



**S.CHAPEL ASSOCIATES**

ANALYTIC SOLUTIONS TO ASSET MANAGEMENT

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# *Aging Assets and the Value of Diagnostic Tests*

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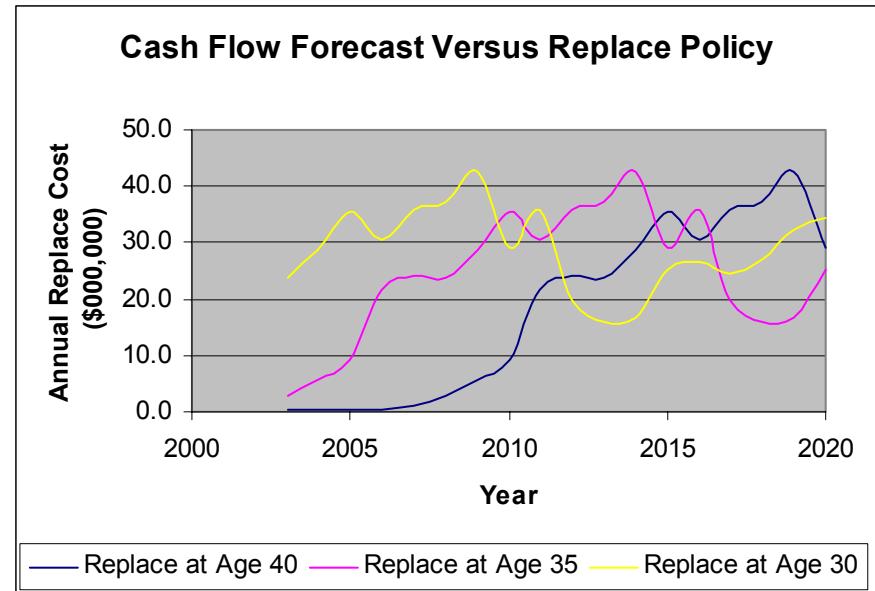
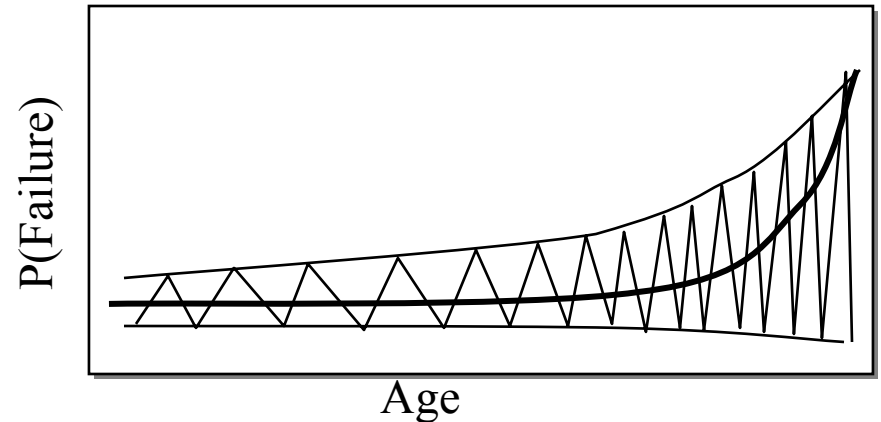
# *Presentation Outline*

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- ➡ • Defining the repair or replace problem
- An example analysis

