USING ANALYTIC TOOLS IN T&D ASSET MANAGMENT

One-Day Workshop for Senior Management

December 2, 2004
San Francisco CA

Sponsored by
EUCI

Stephen Chapel, Charles Feinstein, Peter Morris
S. Chapel Associates, VMN Group LLC

Agenda

- Introduction
  - Some Common Asset Management Beliefs - Fact or fallacy?
  - History of our Asset Management Research
  - T&D Asset Management Issues – Problems to be solved
  - Critical Thinking about Asset Management
- Repair / Replace Decisions
- Prioritization / Project Portfolio Management
- T&D Strategic Reliability
- Choosing Analytic Tools

- Optional Topic - T&D Expansion Strategies

Some Asset Management Ideas – True or False?

- Problems can be solved by organizational change and asset management teams
- "Cost Benefit analysis, the "tried and true" method for ranking projects is a perfectly reasonable way to select projects to fund."
- The first important step is to gather data
- All projects can be valued using the same aggregate measures (i.e. $)
- Projects are risky because of uncertain financial consequences
- Beta is an appropriate way to measure project risk

Some Asset Management Ideas – True or False?

- An important objective is near-term profitability
- The biggest problem for asset management is insufficient data.
- ROI is a good metric for evaluating investments.
- Ranking is a good way to prioritize projects.
- Strategic alignment is a good metric for prioritizing projects.
- Balanced scorecards are a good way to prioritize projects.
- Hurdle rates are a good way to account for risks.

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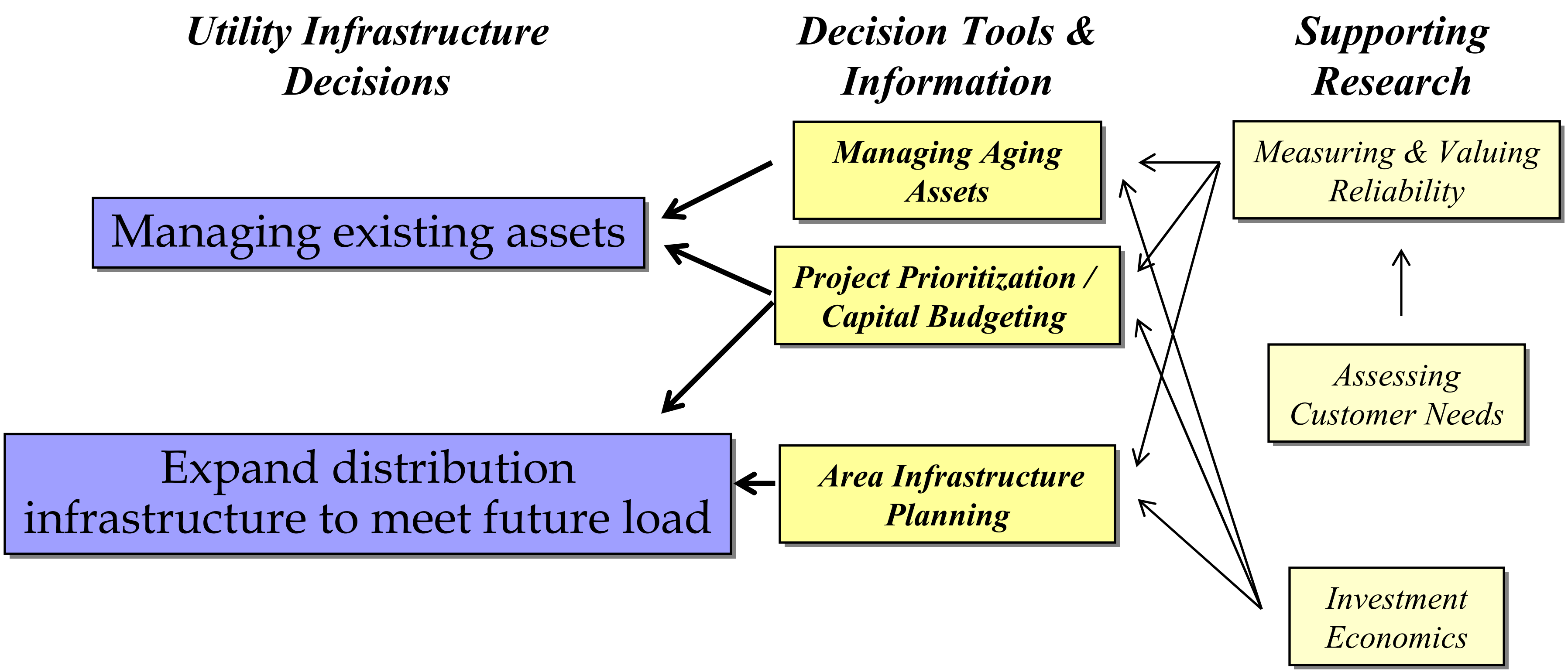
T&D Research 1997 – 2003

- December 1996 Chicago Focus Group
- 1997 - 1998
  - Create the portfolio – distribution planning
  - Produce V1.0 Area Investment Planning Tools
- 1999
  - Start work on Customer Needs & Reliability projects
  - V1.5 Strategy Model & V2.0 LoadDynamics
  - Methodology design for Project Prioritization (AEP)

T&D Research 1997 – 2003 cont.

- 2000
  - Aging Assets - Started
  - Project Prioritization – method & software designed
  - Customer Needs & Reliability – EPRI white papers
  - Area Investment Planning – tech transfer
- 2001: Focus on Aging Assets and Project Prioritization
- 2002:
  - Continued focus on Aging Assets and Project Prioritization
  - Some work on Measuring & Valuing Reliability
- 2003:
  - Aging Assets – refine existing software & explore better ways to analytically address the problem
  - Project Prioritization: Refine existing software & continue improve methods for measuring T&D value

Utility Infrastructure Decision Making – The Focus of Our Work



Underlying Objective: Minimize the lifecycle costs of distribution infrastructure while meeting customer needs for reliability & power quality

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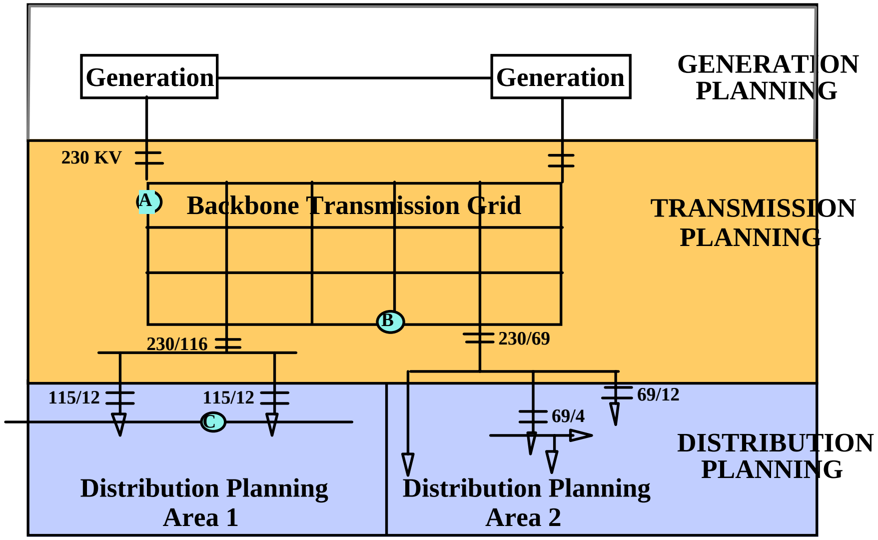
T&D Asset Management is Complex

- What about reliability - how far can we push the system before falling off the edge?
- How do we get the right-sized capacity when it is needed?
- Can we save $ by deferring maintenance?
- What risks are we taking by practicing “doing-less” decision making (do we really know how close we are to the edge)?

T&D Asset Management is Mostly About Solving Investment Problems

- 40% to 50% of electric utility net investment
- Business issues
  - Minimizing investment costs
  - Having "right" infrastructure to meet customer needs
  - Making money
- Key strategic needs
  - Managing assets
  - Linking investment and O&M decisions to customer needs



Net Invest.

Gen. = $8.7B

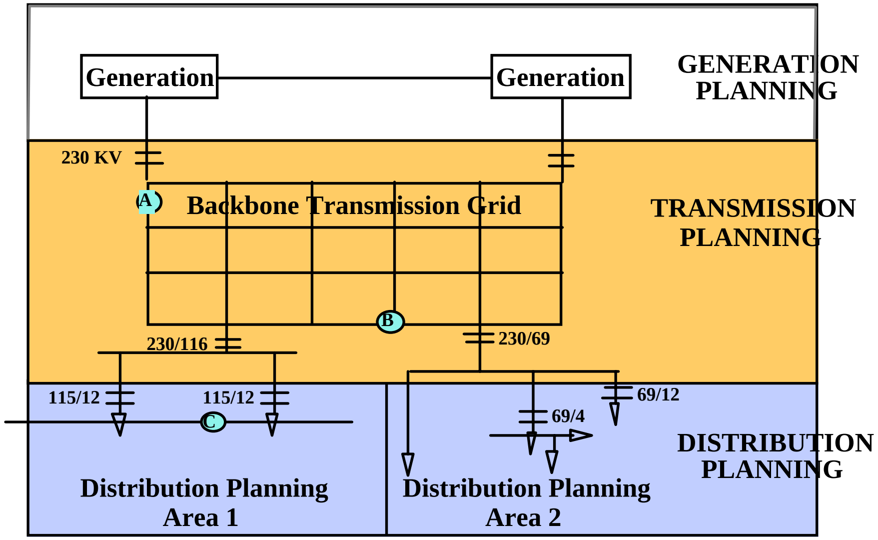
Tran. = $4.5B

Dist. = $13.5B

Total = $26.7B

T&D Asset Management

- Two driving facts
  - Very low revenue to asset ratio
  - Large embedded asset base
- Substantial care and feeding is required
  - Repair / Replace
  - Expand / Prepare for future
  - Reliability



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Gen. = $8.7B
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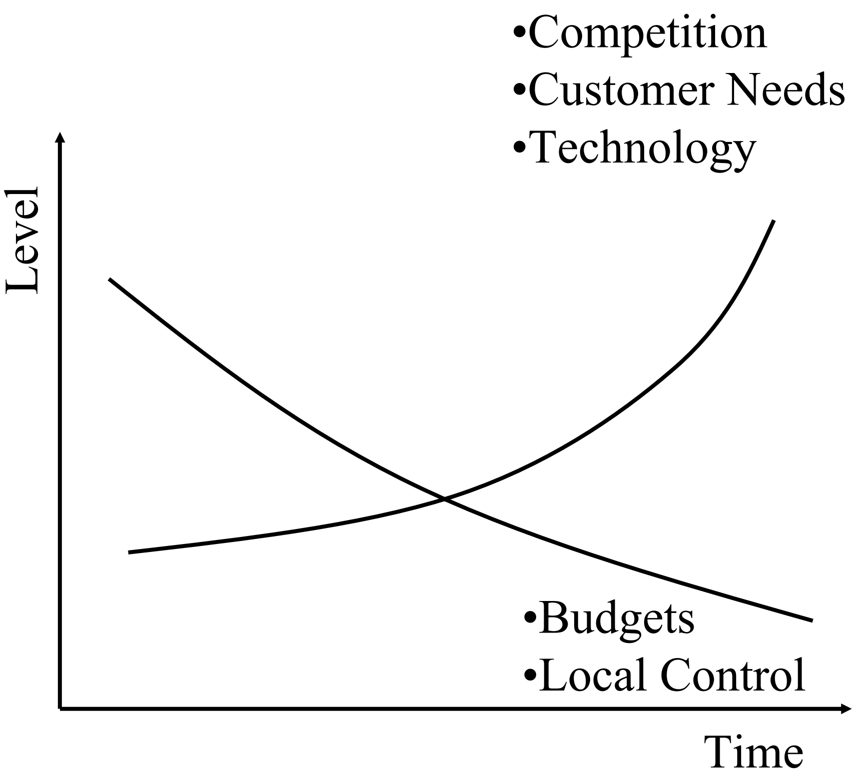
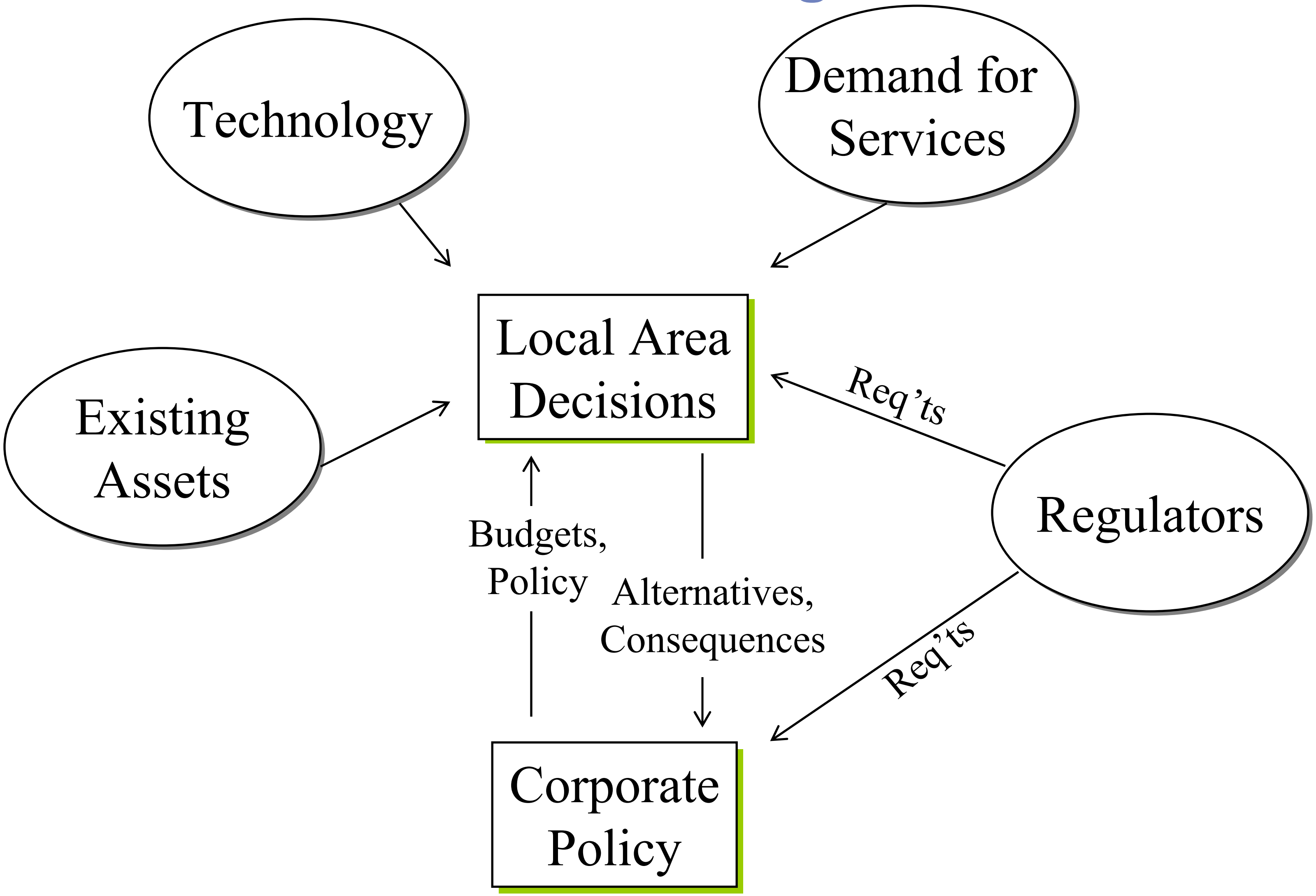
Total = $26.7B

