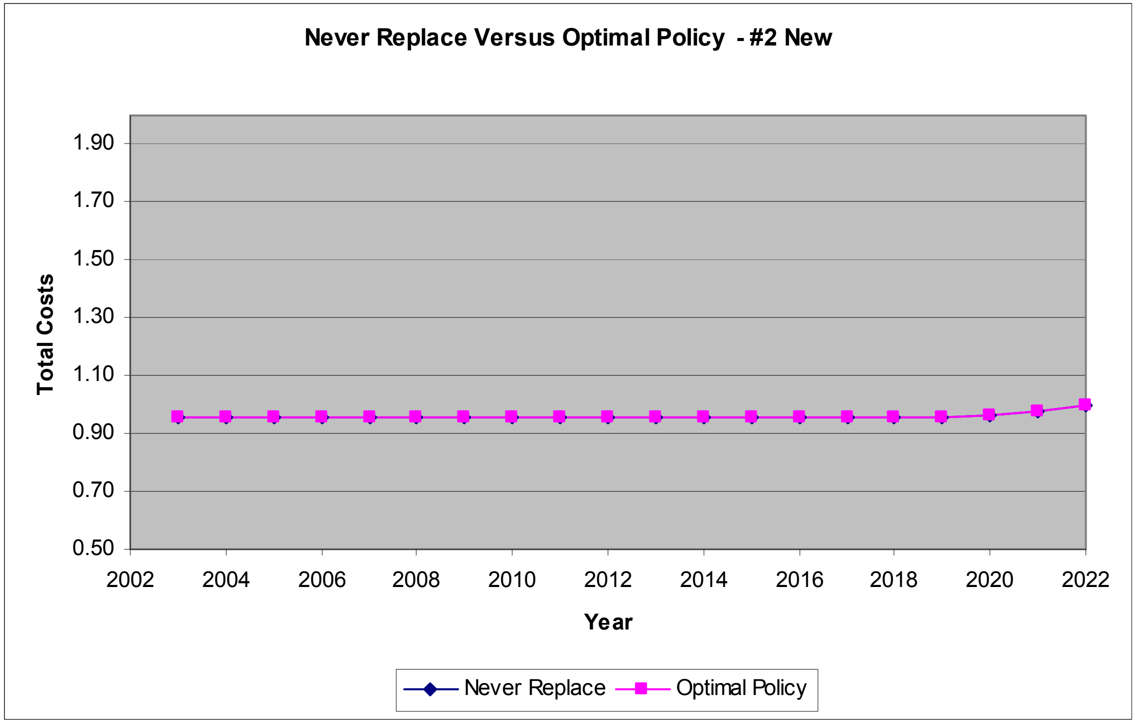
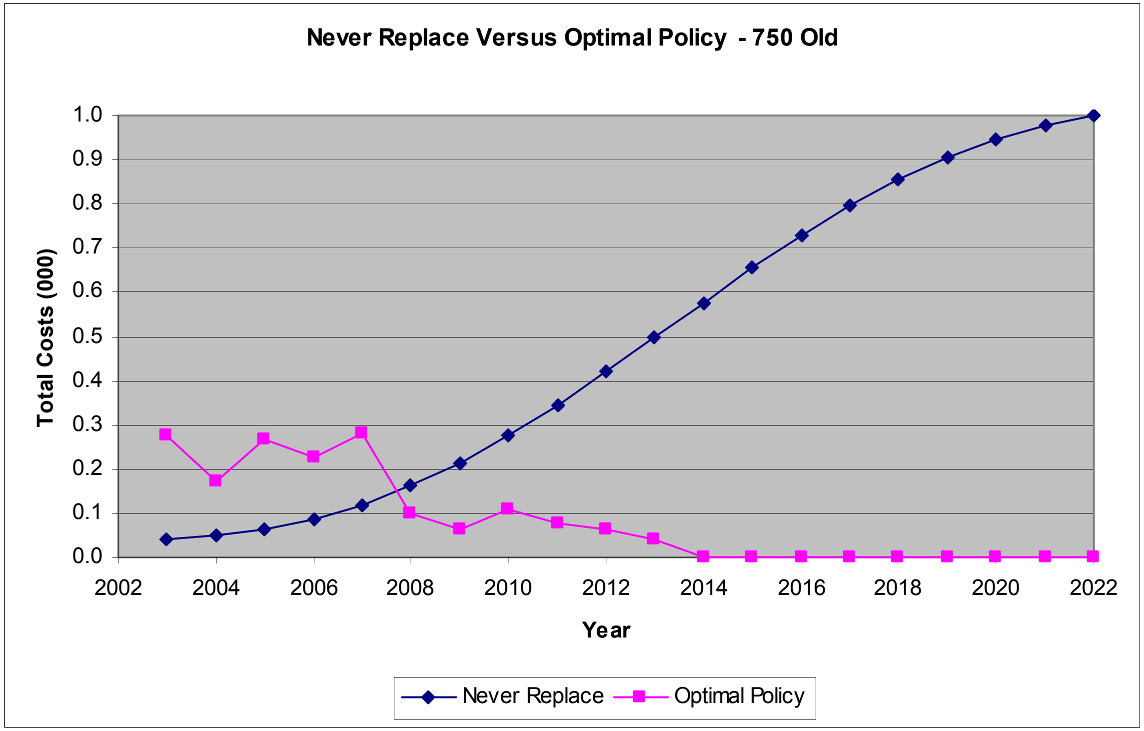