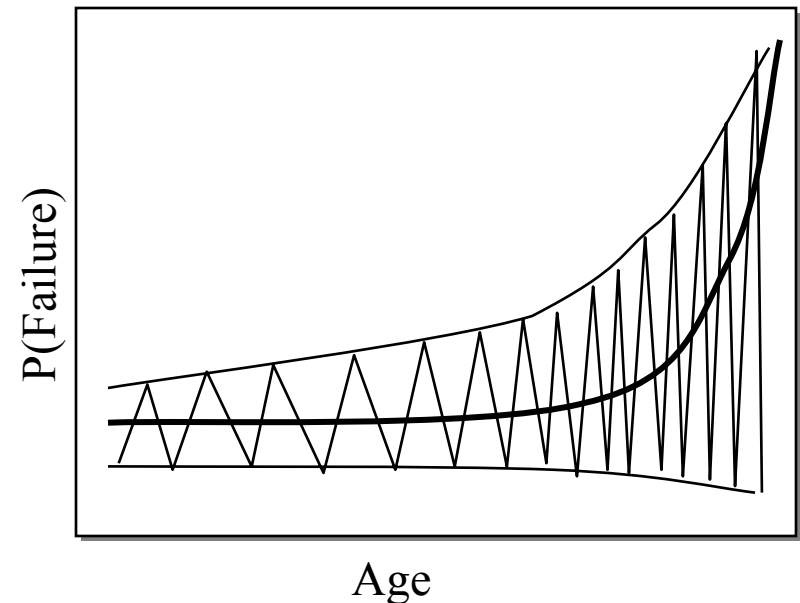
# Repair / Replace – Two Fundamental Problems

- 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



# Solving the Repair or Replace Problem

- Solving the problem depends on:
  1. The type of asset (transformers, cable, etc.),
  2. The asset's characteristics (age, condition, future performance, maintenance costs, etc.),
  3. The decision alternatives (repair, replace, rebuild, refurbish, test, maintain),
- Probability of failure is a key driver of the best solution – the “hazard function.”
  - Failure is uncertain
  - In some cases diagnostics can reduce that uncertainty

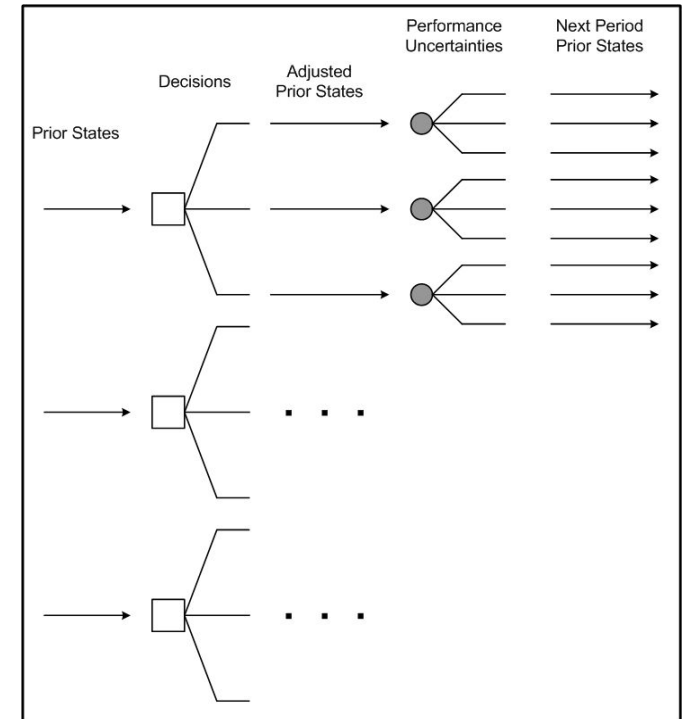


# There Are General Solutions ...

- For finding an optimal repair / replace policy
- For forecasting cash flows given a specific repair / replace policy

*However*

- These solutions do not include testing decisions and results



# Why Test?

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- Equipment underlying condition is unknown or uncertain
- Equipment failure is potentially costly
  - Customer “loss of service” costs
  - Utility direct repair costs
  - Safety risks
  - Regulator penalty risks
- Where the consequences of failure are *not significant* or the underlying equipment *condition is known*, testing is obviously not needed

# What to Test?

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- The Utility has a budget allocation problem
  - The utility has many types of distribution equipment, of various ages
  - But the utility does not have the time, money or manpower to test every piece of equipment
- *Value of a Test* – tells you what to test
  - Estimating the “*Value of a Test*”
    - Is an empirical issue that requires probability theory and a decision model
    - Is not time consuming or expensive
  - *Value of Test* information is a key input to (1) the budget allocation process and (2) a low-cost repair / replace decision strategy