Opposing Trends are Changing the Business

- Increasing levels of key drivers
  - Restructuring & deregulation
  - Regulatory & Corporate scrutiny
  - Customers demand for reliability and service quality
  - Technology change
- Reduced budgets & increased corporate control
- Together these are creating a collection of problems

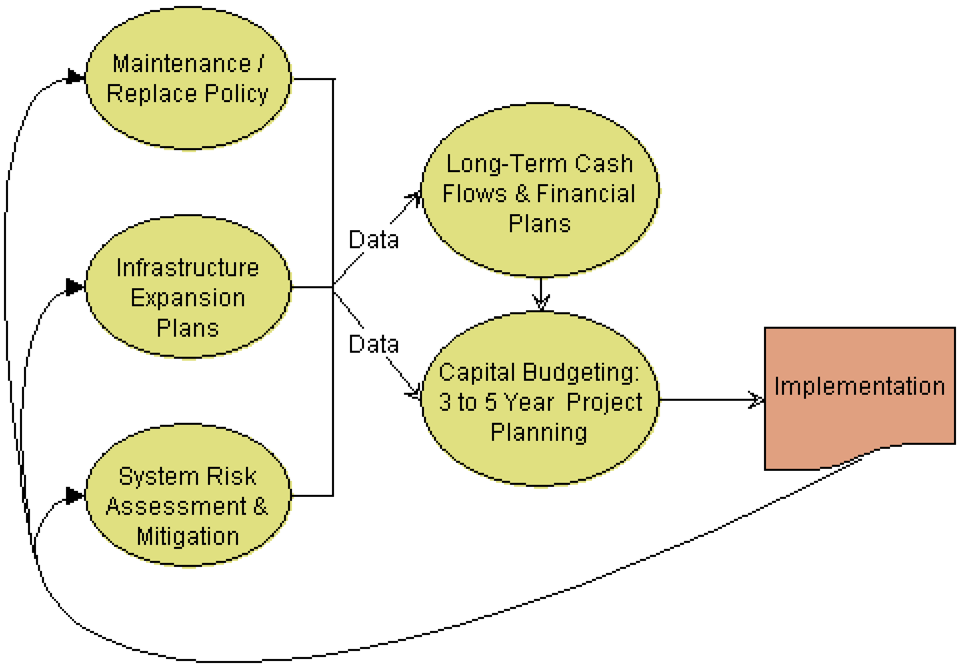


Nature of Business Planning Problem



T&D Asset Management – Project Planning & Financial Planning

- Fundamental engineering economic problems
  - Maintenance / Repair / Replace
  - Capacity expansion
  - System Risk Assessment & Mitigation
- Financial planning problems
  - 3 to 5 year Capital Budgeting / Project Planning
  - Long-Term Financial Planning



In Summary T&D presents special challenges

- Huge investment in assets
- Regulations / Oversight
- "Right" infrastructure for customer needs
- Competitive pressures - extract maximum value from every asset
- Performance vital to other industries & economy
  - Recent NE power blackout estimated to cost $7-10B
  - Loss of electric power to city of New York costs about $36m/hr

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Critical Thinking about Asset Management

- Order of operations: specific problem statement → methodology→ data & judgment →analysis
  - Problem statement: what is the problem, what is a solution
  - Data gathering: the next-to-last thing you do
- Asset Management is Financial Engineering
- Essential to specify V^2D^2:
  - Values: what the company wants to accomplish
  - Variables: what is measurable and determines how much value is achieved
  - Decisions: or controls, what can actually be chosen
  - Dynamics: the effect of controls on variables over time
- Methodology
  - Captures fundamental relationships among V^2D^2
  - Does not impose false criteria, false methods, false theories

Critical Thinking (cont’d)

- Role of Data
- Role of Judgment
- Analysis
  - Art of analysis
  - How to compute and what the computations mean
  - Financial Engineering objectives

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Repair and Replace Strategy for Aging Systems Assets

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December 2004

Outline

- The Aging Asset problem
- Substation transformer example—single asset
- The need for a Learning Model – group exercise
- Aging Asset model structure-single asset
- Control of Asset Population - Cable Case Study
- Organizational Issues

The Aging Asset Problem

- 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
  - A set of alternatives
    - Repair
    - Replace
    - Rebuild
    - Refurbish
    - Test
    - Maintain
- What should we do, when, and under what conditions?

Problem Statement

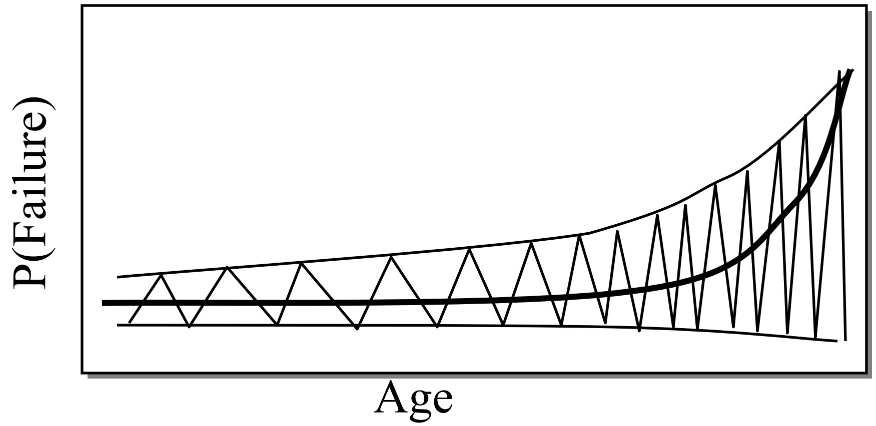
- The current system contains (x miles of cable, y power transformers, z breakers, …). These assets are aging and may present a risk of failing in groups at the same time. The company is not satisfied with its current replacement policy.
- Objective: develop a least-cost strategy for repair/replacement of these assets
- Specify a forecast of the expenses by category associated with this strategy

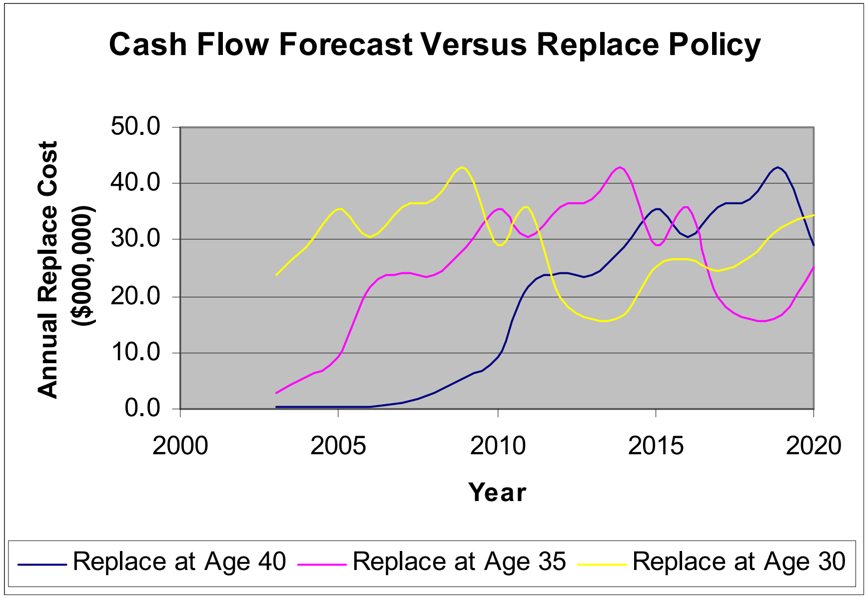
Aspects of the Aging Asset Problem

- Optimal management of a single asset
- Optimal policy for entire asset population
- Cash flows for repair/replace for entire asset population
- Role of diagnostic tests

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





Optimal Management of a Single Asset

- Repair / replace strategy
- Diagnostic tests
- Individual performance—hazard function
- State of asset
  - Observable
  - Unobservable
- Solution method: state-dependent optimal control

Diagnostic Tests

- Several tests exist for each asset
- Example: Underground Cable Tests
  - Partial Discharge
  - Time Domain Reflectometry
  - Isothermal Relaxation Current
  - Dissipation Factor
  - Dielectric Spectroscopy
  - Wafer Test

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Substation Transformer Example

- Decisions
  - Repair (under what conditions?)
  - Replace
  - Maintain
  - Evaluative screening interval
  - Number of mobile, backup substations
  - Number of spares
  - Transfer load

Substation Transformer Example

- Economic Variables
  - Number of customers
  - Type of customers
    - Residential
    - Commercial
    - Industrial/Critical
  - Cost of Action
    - Maintain
    - Rebuild
    - Replace

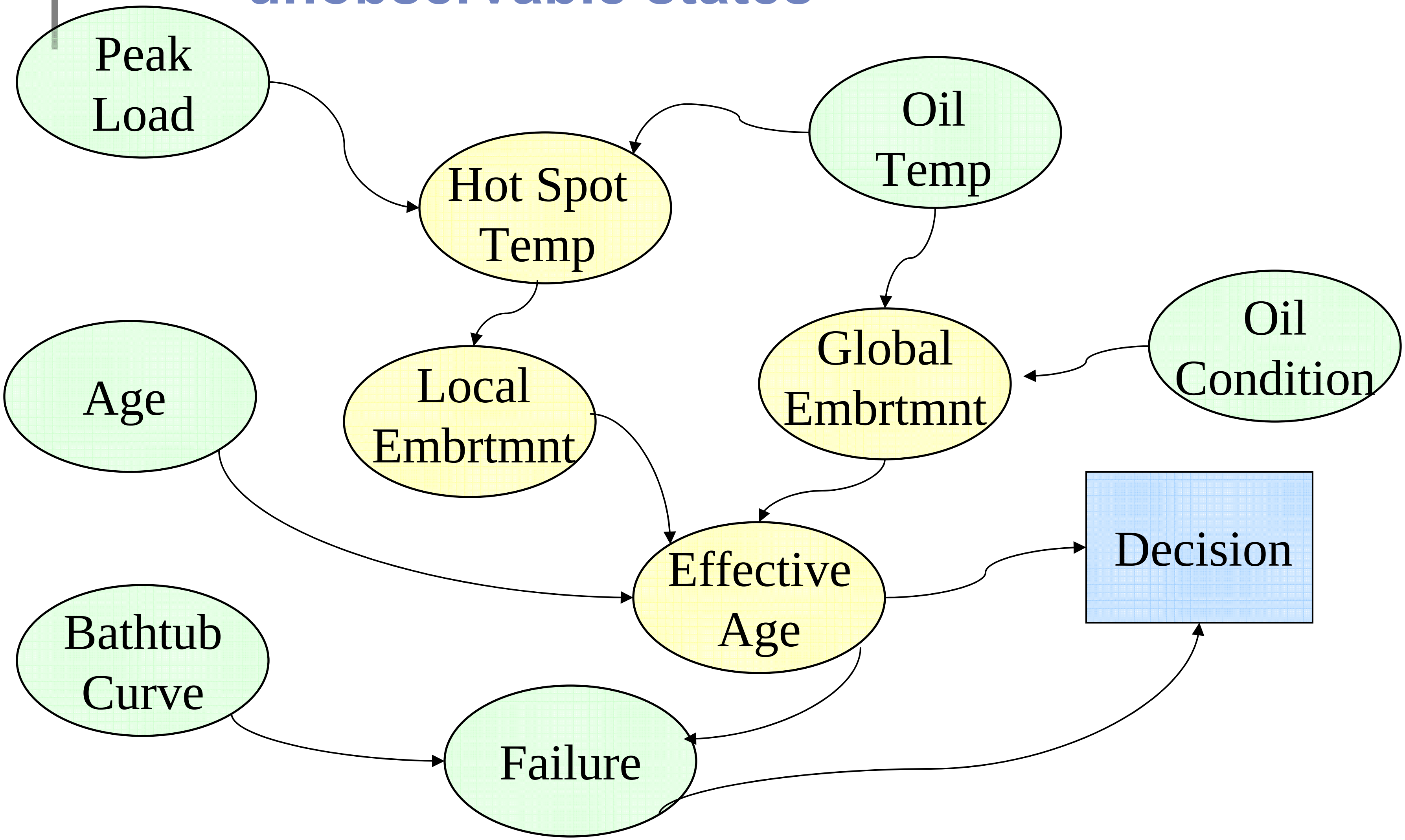
Substation Transformer Example

- Observable States
  - Age
  - Peak load
  - Oil condition (result of chemical test)
  - Oil Temperature (result of temperature test)
- Observable states are *"Decision Contingent"*
  - Policies are contingent on observable states
  - Critical to model decision flexibility

Substation Transformer Example

- *Unobservable States* reflect expert knowledge & problem structure
  - Hot Spot Temperature
    - Function of temperature and peak load
    - Calculable from current and load
  - Oil condition (result of chemical test)
  - Oil Temperature (result of temperature test)
  - Degree of Global Embrittlement (the entire transformer)
    - Condition of insulation
    - Influenced by oil temp (temp can “half or double insulation life”)
  - Degree of Local Embrittlement (around hot spot)
    - Influenced by hot spot temperature
  - Effective Age
    - Influenced by local and global embrittlement
  - Company-specific deviation from Industry Bathtub Curve

Relationship among observable and unobservable states



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Inference Example: Why we need Learning Model

- Uncertain Event: "Terrorist attack in USA in next week"
  - You believe the probability is about 1%
  - Simulation: Toss coin ten times, observe zero or one head

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- Uncertain Event: “Terrorist attack in USA in next week”
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- Now you receive information: FBI/CIA Intelligence Report
  2 possible results: **Threat** “Credible evidence of attack ”
  No Threat “ No credible evidence ”

Inference Example: Why we need Learning Model

- Uncertain Event: "Terrorist attack in CA in next week"

  You believe the probability is about 1%

- Now you receive information: FBI/CIA Intelligence Report

  2 possible results: **Threat** "Credible evidence of attack "
  No Threat " No credible evidence "

- Suppose you believe the agencies to be highly reliable:

  Given **Attack** 99% chance agencies pick up **Threat**
  Given **No Attack** 99% chance agencies say **No Threat**

Why we need Learning Model

Probability calculation:

- Given **"Threat"** Probability of Attack = ?
  - (Or: How many tosses and how many heads?)
- Given **"No Threat"** Probability of Attack = ?
  - (Or: How many tosses and how many heads?)

