Asset Management White Paper

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This white paper covers two topics. First is a brief description of Asset Management. Second is an overview of the decision tools needed for managing both individual assets (repair/replace decision making) and for managing a portfolio of diverse assets (project and portfolio valuation).

Stephen W Chapel,
S.Chapel Associates

WHAT IS ASSET MANAGEMENT[1]

Broadly, asset management describes any activities used to get the most out of something. Most industries today employ some form of asset management to control the costs of providing good service. Asset management typically revolves around making decisions about appropriate maintenance for existing assets and making decisions about wise investments in new assets. What is 'appropriate' and what is 'wise' depends on the industry and on the specific concerns of the organization in question.

Asset management involves two primary activities. One activity is managing each individual asset as cost-effectively as possible. The other activity is, given budget constraints in each year, choosing which projects to do in the current year and which to defer to a future year. The objective of this second activity is to maximize the aggregate value of the projects done in each year.

MANAGING INDIVIDUAL ASSETS

For any single asset, management typically falls in one of three approaches. One – ignore the asset until it fails, and then replace it. Two - run the asset for a specified length of time and then service or replace it once that time is up. Three - monitor or test the condition of the asset and take care of it once the risk of problems grows to some pre-set level.

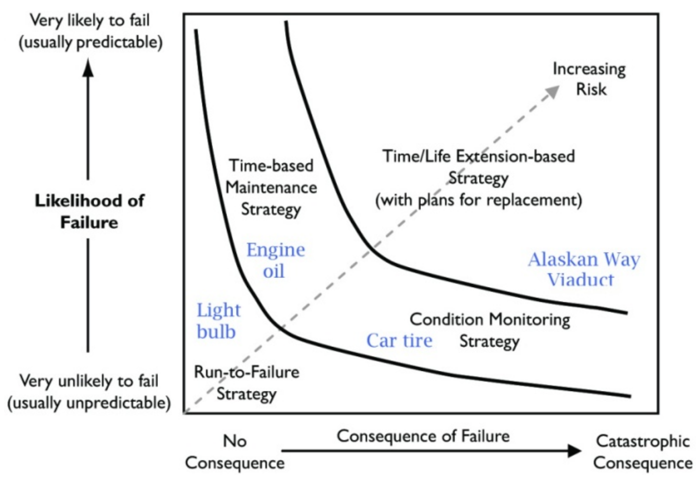

Figure 1
Asset Maintenance Strategies for Different Degrees and Types of Risk

Approach one, run until failure, is commonplace for assets that cause little or no problems when they fail, such as a light bulb in a car or home. Approach two, time-based preventative maintenance or replacement, is typical for assets for which failure is predictable or can produce a major problem, for assets for which no good test exists to check condition, or for which the cost of servicing or replacement is moderate. This approach is used, for example,

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[1] This discussion of "What is Asset Management" is largely from Chapter 2 of a document produced for Seattle City Light. That document, *Lifecycle Asset Management Program (LAMP) Implementation Strategy Report*, June 2008. Chapter 2 was written by Paul Haase.

with the engine oil in a car, which is changed every so many thousands of miles. Approach three, monitoring, is common for costly or critical assets for which failure can precipitate a catastrophe. Car tires, for instance, are watched and replaced once the tread wears below a certain level or other signs of problems appear. A variant approach may be used with very expensive assets, or those having long lead-times for replacement, such as a highway bridge. For such assets, life-extending treatments may be combined with frequent monitoring to safely keep the asset in use for as long as possible.

These approaches represent generalities. The best approach to manage any particular asset depends on that asset and how it is employed. Most light bulbs are run to failure, but bulbs in critical applications, such as those in a control panel at a nuclear power plant or a jetliner, may be changed every so often no matter what. It all depends on the health, wealth, and performance associated with the asset: the condition, the likelihood of failure, the costs of failure, of repair or replacement, of monitoring and testing.