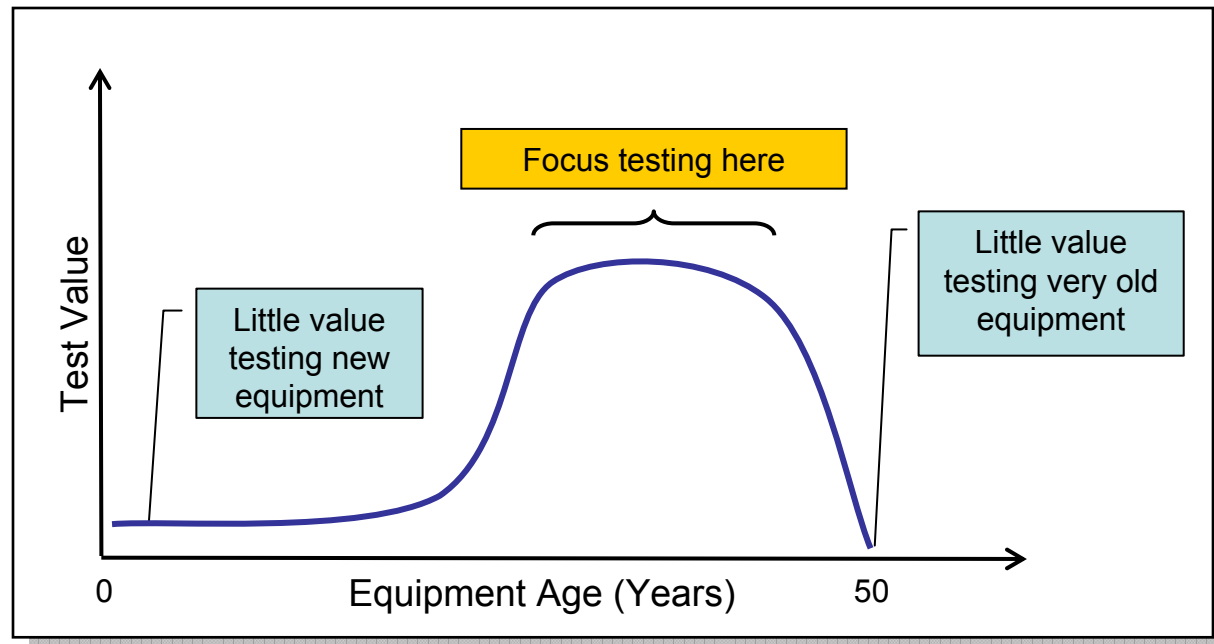
# *What to Test? cont.*

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- The Engineering And Finance Question: where should the utility focus its testing efforts?
  - Equipment for which failure causes largest impacts on costs, safety, reliability
  - Equipment for which testing is most likely to provide better information about likelihood of failure (“power” of the test)

# Value of Testing and Equipment Age

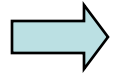
- Benefits of testing depend on likelihood & uncertainty of failure (among other things)
- Estimating “Test Value” requires applying probability theory and a decision model – see the next section
- Intuition does not work – a “bad” test outcome does not always mean a high probability of “bad” underlying condition



# *Presentation Outline*

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- Defining the repair or replace problem