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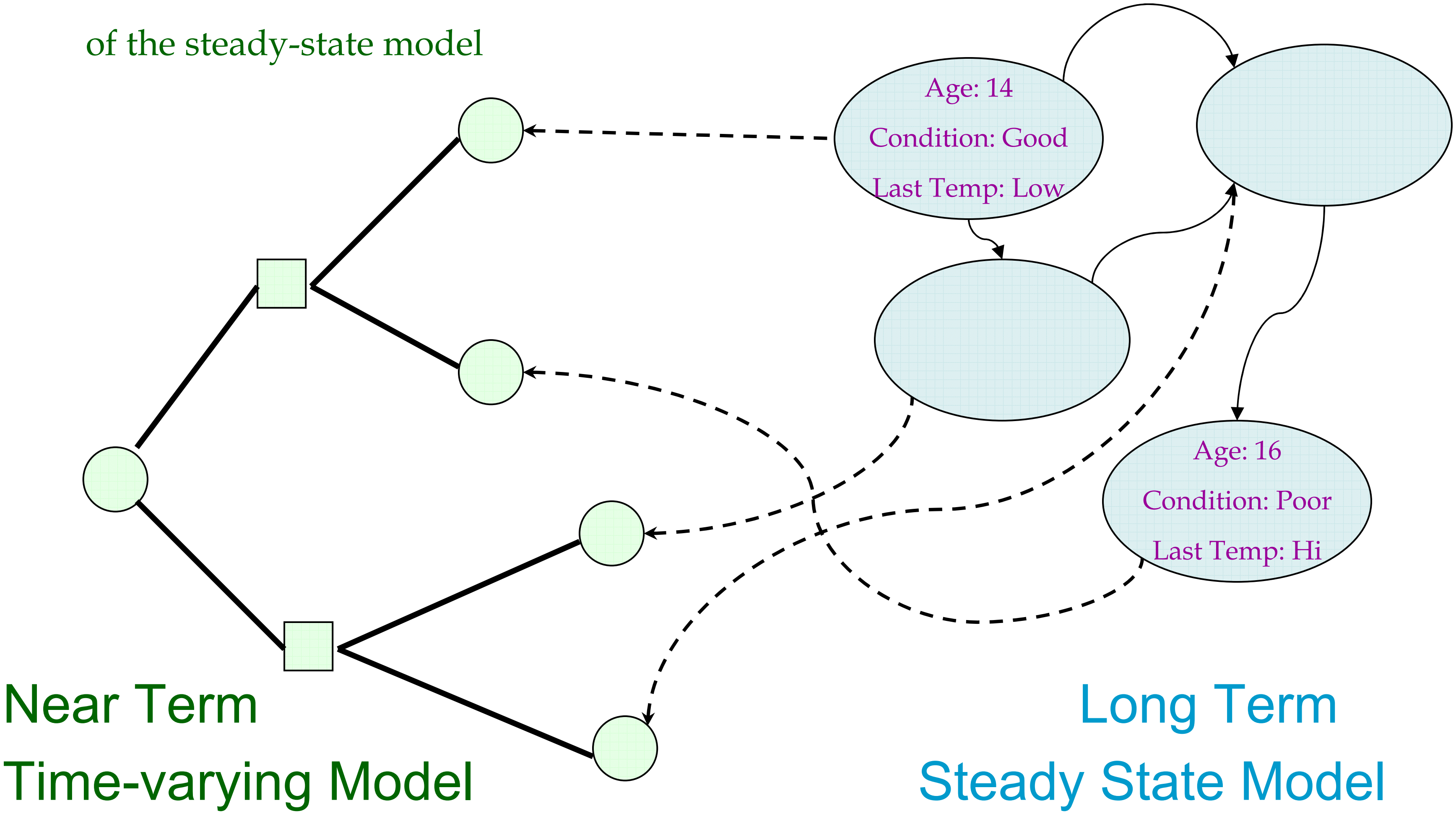
Aging Asset Model Structure-Single Asset

- Two model forms to fit problem characteristics
- **Planning Period**
  - Uncertainties and decisions may change year to year
  - Have detailed knowledge about near-term issues
  - One-of-a-kind events may be on the horizon
  - Stochastic dynamic program yields Time- and State-dependent policy
- **Post-Planning Period**
  - Have less detailed year-to-year knowledge
  - Still need to capture long term policy
  - Markov decision process yields State-dependent policy

Model linkages

- Each terminal node of the time-varying model plugs into a state of the steady-state model



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Optimal Population Management – Underground Cable Case Study

- 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

Population Hazard Function -- Example

- A1: Failures:

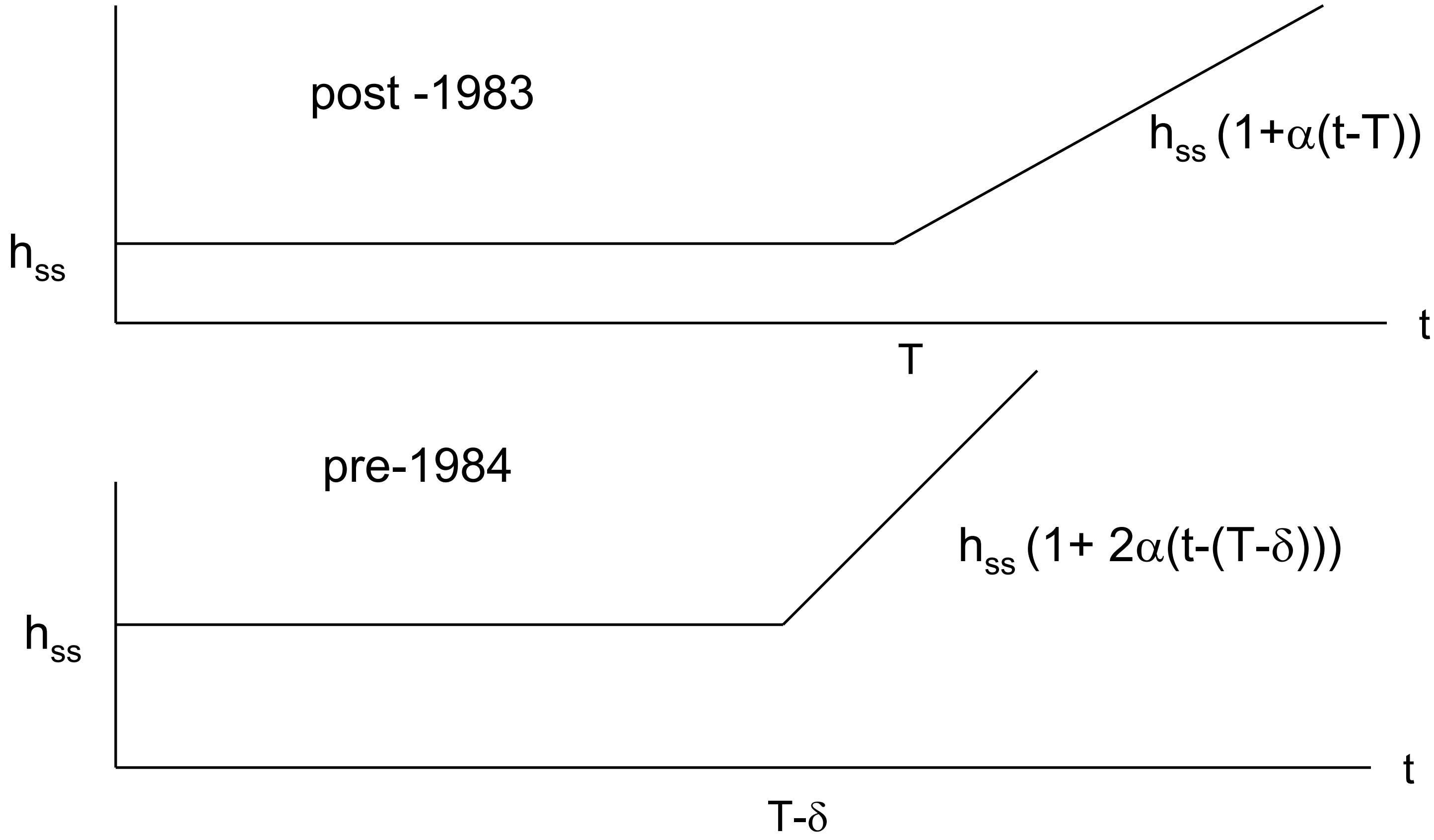
2AWG	1/0	2/0	4/0	500	750
394	152	61	24	*	28

- 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

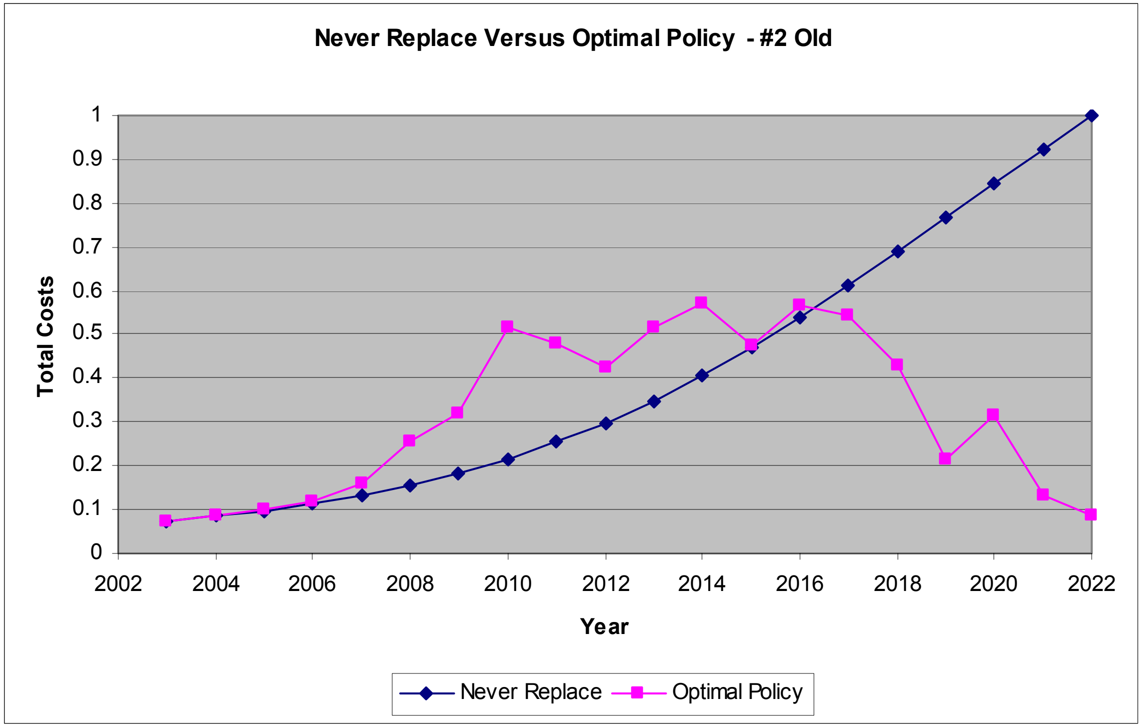
* 500 assumed to fail as 750

Hazard Function (cont'd)

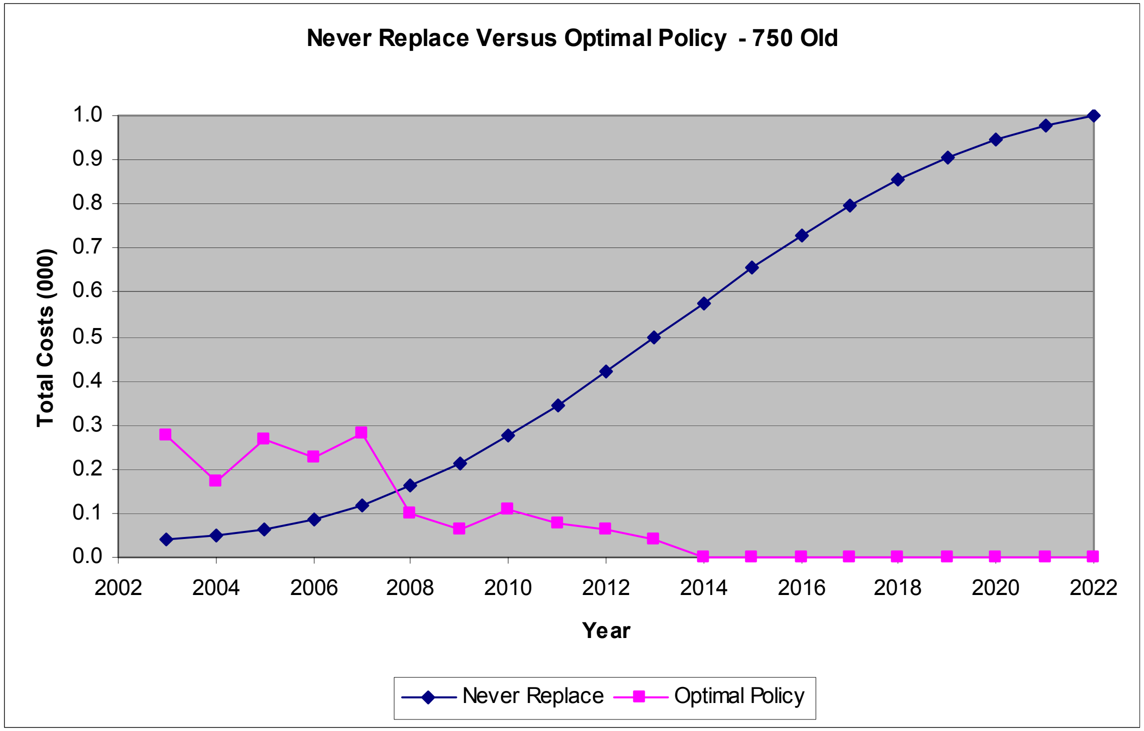
- A4: Two functional forms



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



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



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Organizational Issues—What is aging asset management?

- What is the objective?
- Process or analysis?
- Analytic requirements
  - Data issues
    - Failure rates
    - Equipment characteristics
    - Customer needs and values
    - Utility costs
    - Constraints (budgets, operating, …?)
  - Commitment to analysis

Prioritization / Project Portfolio Management

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- Overview of Method
  - Problem statement
  - Objectives of analytic system
  - Technical overview - how the problem is solved
- Risk
- Implementation Issues
- Software Demo

Problem Definition

- The company does not currently *quantitatively* evaluate and compare all distribution projects. (A formal, repeatable, and uniform approach for valuing projects does not currently exist.)
- The value of doing a particular project is not compared with the values of competing projects.
- For the projects that are evaluated, the company is not satisfied with the current procedures.