PROJECT & PORTFOLIO VALUATION (P^2V) – MANAGING MULTIPLE ASSETS TOGETHER

The second major asset management activity arises because budgets are limited and even though repair/replace polices dictate that certain projects should be done, some may have to be deferred. The question is which projects should be deferred? For this activity, very different assets and situations must be evaluated against one another for need and the results integrated together in order to identify the priority choices.

The project and portfolio valuation problem in an electric utility appears very complex. There is a widely diverse set of assets including transformers, trucks, towers, dams, generators, poles, gloves, insulators, cable, circuit breakers, brackets, and much more. In addition projects are done to solve many different kinds of problems – safety, reliability, financial, customer satisfaction, and environment. The good news is that there is a solution to this problem. It lies in the application of multi-attribute decision analysis. Both the methodology and software have been developed, tested and applied in multiple applications at electric utilities.

The multi-attribute methodology allows for the explicit quantification of the consequences of doing a project in the current year, versus deferring the project, where the potential value of the project is from one or multiple attribute sources.

At the highest level, the reason projects are done is that they have impacts that contribute to overall corporate objectives (objectives that are determined by the stakeholders that the company serves). The valuation methodology allows for a company to define the measures of value that projects provide and to specify the tradeoffs of these competing values. The result is a method for measuring the value of doing a project in the current year and the value that is given up if the project is deferred. The methodology also includes an optimization approach that chooses projects so that the value of the portfolio of projects done in the current year is maximized.

DECISION TOOLS – MANAGING INDIVIDUAL ASSETS

As stated previously, there are three decision strategies: (1) run to failure, (2) run to a specified length of time and service or replace and (3), monitor or test the condition of the asset and take care of it once the risk of problems grows to some pre-set level.

When choosing decision tools the first task is to determine which of the three strategies best matches the nature of the specific asset in question.

- Run to failure assets are easy to identify – those that have minimal cost impacts when they fail. These assets, once identified, do not require repair/replace decision tools.
- However for run to failure assets, identifying the appropriate spares inventory could benefit from the application of standard textbook inventory methods.
- The other two classes of assets, those where run to failure is to be avoided, benefit from the application of decision tools. The decision problem for the second class of assets is to identify the best time period for servicing/replacement. The question for the third class of assets is, on a periodic basis, should an asset be inspected or tested and based on the inspection what is the best repair/replace course of action. The decision tools for these two classes of assets are the same. In both cases if inspection/diagnostics is an option it should be included in the decision model. The decision model will indicate the conditions under which inspection/diagnostics are cost effective.
- For the second two classes of assets the spares problem is more difficult. This is true because, for these classes of assets, the repair/replace solution and spares solution are interrelated. The interested reader is directed to a paper by Feinstein and Morris.[2] The paper can be downloaded from the following link.

  Link to Grid Reliability Paper

The analytic tools appropriate for managing individual assets are based on the discipline of Decision Analysis. Decisions Analysis is essentially a process for identifying good decisions where future outcomes are uncertain. This section does not explain the details of Decision Analysis. Rather an example is used to illustrate the application of the Decision Analysis process to the problem of managing an individual asset. The example includes the use of diagnostic testing.

A ONE PERIOD DECISION MODEL

A Decision Analysis framework that includes value of information is fundamental to the electric utility asset management problem. For every class of assets the following three elements are present:

1. *A decision cycle* – inspections and repair decisions occur on a periodic basis.

2. *Diagnostics testing* – potentially provides useful information and is an integral part of the asset management process.

[2] "Spare Transformers and More Frequent Replacement Increase Reliability, Decrease Cost". *Natural Gas and Electricity.* Feinstein C.D and Morris, P.A. February 2008.

3. *Maintenance and replacement options* – the key is to find a combination of diagnostics/inspection options and repair/replace options that minimize the lifecycle costs of the asset class.

The diagnostic testing protocol associated with any class of assets provides information about the state of specific assets in the asset class. However, diagnostic testing results alone do not directly prescribe which repair/replace decisions should be made.

- The best decisions are only identified when the information provided by the testing protocol are embedded in a decision model.
- The value of specific testing protocols can be directly computed when the protocols are imbedded in the repair/replace decision model.
- Diagnostic testing is only valuable if the information provided by the testing change the optimal repair/replace strategy. These points will be demonstrated using a simple decision model.