- An example analysis

# Decision Problem w/o Testing

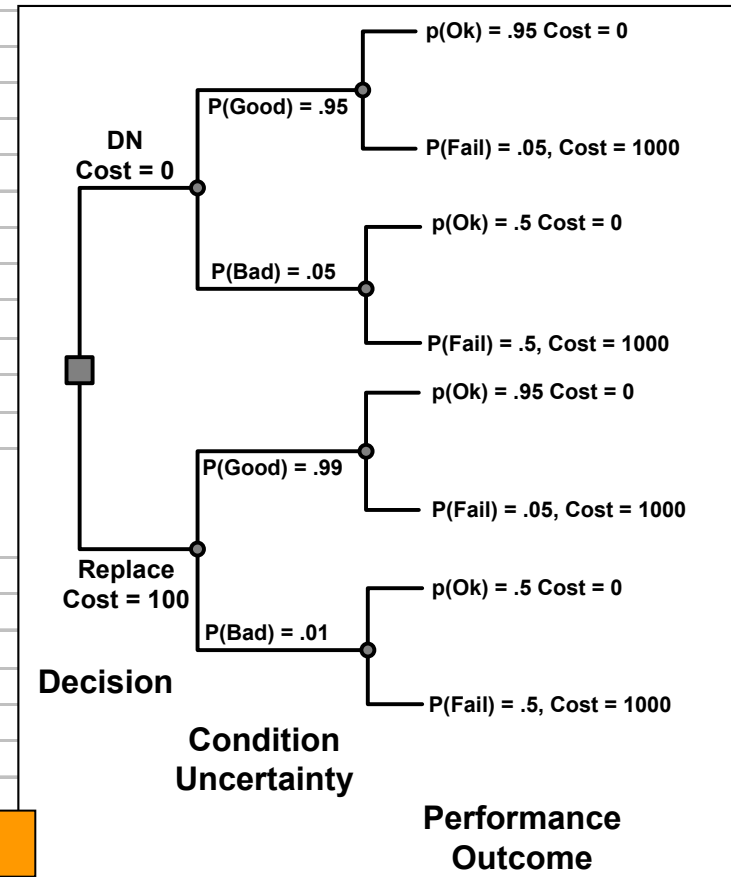
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- The equipment's condition is either good or bad
- We have imperfect information about the condition
  - For brand new machines: 1% chance condition is bad
  - For existing machines: 5% chance condition is bad
- The probability of failure depends on the condition:
  - $p(\text{failure} \mid \text{if condition is good}) = 5\%$
  - $p(\text{failure} \mid \text{if condition is bad}) = 50\%$
- The decision: Replace or Leave Alone (do nothing)
  - Replacement cost: \$100
  - Do nothing cost: \$0
  - Failure cost: \$1000

# The Decision Model w/o Testing

INPUTS	
p(condition bad   new machine)	0.01
p(condition bad   not-new machine)	0.05
p(Fail   condition good)	0.05
p(Fail   condition bad)	0.5
Cost of Replace	100
Cost of DN	0
Cost of Fail	1000

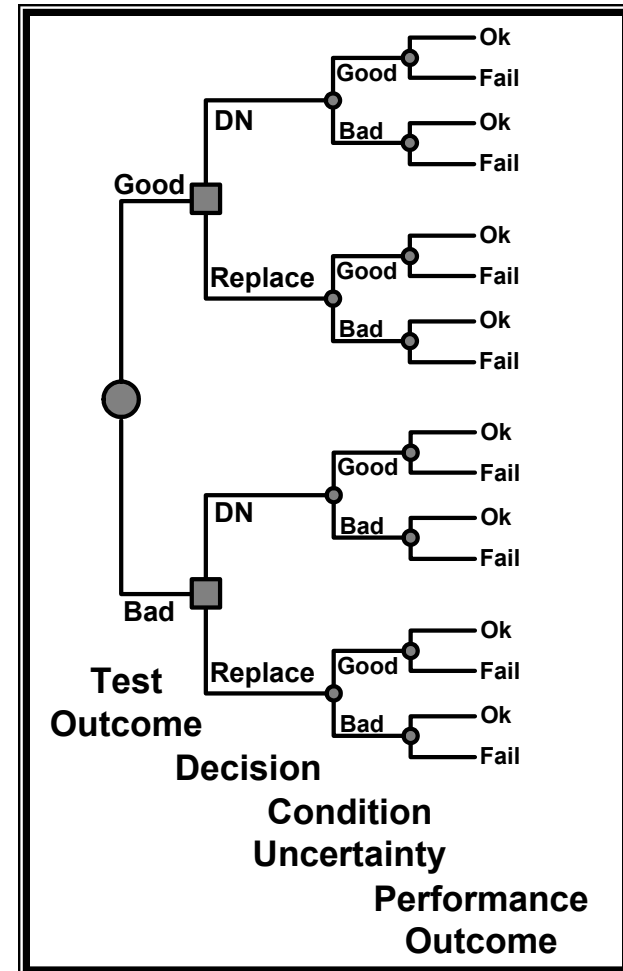
RESULTS	
EV(Decision) = Decision Cost + { p(fail   condition good) + p(fail   condition bad) } x 1000	
EV(Replace)	154.5
EV(DN)	72.5