Scope of Prioritization Problem

- Large number of projects
- Multiple performance measures
- Projects done for different reasons
- Analysis of uncertainty
- Risk of deferral
- Respond to budget signals

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Objectives: Prioritization System

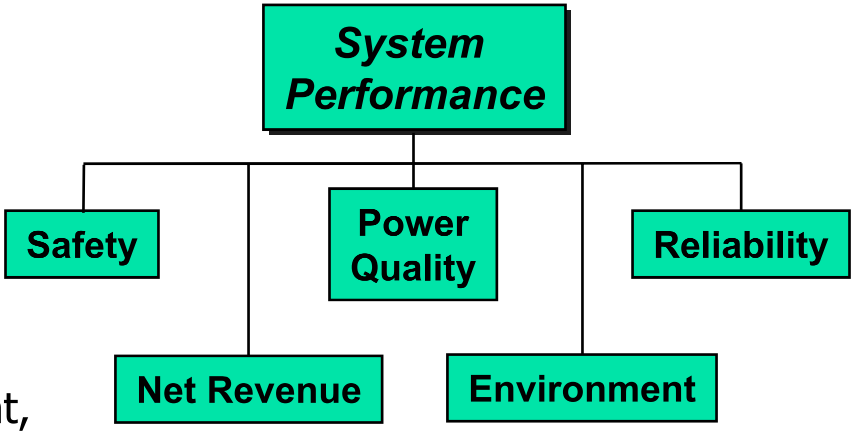
- Level playing field for all projects
- Resolve differences of opinion rationally
  - Techniques for resolving differences of opinion and determining which differences matter
- Defensible logic for peer review
- Transparent analysis
- Completeness with respect to performance measures
  - Multiple performance measures for multiple objectives
- Bias- and error-free

Objectives - continued

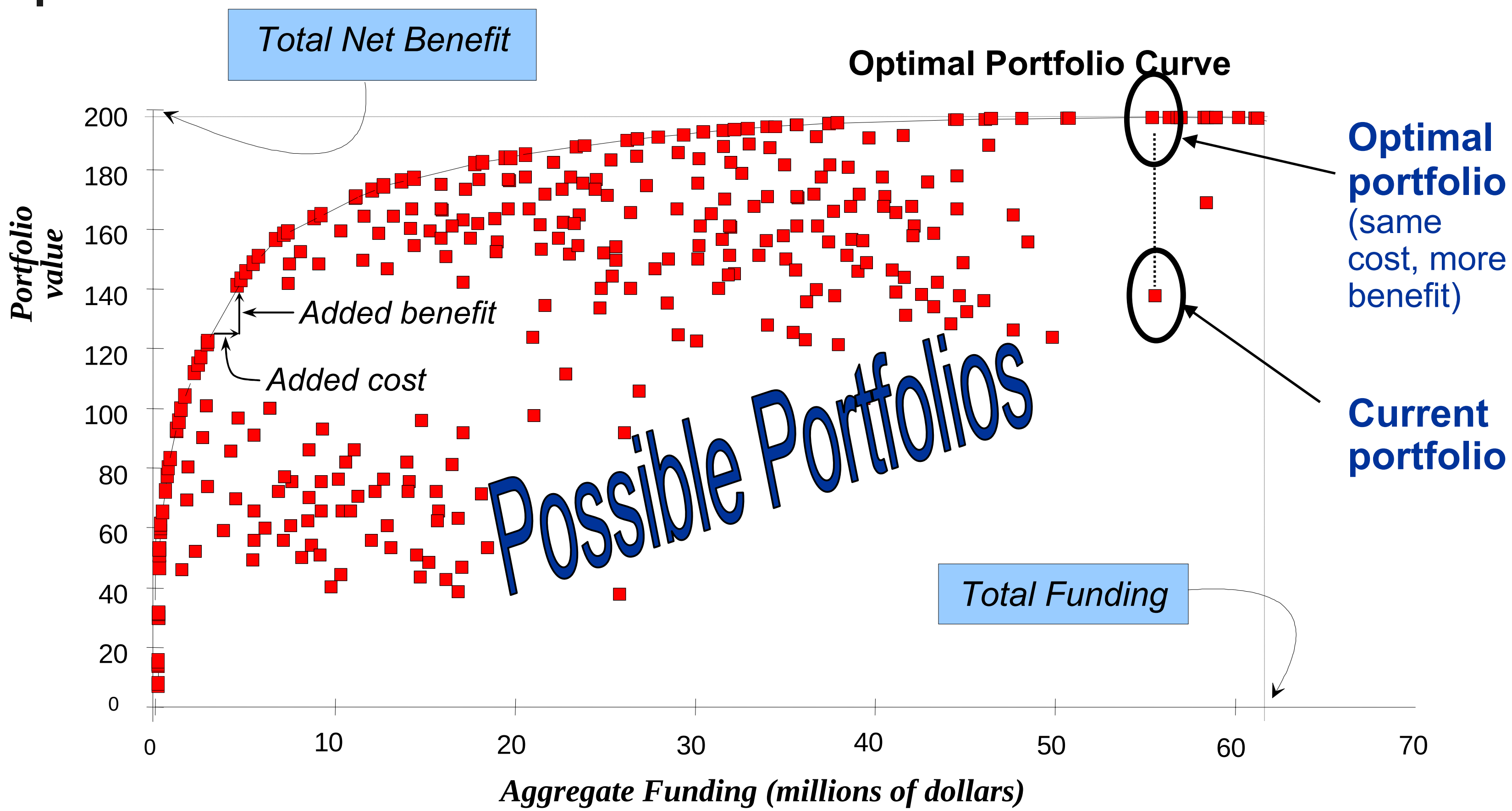
- Practically applicable with respect to time and cost
- Compatible with existing business practices
- Explicit treatment of uncertainty
- Ability to quantify what is lost from insufficient funding
- Software to manage and compare large numbers of diverse activities – client/server database (Oracle, SQL Server)

Objectives - continued

- The system must be:
  - Multi-year
  - Multi-attribute
  - Value driven
- Three key dimensions
  - Objectives of the project portfolio
    - minimizing or maximizing important, measurable aspects of system performance
  - Values
    - capture relative importance of competing objectives.
  - Project attributes
    - describe how each project contributes to attainment of objectives



Objective: Identify the optimal portfolios



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Required I/O + Transformations

INPUTS

- Corporate budgets
- Projects + Alternatives
- Objectives
- Values
- Attributes

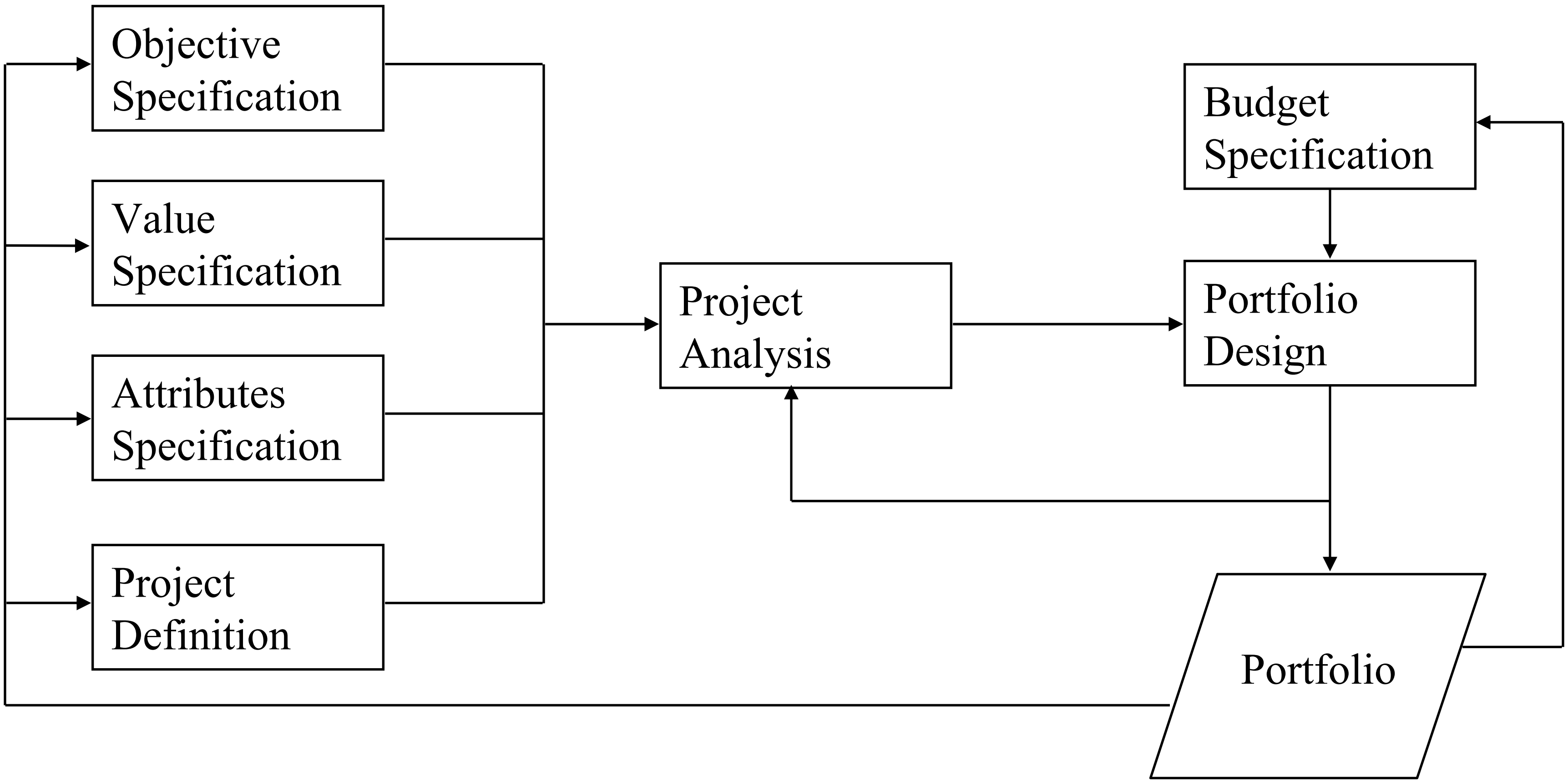
OUTPUTS

- Project Rankings
- Portfolio of projects
- Timing of projects
- Value of additional budget
- Value
- Risks
- Costs

TRANSFORMATION PROCESS

- Attribute + values + objectives → Benefits
- Projects + Alternatives → Budget requirements
- Benefits + budget req'ts → Portfolio
- Δ Budgets → Δ Portfolio

Overview of System Structure

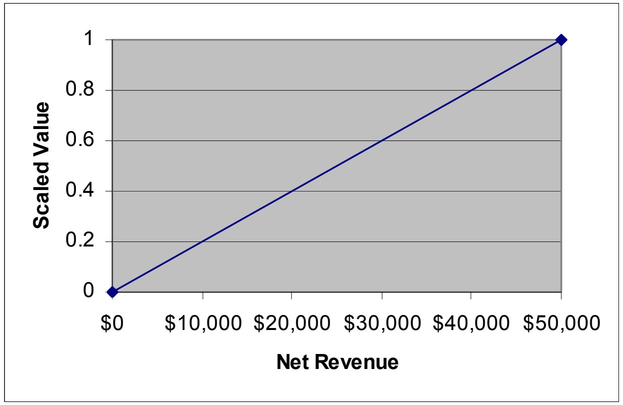


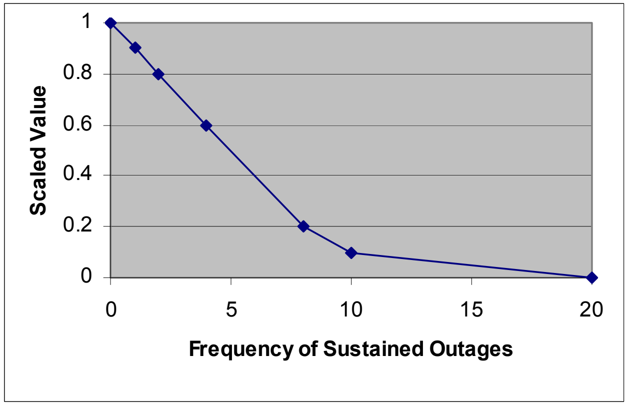
Natural Units – measure system performance

- Power Quality
- Reliability
- Costs / Revenue
- Environmental
- Safety

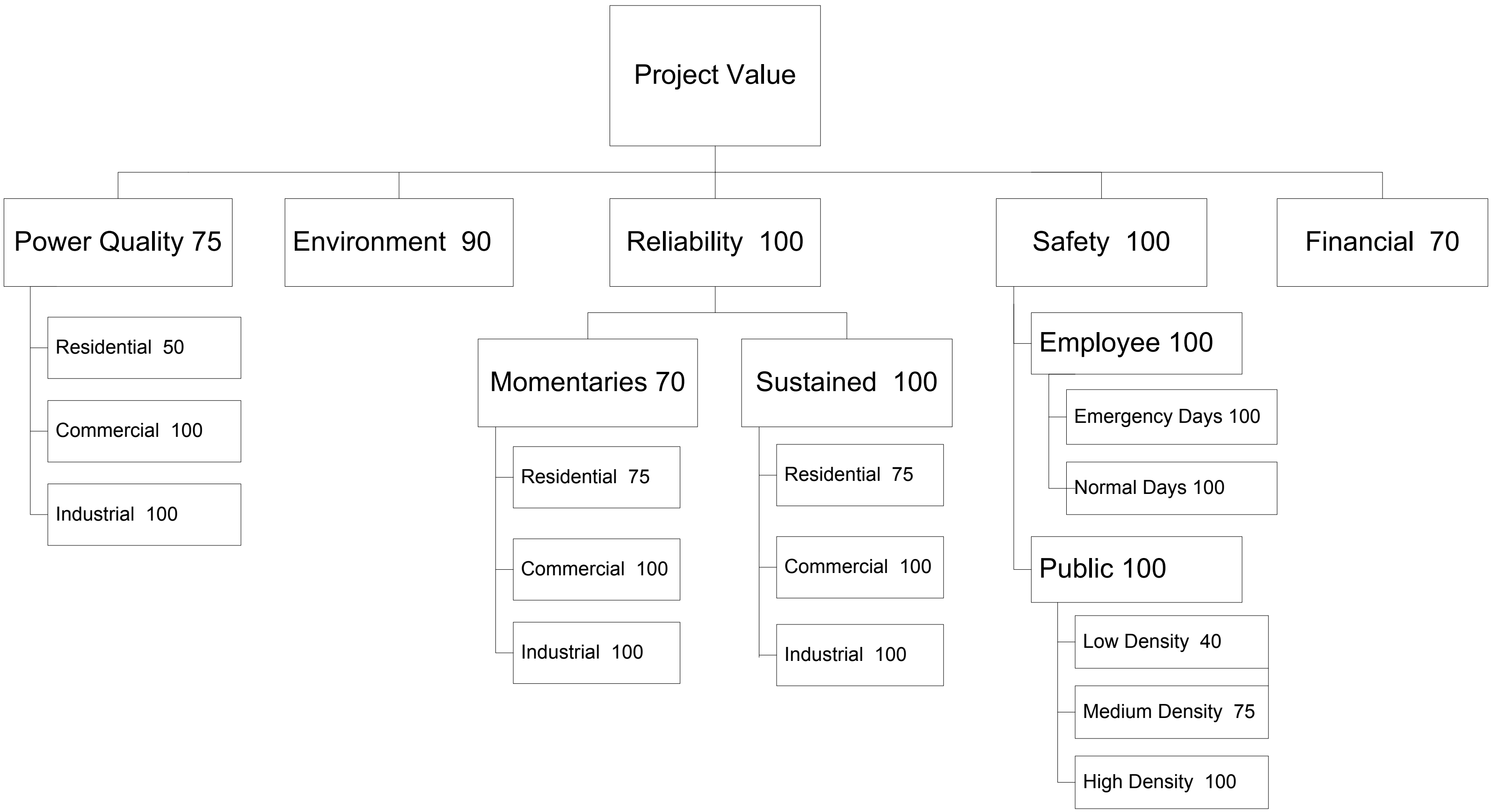
Scales – measure value of change

- Linear
  - Dollars
  - Customers
- Non-linear
  - Frequency
  - Duration
  - Momentaries