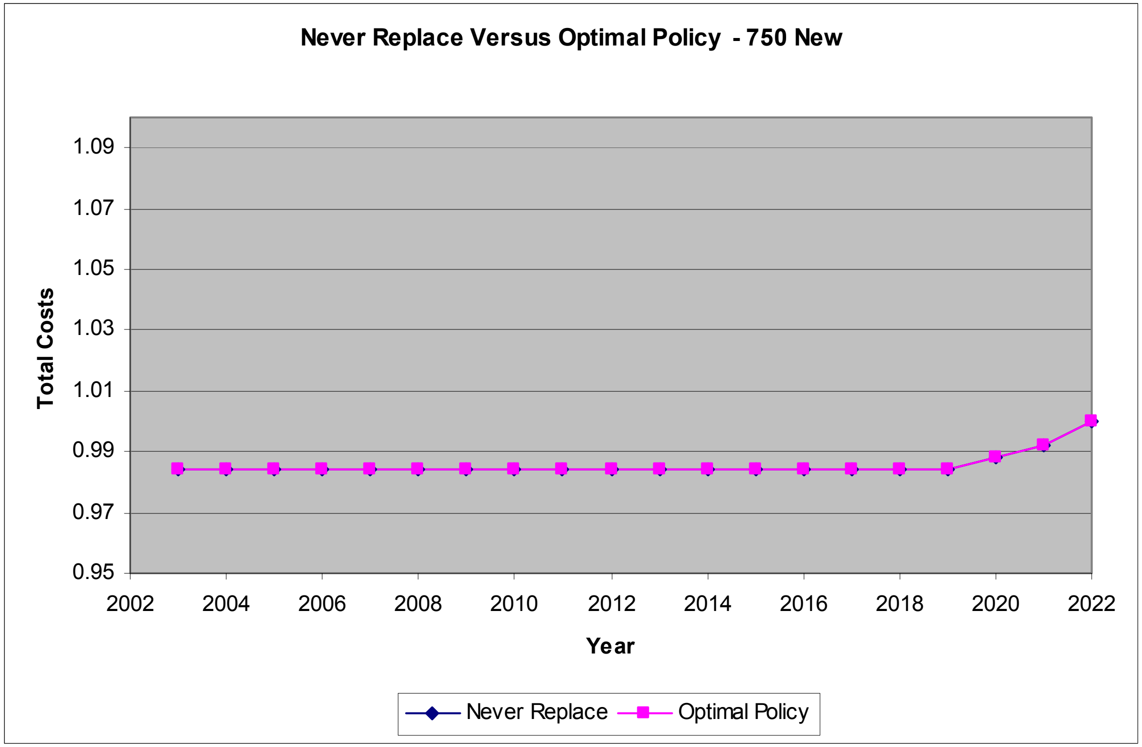