The example presented here has been constructed to be similar to a real asset management repair/replace decision. Suppose there is a 5/ 50 chance that an asset is in poor health and if left unrepaired it will fail and cost $1000. However the asset can be repaired for $100 and after the repair will not fail. This situation looks exactly like a lottery. If you choose to play the lottery you face the chance of a $1000 expense but avoid the certain $100 cost of repair. Suppose also that you have the option to inspect the asset prior to your lottery decision. The decision tree below illustrates this situation.

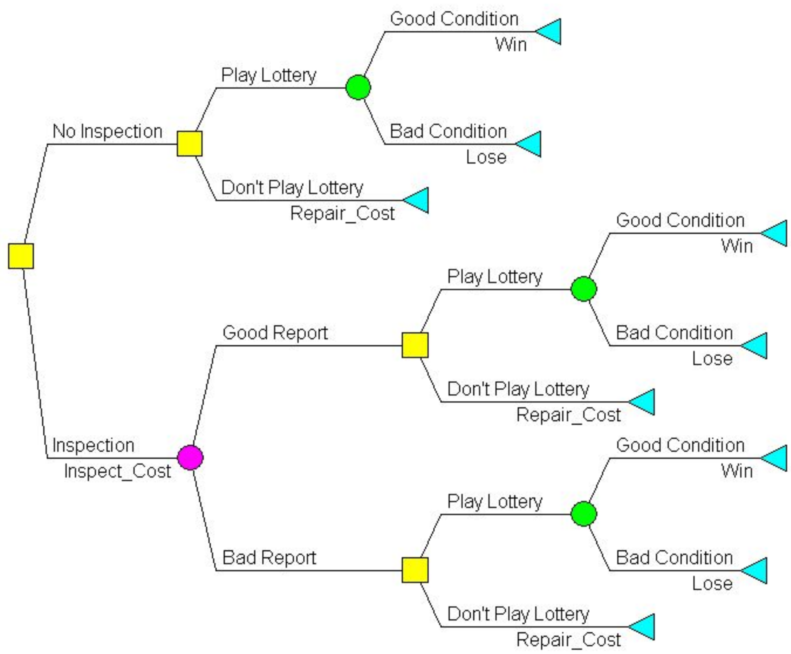

Figure 2
Example Inspection/Repair/Replace Decision Problem

With no inspection there is a 50/50 chance you will lose and pay $1000. The expected value is $500 and it costs $100 to do the repair and avoid losing. Clearly if there is no inspection, based on expected value decision making, you do not want to play the lottery.

Now consider the case if you inspect. Suppose the inspection is 95% accurate. If the inspection report indicates that the asset is in good condition, there is a 5 percent chance that it is in bad condition. If the report indicates bad condition, there is a 5 percent chance that it is in good condition. Prior to inspection there is a 50/50 chance that the inspection report will indicate bad condition. In this situation the best decision depends on the outcome of the inspection report.

1. If the report indicates good condition there is only a 5 percent chance that it will be bad and cost $1000 (expected value of $50). If you choose not to face the lottery and do the repair you incur a certain cost of $100. Based on expected values it is best to take the risk that the asset will not fail.

2. If the report indicates bad condition there is a 95 percent chance that it will be bad and cost $1000 (expected value of $950). It is clearly preferable to repair the machine and pay a certain $100.

What is the value of information here – e.g., how much should you be willing to pay for the information provided by the inspection? Without inspection the expected value is -$100. This is the best option in the top part of the decision tree. With inspection the expected value is -$75. This value is from the bottom part of the tree. Thus the value of the inspection is $25. This $25 is the maximum amount that you would be willing to pay for the inspection. Figure 3 shows the decision tree with expected values and "best decisions" identified.