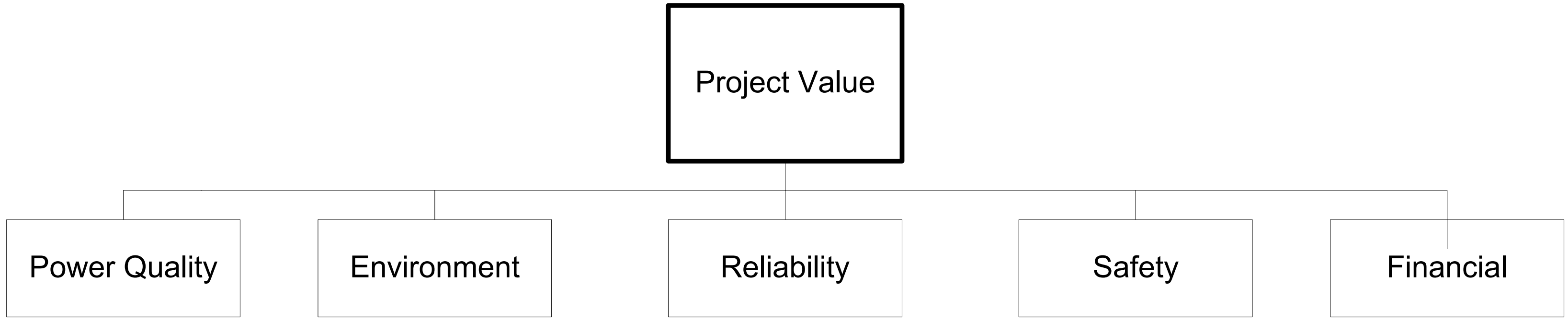


Weights – measure relative value of change



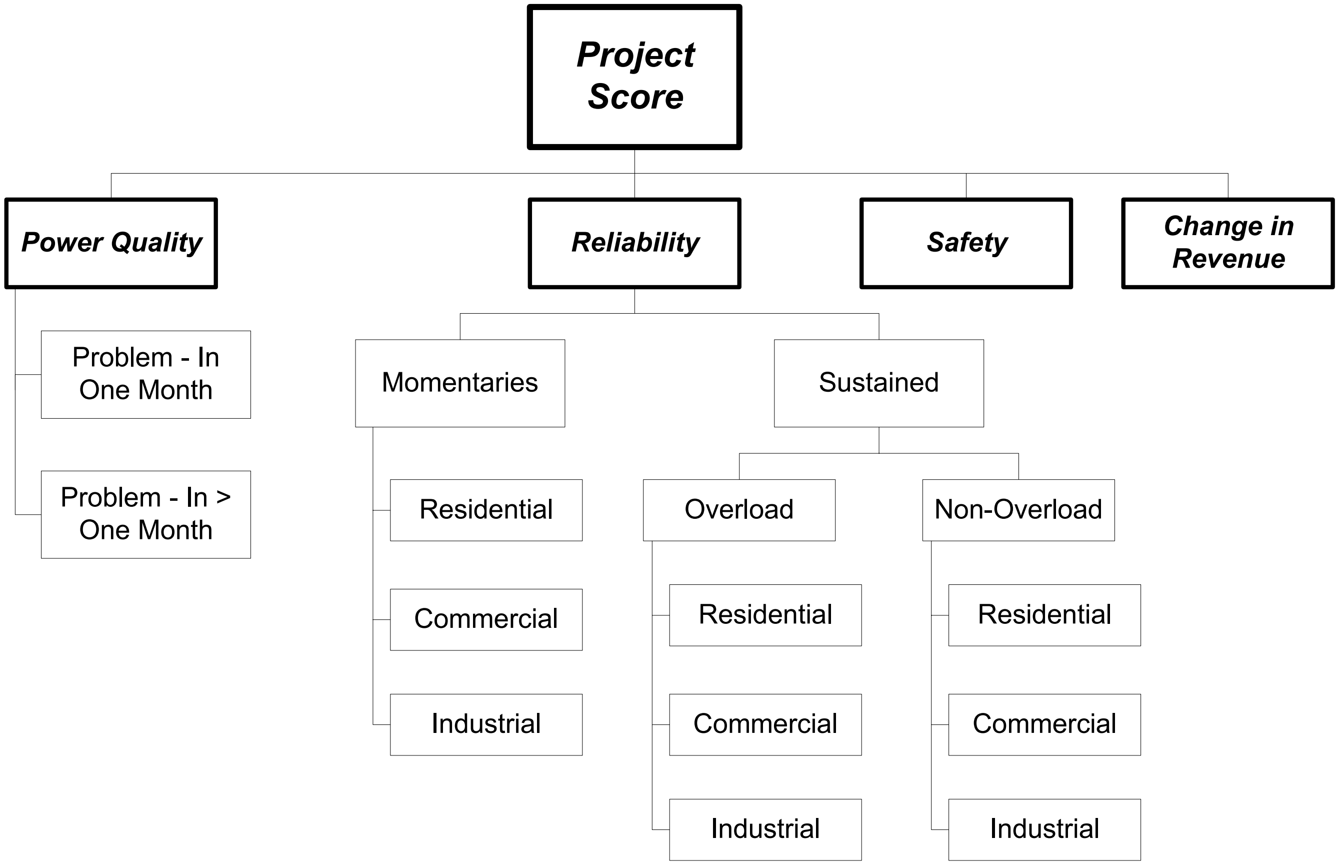
Attribute Structure

- At the highest level, the attributes are essentially the same



- Attribute structure differs in how the high level attributes are measured – another approach follows

Attribute Structure – Alternative Measurements



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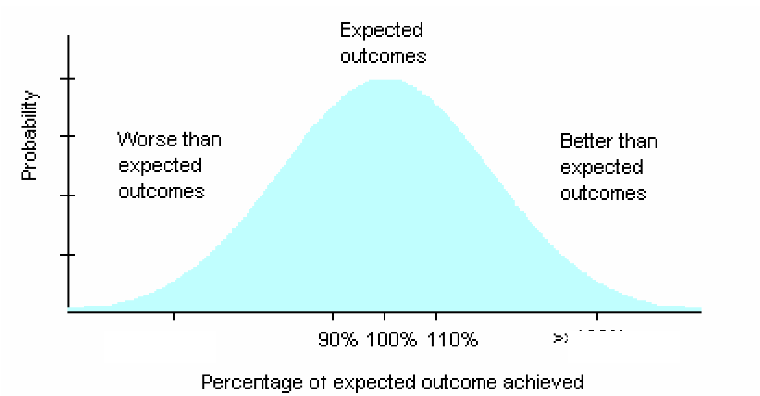
Definition of risk

- *Risk* A situation wherein different things might happen, and at least one of the possibilities is bad.
- Note
  - Risk involves *uncertainty* and *value*
  - Risk is not "probability" or "probability times consequence". These are *measures* of risk.

Discrete Risk

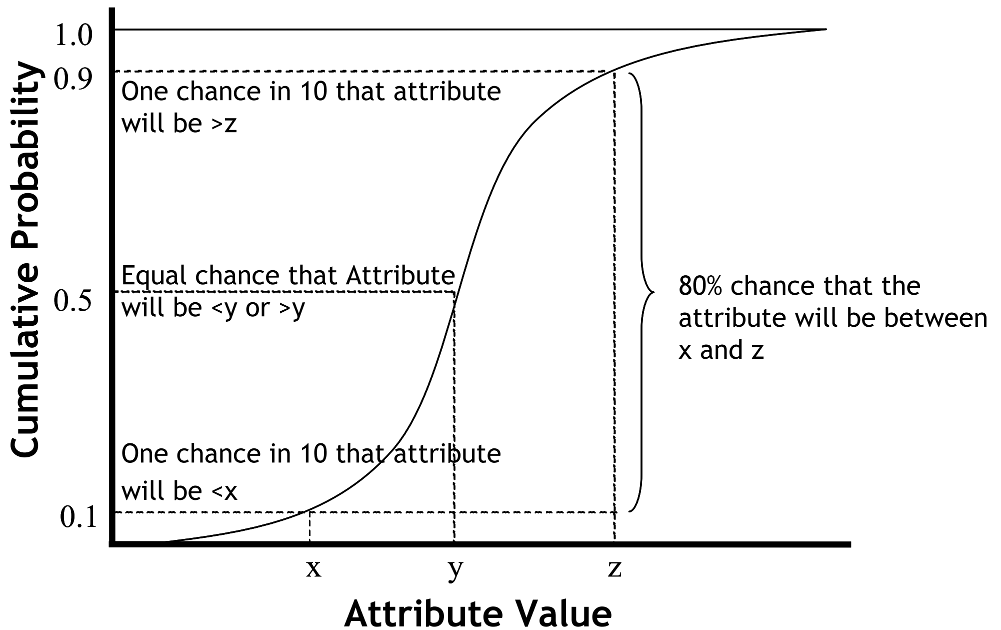
Consequence if risk event occurs = $1M loss
Probability of risk event = 1 in 10,000

Continuous Risk



Characterizing Risk

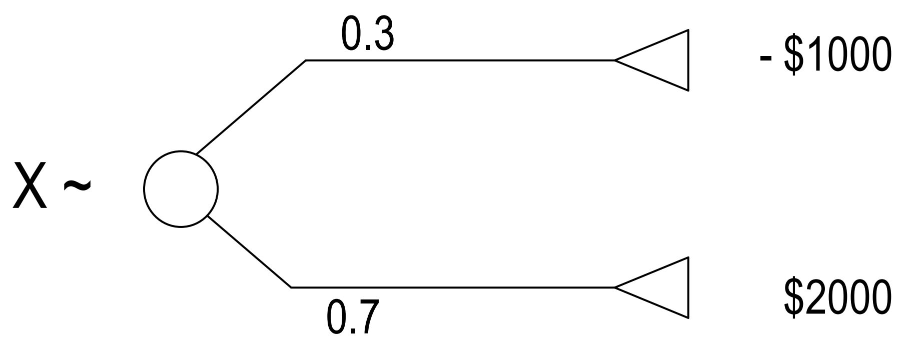
- Must make forecasts of attribute levels
- Better to be accurate than precise
  - measuring both expected values and project risk depend on being accurate and not precise
- For continuous risk P2 uses the 10-50-90 approach



Expected value is a single number that represents the entire distribution

- Expected value is a probability weighted average of the outcomes.

E(X) = \$1100

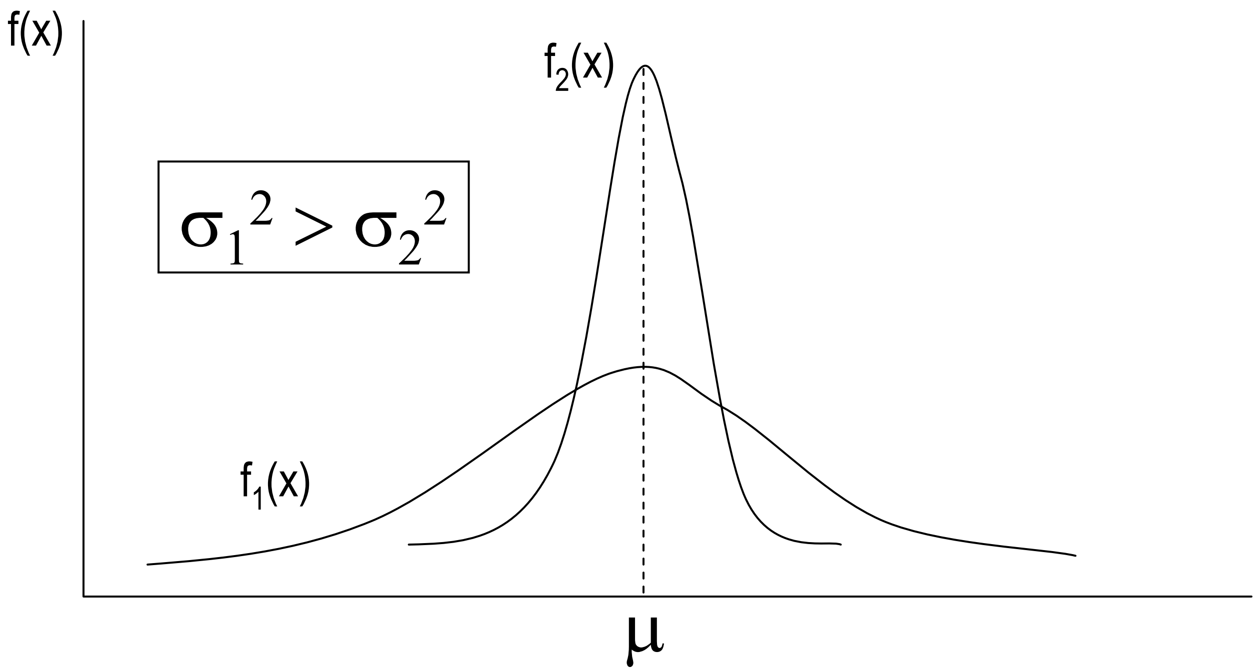


Averages


BALDO
BY CANTÚ AND CASTELLANOS
WHAT ARE YOU STUDYING, GRACIE?
AVERAGES!
AVERAGES?
YEAH... YOU KNOW...
LIKE, IF A WOMAN LIVES IN NEW YORK HALF THE YEAR...
AND SPENDS THE OTHER SIX MONTHS IN FLORIDA...
ON AVERAGE, SHE LIVES IN NORTH CAROLINA!