Sample Results - Total Costs - Continued Repair & Optimal Replace – 750 Old



Sample Results - Total Costs - Continued Repair & Optimal Replace – 750 New



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RCM

RCM Approach

- Do cheap and easy
- Prevent failure modes that have catastrophic consequences
- Wait for squeaks

RCM Tasks

- Identify the System
- Decompose into subsystems
- Identify failure modes of subsystems
- Identify maintenance tasks related to failure modes
- Identify consequences of failure modes
- Select maintenance tasks based on risk assessment and cost of maintenance
  - Check oil & water, lube chain
  - Change oil, clean air cleaner
  - Wear helmet

Repair / Replace - RCM

RCM – Operations

- Minimize maintenance cost while providing a reasonable level of system function
- Aimed at preserving function
- Implicitly long-term economic evaluation
  - no explicit analysis of the LT consequence of a policy

Repair / Replace – Strategy

- Identify a policy that minimizes the expected long-term costs of providing a function
- Based on costs, risks, changes in technology
- Driven by uncertainties
  - Occurrence of failure – will it fail?
  - Don’t know the likelihood of failure - what hazard function?
  - True state of asset?
  - Information provided by diagnostics?

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Breaker Case Background

- Air Breakers:
  - installed in 138—230—500 kV transmission system
  - Inventory in system: 25 or 26 air breakers; all approximately 30 years old. None has failed yet.
- Two failure modes
  - *catastrophic mode*: pressurized porcelain tube blow up and shatters, scattering parts up to 700 feet away
  - *non-catastrophic* mode:
    - Breakers develop air leaks which will induce compressor failures
    - cause is worn parts, such as aging gaskets. The critical time for this
    - failure mode is dependent on asset age -- appears to be in the range 8-10 years

Background cont’d

- The impact of a failure on customers varies
- The current maintenance cycle
  - yearly inspection and maintenance
  - special procedures every three, four, six, and nine years
  - field rebuild every nine years

Decision Problem

- The problem: Company does not have a repair / replace policy for air breakers
  - when to replace air breakers,
  - when to rebuild them
  - when to maintain
  - how best to treat air breakers that exhibit poor performance
- Objectives:
  - Develop repair replace policy old air breakers that minimizes life cycle costs including customer and utility costs
  - Evaluate the current policy of rebuilding air breakers on a nine-year cycle

Decision Problem - cont.

- Decision - what to do with an old breaker?
  - maintain the breaker without rebuilding it
  - rebuild the breaker in place, which costs approximately $150,000
  - refurbish the breaker in a shop
  - purchase a new breaker, which costs approximately $300,000.
- Uncertainties (and relevant parameters describing uncertainties):
  - Probability of failure of new and old breakers as function of age
  - Probability of failure as a function of time since rebuild
  - Probability of failure conditional on a breaker performance - good or problem

Analysis - Approach

- A multi-stage decision tree was used to evaluate and identify the least-cost repair / replace strategy.
- Under this approach the user specifies all decisions, uncertainties and outcomes
- The method identifies the set of decisions over time that meet the objective

Analysis - Inputs

- Types of technology
  - Old breaker
  - New breaker
- Policy decisions: maintain, rebuild, replace with new
- Technology performance states:
  - Good
  - Problem
  - Failure
  - C-failure
- Decision stages: 8 stages, each stage is 3 years in length
  - Make a decision on a breaker then revisit every three years
  - Model behavior for 24 years

Inputs con’d - Probability Tables
Old Tech. Performance

Technology Performance Probabilities
(Old Breakers, Prior Performance = Good)

	Breaker Age (Decision Stage)					
Perf. State	*1-3*	*4-6*	*7-9*	*10-12*	*13-15*	*16-18*
Good	0.8	0.75	0.6	0.4	0.4	0.4
Problem	0.15	0.15	0.2	0.3	0.3	0.3
Failure	0.05	0.05	0.15	0.2	0.2	0.2
C-failure	0	0.05	0.05	0.1	0.1	0.1

Technology Performance Probabilities
(Old Breakers, Prior Performance = Problem)

	Breaker Age (Decision Stage)					
Perf. State	*1-3*	*4-6*	*7-9*	*10-12*	*13-15*	*16-18*
Good	NA	0	0	0	0	0
Problem	NA	0.7	0.65	0.5	0.5	0.5
Failure	NA	0.25	0.3	0.4	0.4	0.4
C-failure	NA	0.05	0.05	0.1	0.1	0.1

Inputs con’d - Probability Tables New Tech. Performance

Technology Performance Probabilities
(New Breakers, Prior Performance = Good)

Perf. State	*1-3*	*4-6*	*7-9*	*10-12*	*13-15*	*16-18*
Good	0.95	0.99	0.99	0.99	0.99	0.95
Problem	0.05	0.01	0.01	0.01	0.01	0.05
Failure	0	0	0	0	0	0
C-failure	0	0	0	0	0	0

Technology Performance Probabilities
(New Breakers, Prior Performance = Problem)

Perf. State	*1-3*	*4-6*	*7-9*	*10-12*	*13-15*	*16-18*
Good	NA	0	0	0	0	0
Problem	NA	0.95	0.95	0.95	0.9	0.9
Failure	NA	0.05	0.05	0.05	0.1	0.1
C-failure	NA	0	0	0	0	0