A decision to do nothing has the lowest expected cost

# Decision Model With Testing

- Add a test outcome node
- The test changes the assessment of condition
  - For not-new equipment the assessment prior to testing is: 5% percent chance that the condition is bad
  - After testing the probability of condition being bad is changed
  - The change depends on the test outcome (good or bad) and the accuracy of the test



# Updating Probability that Condition is Bad

- We use the test to update our initial assessment of the equipment's condition
- Interesting case is when test indicates a "bad" condition
  - A "bad" test outcome may not mean replacement is the best approach
  - The answer depends on the test's accuracy & other factors!

<b>INPUTS</b>	
p(condition bad   not-new machine)	0.05
P(Fail   condition good)	0.05
P(Fail   condition bad)	0.5
<b>Test Accuracy</b>	
False Positive: p(Tests Bad   Condition Good)	0.05
False Negative: p(Tests Good   Condition Bad)	0.05
<b>Updated Condition Assessment</b>	
P(condition bad   test result = bad)	0.5
P(condition bad   test result = good)	0.003
<b>Cost of Replace</b>	
Cost of Replace	100
Cost of DN	0
Cost of Fail	1000

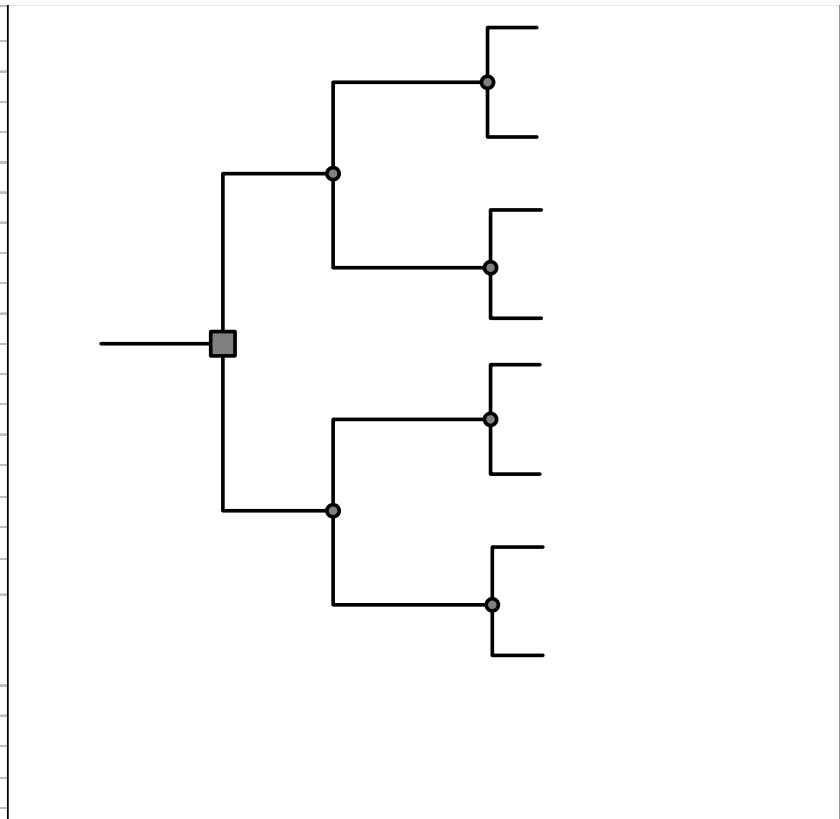
Bayes' Law

$$p(\text{bad} | \text{tested bad}) = \frac{p(\text{tested bad} | \text{bad})p(\text{bad})}{\{p(\text{tested bad} | \text{bad})p(\text{bad})\} + \{p(\text{tested bad} | \text{good})p(\text{good})\}}$$