Variance is measure of departure from mean of distribution

- Two distributions may have the same mean but very different variances



Forecasting Methods: the Underlying Model

- $A_t = E(x_t) + e(x_t)$
- Estimate $E(x_t)$ from data or judgment
  - Linear
  - Exponential
  - Polynomial
- Estimate $e(x_t)$ by fitting past data to model or judgment

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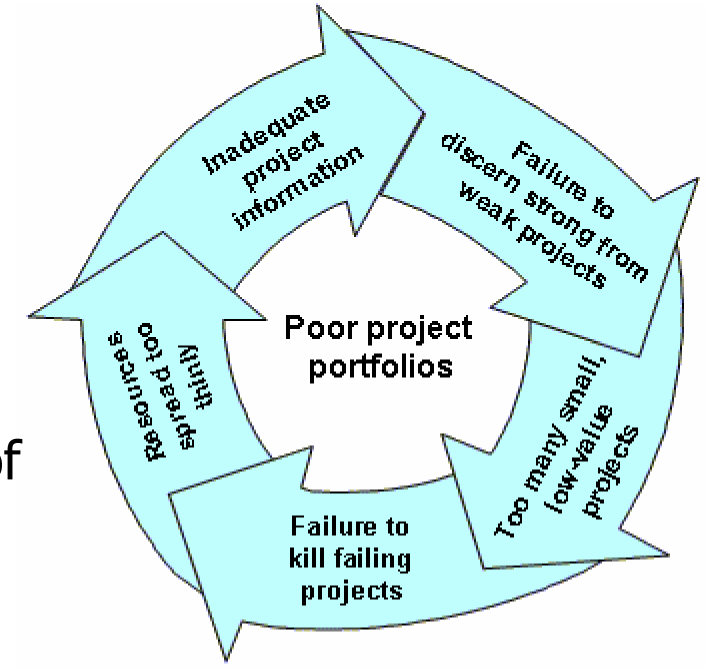
Project Prioritization Requires Managing At The Portfolio Level

- Most organizations put ample effort into making individual projects successful
  - Highly motivated project managers
  - Once funding obtained, focus is on achieving the costs, schedules, and performance mandates of their specific projects
- ...but put insufficient effort into making the entire portfolio of projects as successful as it could be
  - Either no one has responsibility for the overall portfolio, or management of the project portfolio is not as effective as it could be.

Problems with project-by-project decision making

In most companies, the basis of a "go" decision is whether the project passes some hurdle

- Many projects pass the hurdle
- ..but, resources are highly constrained
- ..so people become more than 100% committed
- …which leads to the downward spiral of poor project portfolios.



Project Prioritization Requires

- High level management commitment to the system
- Project portfolio manager with
  - authority to administer the system and perform analysis
  - authority to work with project champions to get data and review project scores
  - accountability for the credibility of the analysis process
- Project Champions that are committed to the system and to working with the portfolio manager

One approach we have seen is a project portfolio management office

- PPM has accountability for the success of the entire project portfolio
  - Given an estimate of funding available
  - Makes recommendations for approval by senior management)
- Office is responsible for
  - Evaluating project proposals
  - Validating project cost and performance estimates
  - Accepting/rejecting proposals
  - Accelerating and decelerating projects
  - Allocating resources
  - Continually managing the project portfolio

Agenda

- Overview of Method
  - Problem statement
  - Objectives of analytic system
  - Technical overview - how the problem is solved
- Risk
- Implementation Issues
- ➡ Software Demo

STRATEGIC RELIABILITY MODELING

Stephen Chapel
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and
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STRATEGIC RISK MITIGATION

Determining System Reliability

It's an analytical problem (known inputs and outputs)
No strategic approach exists
It's potentially far more important than detailed engineering models

Key Issues

What's important?
Common cause failures
Triggered failures -- the avalanche effect

Summary of Approach

Common cause failures review
Trigger model
Defining a catastrophe
Impact of trigger rate
Impact of failure rate
Impact of asset age mix
Marching toward the Precipice

Implications

Analytic Reliability Modeling

Classic reliability models don't address the full range of customer outcomes

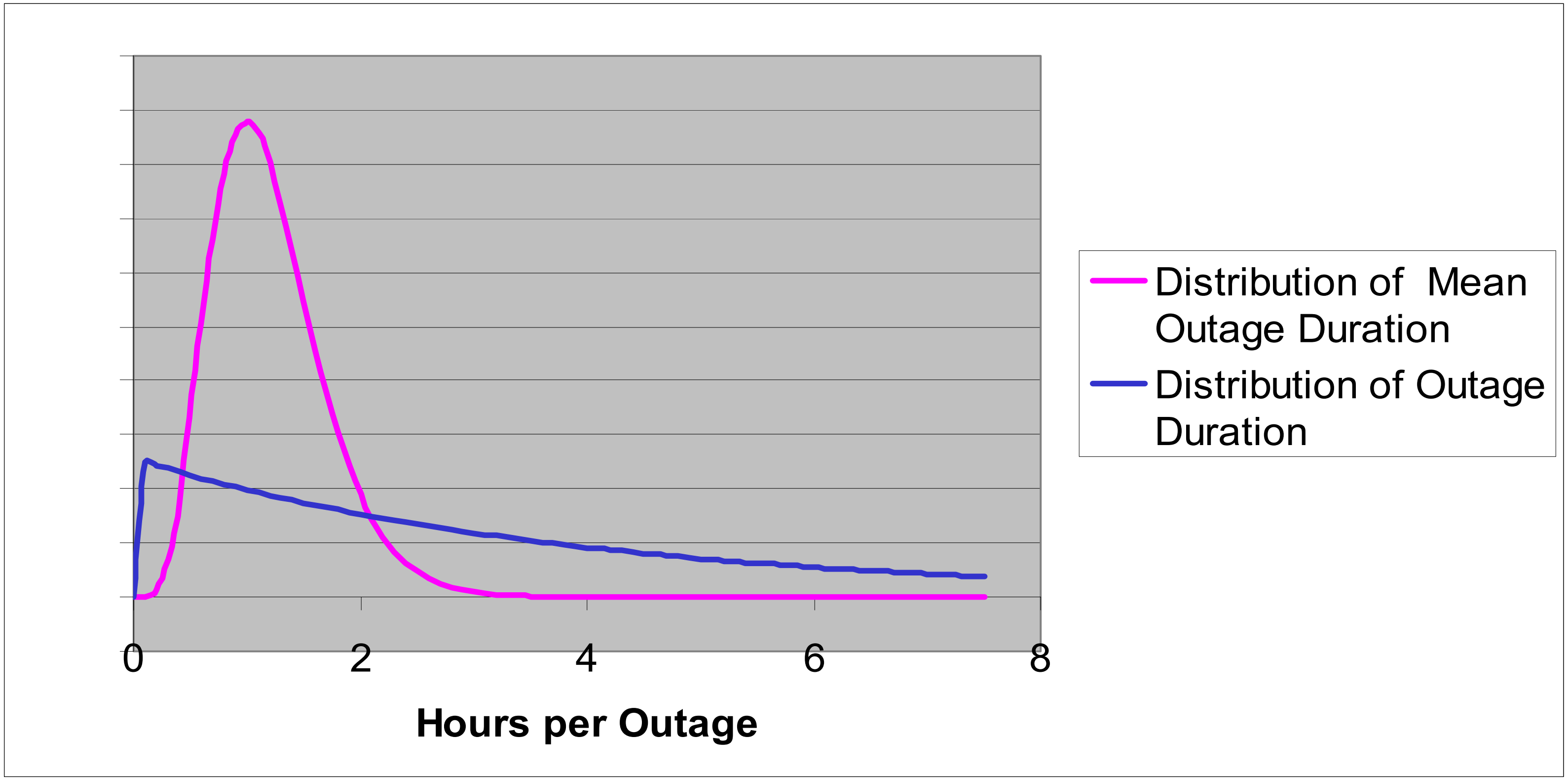
- Analytic models based on classic reliability theory estimate reliability indices, which measure system averages
- Simulation models simulate variations in system averages
  - »Simulations of average measures like SAIFI greatly underestimate the range of outcomes for customers
  - »Simulation's classic problems: "Simulation is not enumerative and may overlook rare and important events" [R. Brown]

Current models are not strategically focused

- They do not focus on the rare but catastrophic events of most concern to utilities and the public
- They do not represent the true range of uncertainty
- They do not optimize strategy

Corresponding Distribution of SAIDI
(average over 100 customers)

4	0.5



MULTI-CIRCUIT PROBABILISTIC RELIABILITY ANALYSIS

Two Circuits, each described by a Markov Process

Circuit A	up	down
up	0.990	0.010
down	0.600	0.400

Circuit B	up	down
up	0.980	0.020
down	0.300	0.700

Specify Special Transition Definition

From: any state

To: A down B down

Specify Common-Cause Failure Probability

0.5

Model Results

Plan Period: 60 Years

Steady State Annual Frequency of Catastrophes: 0.061

Steady State Average Years Between Catastrophes: 16 Years

Probability Distribution	
Number	**Probability**
0	0.25854902
1	0.12336655
2	0.11155024
3	0.09772787
4	0.08343982
5	0.06970907
6	0.05715274
7	0.04608609
8	0.03661191
9	0.02869281
10	0.02220676

Triggered Failures and Avalanches

Some of the Issues

Linked or Interdependent Assets

One Transformer Goes Down ----> More Load on Others ----> Increased Chance of Mul

Lack of Asset Diversity

Assets Roughly Same Age ----> Triggers Simultaneous Degraded Performance ---->

Degree of System Complexity

Higher Interdependence (more links) ----> Fewer/Shorter Customer Outages During Normal

----> Higher Chance of System Breakdown in Abnorm

Ability to Deal with Multiple Contingencies

Inflexibility with Multiple Contingencies ----> Fewer Failures for Catastrophe

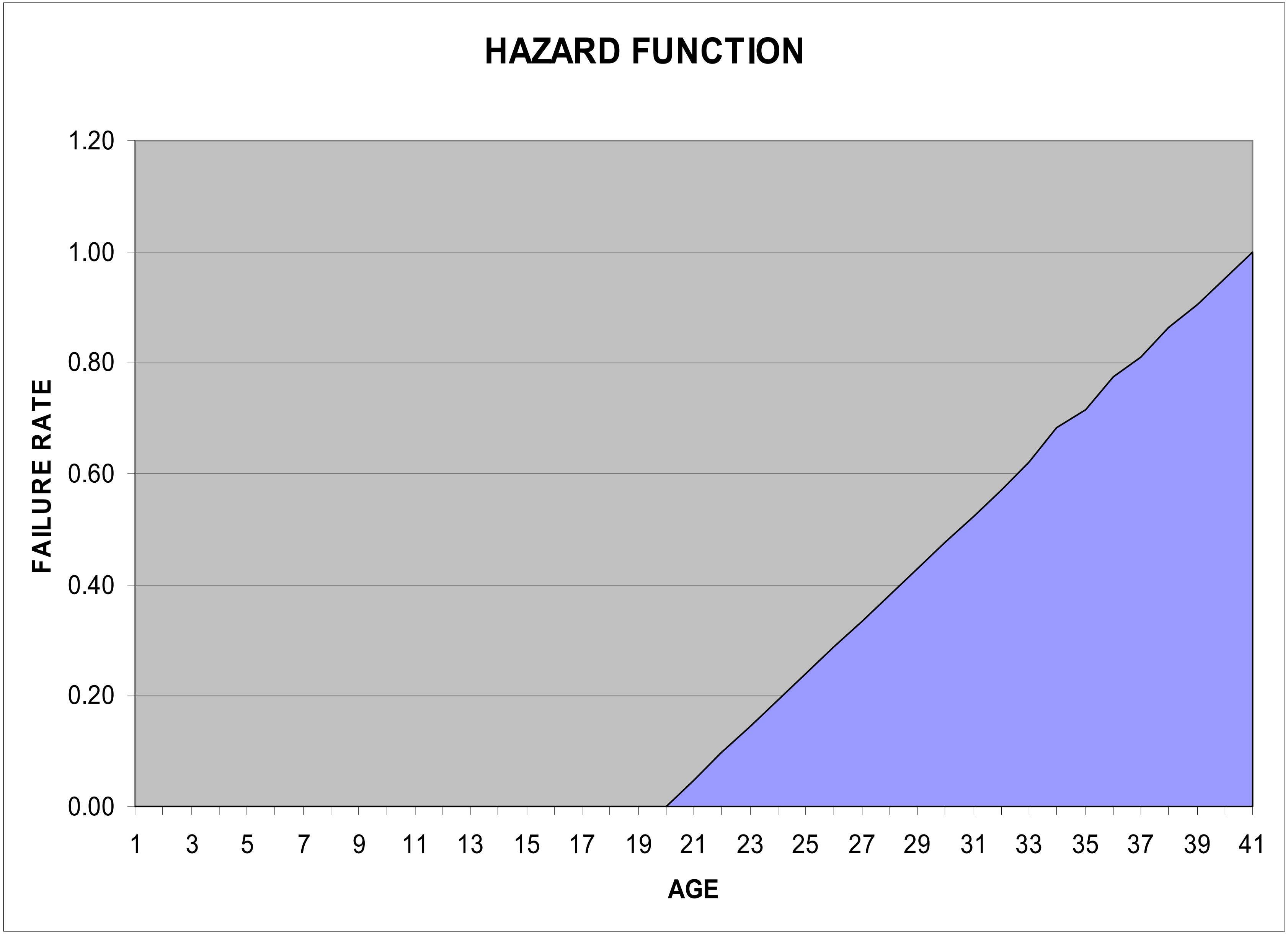
Strategic Tradeoffs: Strength of Links versus Number of Links versus Grouping of Assets

Which is Better?

2 Independent Groups of 5 moderately-linked Assets
or
5 Independent Groups of 2 strongly-linked Assets

Strategic Design Issue: Complexity versus Dependency

Number of Independent Assets Clusters
Number of Links in Clusters
Strength of Links Within Clusters


HAZARD FUNCTION
FAILURE RATE
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
AGE

Avalanche Model

HAZARD FN.