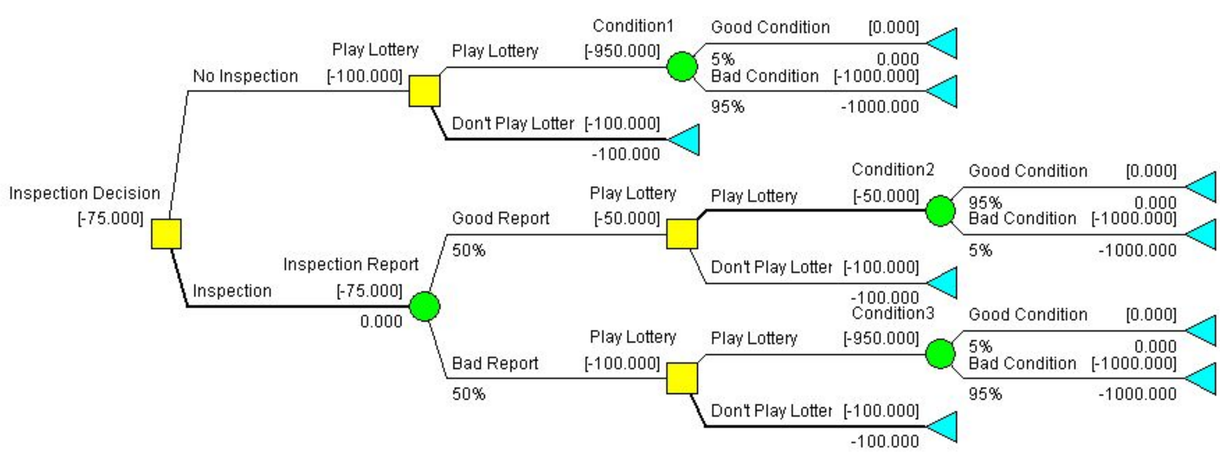

Figure 3
Decision Problem – showing best decisions and expected values

REAL WORLD ASSET MANAGEMENT PROBLEMS – MULTI-PERIOD DECISION MODELING

The model in the example above is for a one period evaluation. In most real world asset management problems, because the objective is to minimize lifecycle costs and because asset condition evolves over time, correctly solving the problems requires multi-period evaluations – what is done at a specific point in time will affect the best course of future actions. Multi-period models that capture long-term dynamics are required. In real world asset management decision models there are several essential elements, including the following:

- Decisions must be based on the estimated health state of the asset.
- Hazard functions (probability of failure as a function of age) are a starting point for estimating the health state.
- Improving the prediction of the heath state of the asset may require using inspections and diagnostics.
- The objective of managing individual assets is to minimize the lifecycle costs of the assets where costs include all cost elements (customer costs and power company direct expenses including initial capital costs and maintenance costs required during the life of the asset).
- The decisions in each period are (1) to test or not, and (2) decide what to do about the asset. If you are sure the asset is in good health or if you are sure it is bad health, testing provides no additional useful information. It is when the health state is uncertain that testing is potentially valuable.

Multi-period models are required for another reason. They provide an answer to the questions: (1) is diagnostic testing justified given the costs of the tests and the accuracy of the information provided by the tests, (2) at what age should testing be initiated, and (3) once started how frequently should the tests be applied?

An IEEE paper "The Optimal Replacement of Underground Cables" provides a detailed description of the application of a multi-period decision model that integrates diagnostic testing decisions and repair/replace decisions. This paper can be downloaded from the following link:

Link to IEEE Paper – Optimal Replacement of Underground Cables [3]

[3] *Optimal Replacement of Underground Distribution Cables*. Bloom J.A., Feinstein C., Morris P. IEEE Power Systems Conference and Exposition, 2006.

DECISION TOOLS - MANAGING MULTIPLE ASSETS TOGETHER (PROJECT AND PORTFOLIO VALUATION, P^2V)

Managing multiple assets together arises because budgets are limited and even though value calculations indicate that certain projects should be done, some may have to be deferred. The question is which projects should be deferred? In addition all organizations must set budget levels. Consequently there is a need to understand the value that is given up if budgets are reduced and the benefits obtained if budgets are increased. For these decisions multiple sources of project value (e.g., financial, environmental, safety, customer satisfaction, etc.) must be considered and quantified and the results integrated together in order to identify the priority choices. The decision tools for this problem are concerned with measuring the value of individual projects and identifying the portfolio of projects with aggregate maximum value.