# Case When Test Outcome = "Bad"

INPUTS	
p(condition bad   new machine)	0.01
p(condition bad   not-new machine)	0.05
P(Fail   condition good)	0.05
P(Fail   condition bad)	0.5
Test Accuracy	
False Positive: P(Tests Bad   Condition Good)	0.05
False Negative: p(Tests Good   Condition Bad)	0.05
Updated Condition Assessment	
P(condition bad   test result = bad)	0.5
P(condition bad   test result = good)	0.003
Cost of Replace	
	100
Cost of DN	
	0
Cost of Fail	
	1000

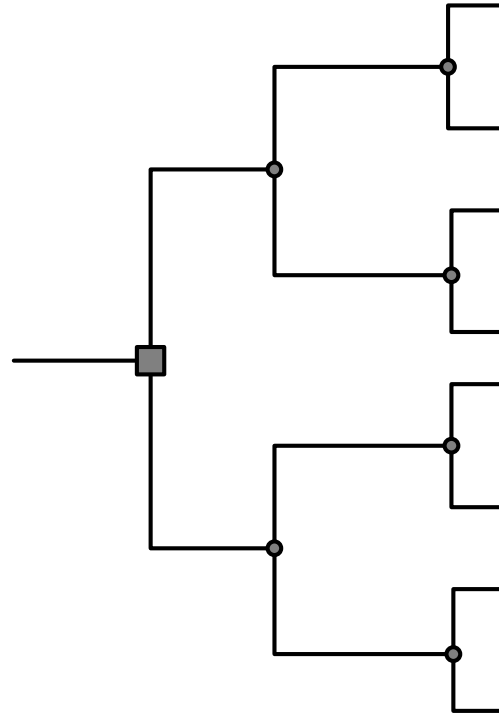
RESULTS - For Case Where Test Indicates "Bad"	
EV(Decision) = Decision Cost + { p(fail   condition good) + p(fail   condition bad) } x 1000	
EV(Replace)	154.5
EV(DN)	275



Replacement now has the lowest expected cost

# Case When Test Outcome = "Good"

INPUTS	
p(condition bad   new machine)	0.01
p(condition bad   not-new machine)	0.05
P(Fail   condition good)	0.05
P(Fail   condition bad)	0.5
Test Accuracy	
False Positive: P(Tests Bad   Condition Good)	0.05
False Negative: p(Tests Good   Condition Bad)	0.05
Updated Condition Assessment	
P(condition bad   test result = bad)	0.5
P(condition bad   test result = good)	0.003
Cost of Replace	
Cost of DN	100
Cost of Fail	0
Cost of Fail	1000
<b>RESULTS - For Case Where Test Indicates "Good"</b>	
EV(Decision) = Decision Cost + { p(fail   condition good) + p(fail   condition bad) } x 1000	
EV(Replace)	154.5
EV(DN)	51.2



# The Value of the Test

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- In this example the test had a positive value
- Value arises because test changes best decision:
  - Without test the least-cost decision is do nothing,  
Expected Cost = \$72.5
  - With test, have two potential test outcomes
    - Test indicates condition is good, least cost decision is to do nothing,  
Expected Cost = \$51.2
    - Test indicates condition is bad, least-cost decision is replace,  
Expected Cost = \$154.5
  - Overall expected cost with testing is:
    - probability of test outcome x cost:
    - $(0.905) \times \$51.2 + (0.095) \times \$154.5 = \$61.0$
- Implication: should be willing to pay as much as \$11.4 for the test  
(\$72.5 - \$61.0)

# *Benefits of Testing Decision Model*

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- Logically rigorous method for incorporating testing into repair / replace decision making
  - Bayes' Law, test accuracy & pre-test assessment of equipment condition
    - $p(\text{Equip. Cond.}) \Rightarrow \text{Test Outcome} \Rightarrow \text{Updated } p(\text{Equip. Cond.})$
  - Formal decision model with decision and outcome costs and value of information calculations
- Decisions that reduce expected costs:
  - Reduce outages rates
  - Identify and selectively replace bad equipment
  - Reduce the chance that good equipment is replaced

# *Next Steps*

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