Base Failure Rate	0.001
Age at Rampup	20
Age at Death	40

Number of Linked Assets 10 — degree of system complexity (number of connected rocks)

Specify Single Constant Age

	Asset 1	Asset 2	Asset 3	Asset 4	Asset 5	Asset 6	Asset 7	Asset 8	Asset 9	Asset 10
Age Pattern	20	20	20	20	20	20	20	20	20	20
Independent Failure Rate	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

incidence rates (size of "rocks")

Constant Age 20

Exponential Increase in Rate

	1 Failure	2 Failures	3 Failures	4 Failures	5 Failures	6 Failures	7 Failures	8 Failures	9 Failures	10 Failures
Trigger Rate for Future Events	0.10	0.20	0.40	0.80	1.00	1.00	1.00	1.00	1.00	0.00

degree of dependency (strength of avalanche)

Initial Trigger Rate	0.100
Maximum Trigger Rate	1.0

Growth Rate of Trigger Rate	2
Failures until Full System Breakdown	4

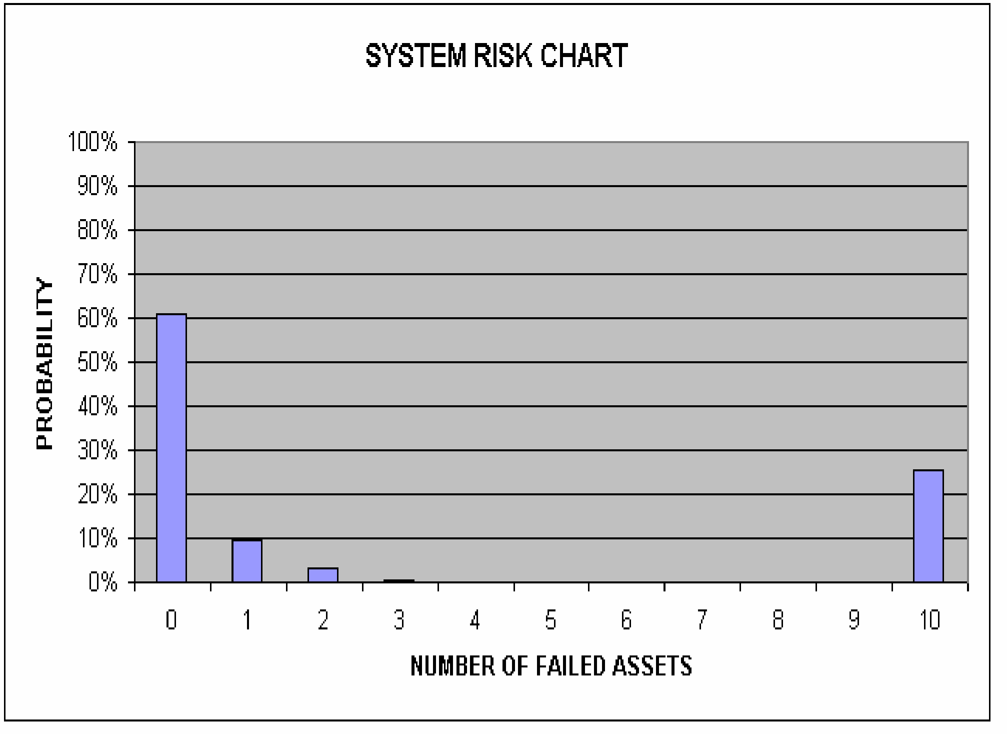
Catastrophe = 3 Simultaneous Failures

disaster management flexibility (avalanche warning system)

RESULTS

Asset Failures	Probability
0	0.6078
1	0.0971
2	0.0332
3	0.0052
4	0.0000
5	0.0000
6	0.0000
7	0.0000
8	0.0000
9	0.0000
10	0.2567
Total	1.0000

Catastrophe Rate 0.2619



Things may look great, but you could be headed for a Precipice!

Sensitivity to Number of Assets, Failure Rate and Trigger Rate

	Asset 1	Asset 2	Asset 3	Asset 4	Asset 5	Asset 6	Asset 7	Asset 8	Asset 9	Asset 10
Age Pattern	20	20	20	20	20	20	20	20	20	20

	1 Failure	2 Failures	3 Failures	4 Failures	5 Failures	6 Failures	7 Failures	8 Failures	9 Failures
Trigger Rate for Future Events	0.10	0.20	0.40	0.80	1.00	1.00	1.00	1.00	1.00

Background Settings

Base Case p(Catastrophe)
0.262

Probability of Catastrophe

10 Assets

		Trigger Rate		
		0.10	0.20	0.30
Base	0.001	0.2619	0.3545	0.3819
Rate	0.003	0.2721	0.3661	0.3939

5 Assets

		Trigger Rate		
		0.10	0.20	0.30
Base	0.001	0.129	0.193	0.213
Rate	0.003	0.134	0.200	0.221

Automatically Runs 12 Cases

Strategic Design Issue: Complexity versus Dependency

Number of Independent Assets Clusters
Number of Links in Clusters
Strength of Links Within Clusters

Total Assets	10	10	10	10
Number of Clusters	10	5	2	1
Assets per Cluster	1	2	5	10

BACKGROUND SETTINGS FOR COMPLEXITY ANALYSIS

			Trigger Rate
Age*	20	1 Failure	0.100
Independent Failure Rate	0.049	2 Failures	0.200
Definition of Catastrophe	3 Failures	3 Failures	0.400
		4 Failures	0.800
		5 Failures	1.000
		6 Failures	1.000
		7 Failures	1.000
		8 Failures	1.000
		9 Failures	1.000
		10 Failures	0.000

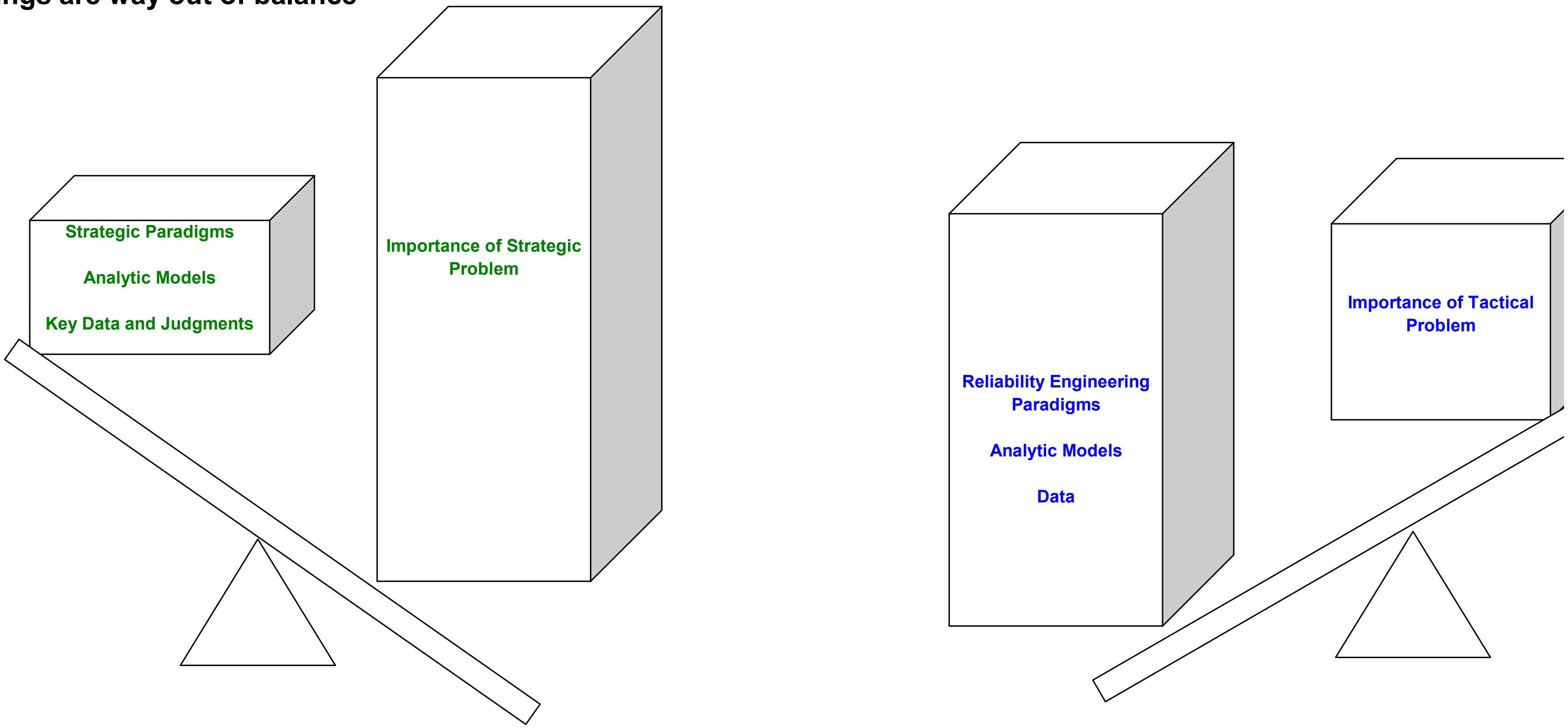
*Constant Age case only

	10 Clusters	5 Clusters	2 Clusters	1 Cluster
0 Failures	0.608	0.608	0.608	0.608
1 Failure	0.251	0.117	0.109	0.097
2 Failures	0.095	0.210	0.039	0.033
3 Failures	0.033	0.031	0.008	0.005
4 Failures	0.010	0.028	0.001	0.000
5 Failures	0.003	0.003	0.196	0.000
6 Failures	0.001	0.002	0.018	0.000
7 Failures	0.000	0.000	0.005	0.000
8 Failures	0.000	0.000	0.001	0.000
9 Failures	0.000	0.000	0.000	0.000
10 Failures	0.000	0.000	0.016	0.257
Total	1.000	1.000	1.000	1.000
Catastrophe	0.04654	0.06493	0.24433	0.26188

Run Complexity Analysis

Implications

Things are way out of balance



Most events and phenomena are connected, caused by, and interacting with a huge number of pieces of a complex universal puzzle." "Linked" by Albert-Laszlo Barabasi

CONCLUSIONS

Approach appears promising

Analytical way to tradeoff COMPLEXITY versus DEPENDENCY

Strategic risk assessment

Strategic system design

Unique model

Complements conventional reliability engineering analysis

Complements strategic tools for identifying risks (e.g., CATALYST)

Mild data requirements

Choosing Analytic Tools

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What kind of tools do you need?

- Tool choice follows from problem statement – what is a solution?
- Tool choice is guided by recognition of fallacies – what must tools be able to do and what must they avoid?
- Tool choice depends on characteristics of the tools themselves – how does a tool find an answer?

Revisiting the Fallacies

- Methodology: Problems can be solved by organizational change & asset management teams
  - Process vs. rigorous analysis
  - Debate outcomes vs. debate assumptions and logic
  - Cost benefit analysis vs. multi-year value optimization
- Procedural: The first important step is to gather data
  - Data first vs. problem formulation first
- Value Measurement: All projects can be valued using the same aggregate measures (i.e. $)
  - Single vs. multi-attributes

Revisiting the Fallacies (cont'd)

- Risk Measurement: Projects are risky because of uncertain financial consequences (beta appropriate way to measure project risk)
  - Financial risk vs. uncertainty in system performance

- Decision Objective: An important objective is near-term profitability
  - Project financial return vs. project system contribution
  - Corporate values vs. project specific system performance
  - Profitability vs. service
  - Short term planning vs. long lived assets
  - Reduced costs vs. appropriately guided investments
  - Asset management is a way to become more efficient and thus more profitable

Characteristics of applicable tools

- Captures company values (V)
- Represents measurable consequences (V)
- Identifies contingent decisions (D)
- Evaluates over sufficient time horizon (D)
- Treats changing information (D)
- Incorporates risk
- Provides transparent results
- Repeatable, explainable, modifiable

And In Closing

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T&D Expansion Strategies

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Outline

- Theory – The Capacity Expansion Problem (valuing expansion alternatives under uncertainty)
  - Planning Problem
  - Analytical Problem
- Data and Models
  - New Methodology
  - Tutorial – Case Study
- Organization Issues (Organizational structure and process for capacity expansion in local planning areas)
- Demonstration of Models – AIS and Load Dynamics

Planning Problem

- Economic value of investments affected by uncertainty future load
- Thus economic evaluations must include characterization of future load levels
- The questions are:
  - how to build the load uncertainty information into the economic analysis?
  - How to design least-cost investment strategies
- Accommodate the need to evaluate non-traditional options such as distributed generation

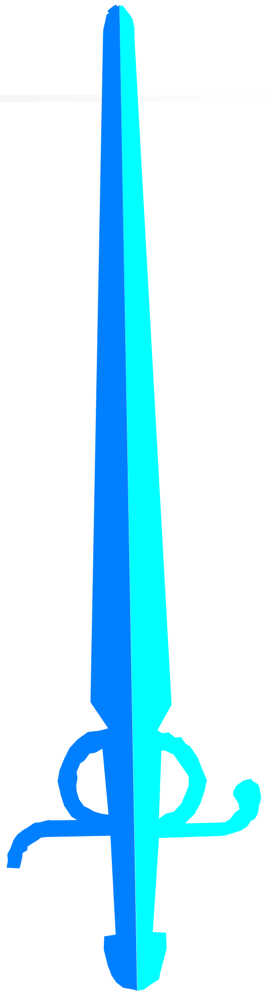
Analytical problem

- Valuation principles
- Economies of scale
- Limitation of scope
- Uncertainty

Investment Planning First Principles

- Deferral has direct economic value - opportunity cost of $
- There is a tradeoff between economy of scale and flexibility
  - big resources are generally cheaper but provide no flexibility
  - small investments defer big investments & provide option to revisit big decision
  - option to delay allows learning before deciding
- The value of being able to revisit depends on nature of uncertainty
  - EV, VAR, CORR, Type of Event
  - no uncertainty no value
- Independent of uncertainty, modularity has value
  - easier siting
  - tracks load better

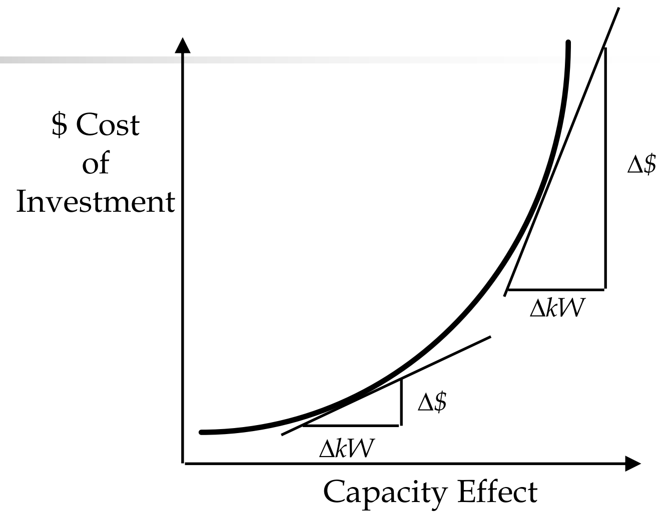
Economy of Scale - The Two-edged Sword



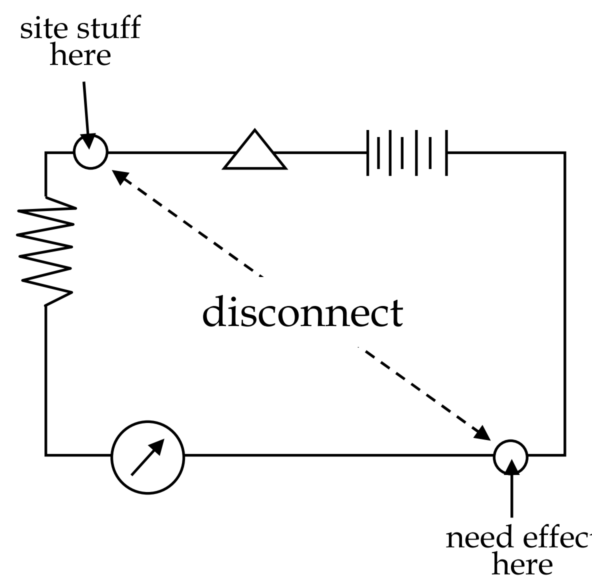
- When to invest in the big stuff?
- Type I Error: convict the innocent
  - avoid investment because first cost is too large
  - this ignores benefits of economies of scale
- Type II Error: release the guilty
  - make investment because the $/kW is small
  - but what if load growth is small or very uncertain?
  - if so, large capital cost for unused capacity for a long time