The underlying principles for solving this decision problem are found in the discipline of multi-attribute decision analysis. Fortunately, via multiple applications at electric utilities, the underlying multi-attribute decision analysis principles have been applied to the problem of project and portfolio valuation (P^2V) problem and this has produced both a specific methodology and software for solving the problem. Key issues associated with P^2V are addressed in the reminder of this section.

P^2V – SOLUTION REQUIREMENTS

For a system to provide a valid solution to the P^2V problem, the system must address four issues:

1. *Consequences of Deferring Projects*: At the project level a system must measure the value contributed by a project and value that is given up if the project is delayed. The fundamental decision is what to do in the current year and what to delay.
2. *Consequences of Reduced Portfolio Budgets:* At the portfolio level a system must measure the value of the portfolio and the value of the portfolio under different levels of funding. The value of the portfolio is an aggregation of project values.
3. *Project Selection:* A system must be based on a project selection method that maximizes the value of the portfolio.
4. *Transparent Results:* The results of the system must be transparent to all parties involved. This means that project scores must be easily understood and results easily communicated to (1) engineers who sponsor projects, (2) managers responsible for company functional organizations, (3) company senior management and (4) regulators.

P^2V – THE VALUE MODEL

Measuring project value requires estimating what an organization is willing to pay in order to obtain the changes that the project will produce. At the project level a P^2V system must measure the value contributed by a project and value that is given up if the project is delayed. The fundamental decisions are which projects to do in the current year and which to delay to a future year. Project value must be measured in terms of contribution to company objectives.

The key to measuring project value is the application of a "Value Model." Value models are organization / company specific and they are not computer programs per say. They are a set of logic that translates the physical world changes, brought about by projects, into measures of value to the organization.

Value models:

- provide a consistent and objective means to evaluate, and then compare, all projects,
- represent each organizations unique value attributes and unique scales and weights that transform project effects into measures of value.

Multi-attribute Decision Analysis provides basic principles for constructing value models. The actual construction is typically done in workshops. At the conclusion of the workshops a company has a fully specified value model that can be implemented in software.

Value models consist of:

- a value hierarchy that specifies the attributes through which projects provide value,
- scales which translate project attributes into measure of value to the organization (a unit-less scale typically with a range of 0 to 1 or 0 to 10) and
- weights that determine the tradeoff among value producing attributes.

Figure 4 is an example of a value hierarchy (represented as an attribute tree). In the hierarchy there are six high level value attributes: Corporate Responsibility, Power Quality, Reliability, Safety, Environment and Monetary. This set of high level attributes is fairly typical of electric utilities and especially of transmission and distribution organizations. A project can provide value through one or several of these attributes. The attribute tree has terminal attributes – attributes with no sub-attributes. Each terminal attribute represents actual physical world changes that projects bring about. These changes must be specified for each potential project. These changes in the physical world are represented by natural unit scales, e.g., voltage levels, numbers of customers impacted, CO2 emissions, frequency and durations of electric service outages.