Limitation of Scope - Cost Versus Capacity Effect

- Part I: For DSM & modular investments, increasing costs for a fixed capacity effect

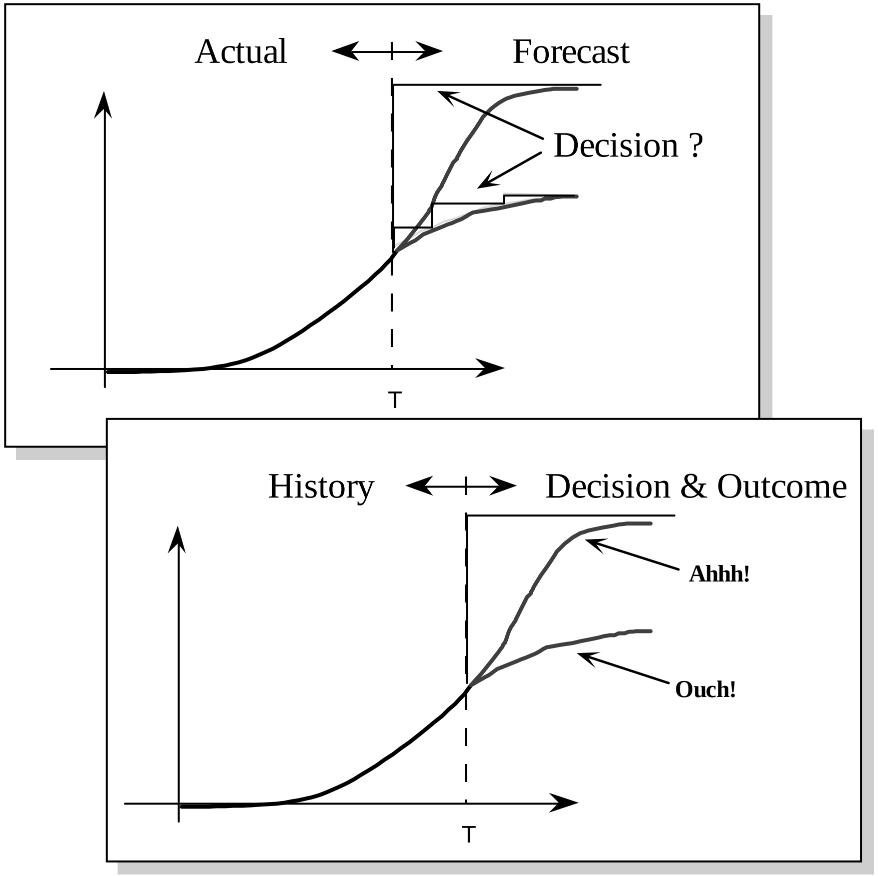


- Part II: Can the modular & DSM investments be located where the capacity needs exist?
  - Yes, but the effect saturates
  - No, so the effect is strictly limited (capacity need but energy benefit)



The Uncertain Load Problem

- Uncertain load and lumpy investments create a planning challenge
  - future load is probabilistic
    - can identify the potential for growth
    - but cannot accurately predict if and when it will occur
- The need for new capacity depends on future load growth
- Thus investment value is probabilistic and risky



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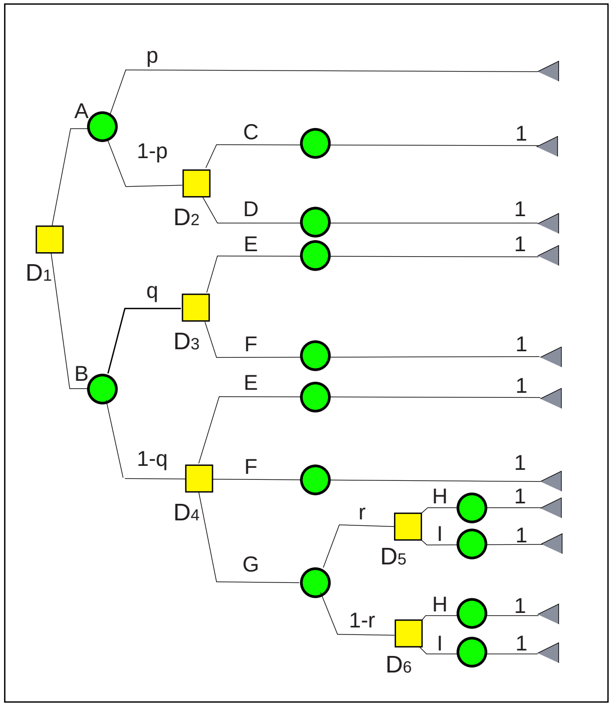
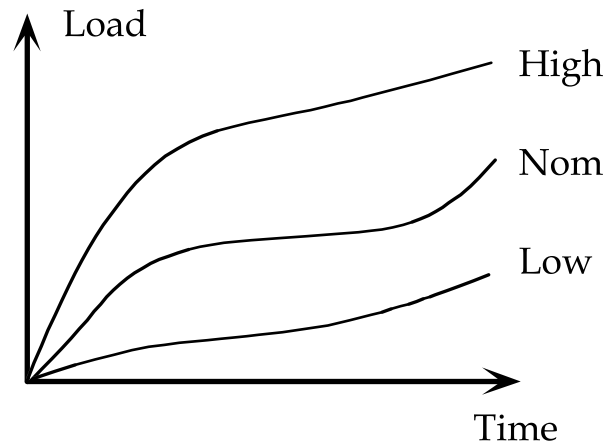
New Methodology

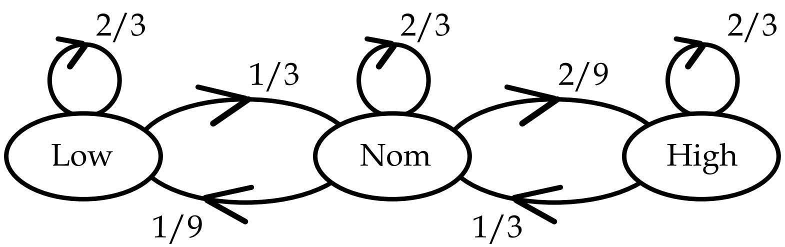
- Purpose
  - Can the system be made more efficient without sacrificing reliability and quality of service?
  - Find least-cost plan under uncertainty
  - Timed sequence of investments that are contingent of various states of nature
- Overview of model operation
  - Dynamic optimization represented as a decision tree
  - Series of nodes (decision - uncertainty - decision - etc.)



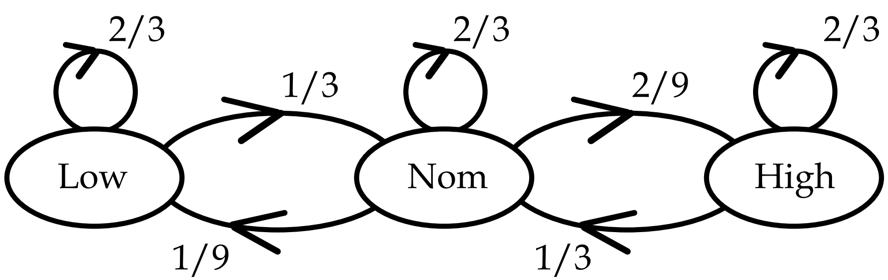
Methodology – Technical Problem

- large number of possible load trajectories that can result in a given future load level
- Many possible future load levels
- Finding the best investment plan requires some probabilistic understanding of the possible load trajectories





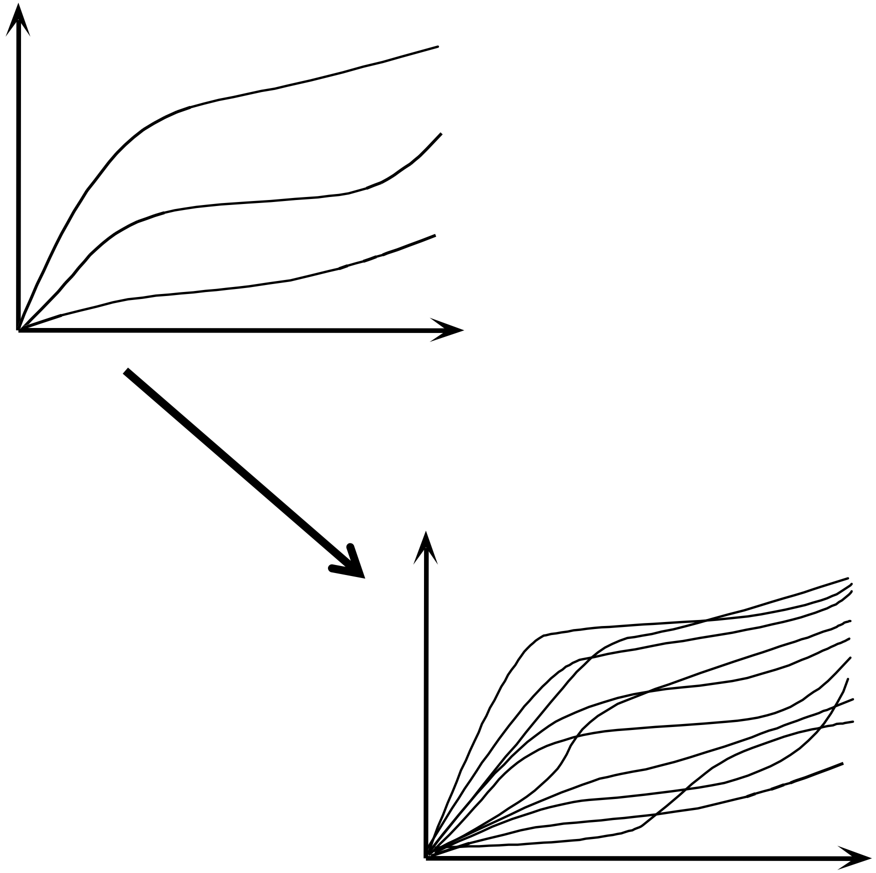
Methodology – Solution Markov chain



To / From	Low	Nom	High
Low	2/3	1/3	0/3
Nom	1/9	2/3	2/9
High	0/9	1/3	2/3

- A key observation : load growth is uncertain but correlated over time
- This lead to the idea that it is useful to describe load growth in terms of trends that persist for uncertain durations
- Key questions:
  - How long does load follow a given trend?
  - When the growth trend shifts, what are the possibilities and how likely is it to follow a specific trend

Methodology - Reasons for technical approach



- Feasible to model literally millions of possible load trajectories
- Provides method for describing true uncertainty (regression models that extrapolate historical trends are biased)

Real Utility Example

- Assumptions
- Case 1: No salvage of DR
- Case 2: Salvage of DR
- Case 3: No learning

Assumptions

ASSUMPTIONS – CASES 1 & 2			
Technologies (Capacity Alternatives)	*Life*	*Size (kW)*	*Cost ($1000)*
S: Substation	40	20,000	$2,000
F: Feeder	30	6,000	$900
E1: Engine 1	30	3,000	$1,500
E2: Engine 2	30	1,500	$750
E3: Engine 3	30	3,000	$2,250
E4: Engine 4	30	3,000	$2,500
Trend Transition Probabilities (Load Growth Specifications)			
	Low (1%)	*Medium (2%)*	*High (5%)*
Low (1%)	0.75	0.25	0.00
Medium (2%)	0.125	0.75	0.125
High (5%)	0.00	0.25	0.75
Initial Load Growth Rate			"Low" 1%

COMMON ASSUMPTIONS FOR STUDY		
Time Horizon	12 years	
Discount Rate	5.77%	
Inflation Rate	4%	
Accounting Method	Before Tax Cash Flow	
Initial Load	44,608 kW	
Maximum Area Load	70,000 kW	
Saturation On-Set Load	60,000 kW	
Terminal Value Specifications		
- Price of Capacity at Terminal Time	$10/kW-yr	
Variable O&M Cost – S & F	$0.02/kWh	
Variable O&M Cost – Engines	$0.05/kWh	
System Avoided Costs	$0.02/kWh	
Emissions Costs	0	
Load Shape	*Time (hrs)*	*% of Peak*
	0	100%
	88	95%
	264	90%
	8759	25%
	8760	0%
Load Growth Trends		
	Growth Rate	
Low	1.01 (1%)	
Medium	1.0201 (2%)	
High	1.051 (5%)	

Case 1 "No Salvage"

- Engines are constrained to remain in place once installed
- Least-cost policy: install feeder followed by substation

Decision (Stage 1)	Chance	Decision (Stage 2)
PV Cost = 2334.52		
F at t=0.00, L=44608	p=0.182, t=11.44, g=1.0111	S at t=11.44, L=50608
	p=0.595; t=7.82; g=1.0163	S at t=7.82; L=50608
	p=0.223; t=4.39; g=1.0292	S at t=4.39; L=50608

Case 2: "Salvage"

- Engines can be removed and reused
- Least-cost policy depends on evolution of load growth

Decision (Stage 1)	**Decision (Stage 2)**	**Decision (Stage 3)**	**Decision (Stage 4)**
PV Cost 1626.22 E1	E2	S(-E1, -E2) F(-E1, -E2) F(-E1, -E2)	T S S
	F(-E1)	S S E1	T T S(-E1)
	F(-E2)	S E1 S	T S(-E1) E2 S(-E1) T

Case 3: "No Learning"

- No trends in load growth
- Learn nothing by waiting
- Results:
  - least-cost policy is similar to that for Case 2.
  - The cost, $1941.62, is much higher – almost 20 percent.
  - If trends in growth exist, you can develop polices that take advantage of the trend information.

ASSUMPTIONS – CASES 3			
Trend Transition Probabilities (Load Growth Specifications)			
	Low (1%)	*Medium (2%)*	*High (5%)*
Low (1%)	0.25	0. 50	0. 25
Medium (2%)	0. 25	0. 50	0. 25
High (5%)	0. 25	0. 50	0. 25
Initial Load Growth Rate			"Low" 1%

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