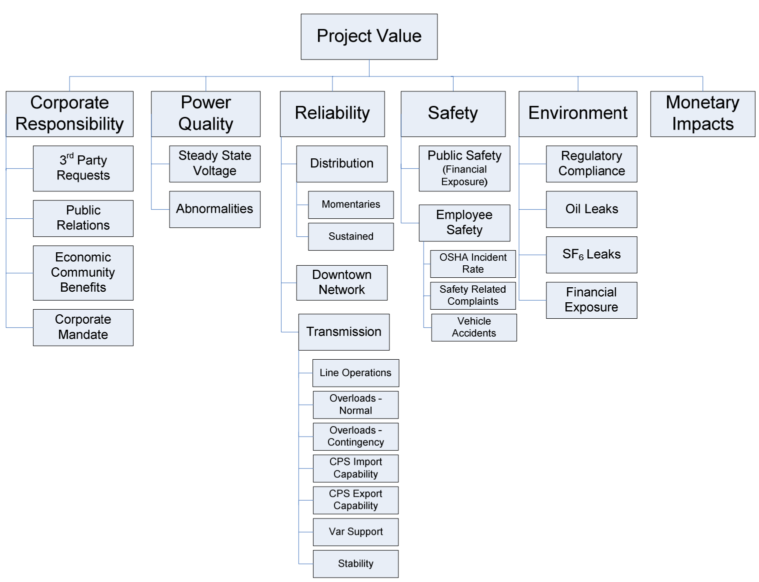

Figure 4
An Example Value Hierarchy

Scales and weights are used to translate the physical world changes into measures of value to the organization. In the construction of the value model, every physical world change defined in the value hierarchy must have a corresponding scale function that converts the natural units into measures of value. Figure 5 below is an example of a scale function. This scale function relates frequency of sustained outages to value. Typically sustained outage values vary by customer class.

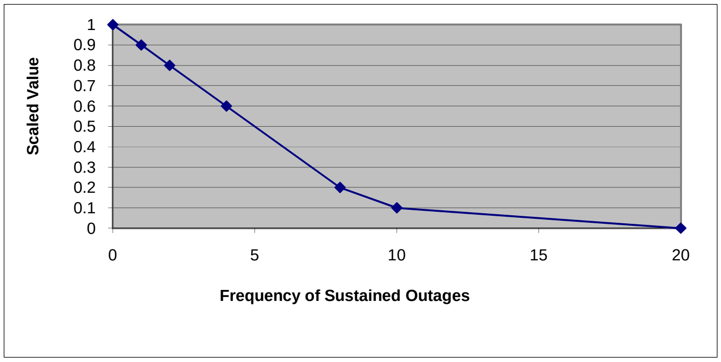

Figure 5
Example Value Scale for Outage Frequency

The third major component in a value model is a set of weights associated with the value attributes. A simple attribute tree is used to illustrate the concept of weights, Figures 6 and 7. In this attribute tree there are two high-level attributes, Public Safety and Sustained Outage. Sustained Outage is divided into three sub-attributes, Residential, Commercial and Industrial.

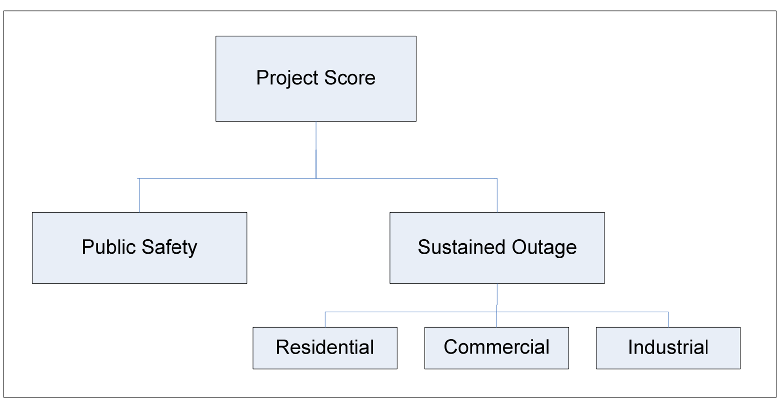

Figure 6
Attribute Hierarchy

In this example attribute tree, Figure 6, there are four terminal attributes: Public Safety, Residential Sustained Outage, Commercial Sustained Outage and Industrial Sustained Outage. The score for any project is a function of the natural units' inputs for these four terminal attributes converted to values (using scales) and weighted.

The basic principal for assessing attribute weights is to start at the bottom of the tree working on one sub-tree at a time and move up through the tree to the top. In this simple case the weights for the three sustained outage branches are assessed first. Then the most important sustained outage customer class is compared with public safety.

To illustrate, if the weights for Residential, Commercial and Industrial are 70, 90 and 100 respectively and if the weights for Industrial Sustained Outage versus Public Safety are 80 and 100 respectively, the normalized weights for the four terminal nodes are easily computed. These values are shown in figure 7 below.

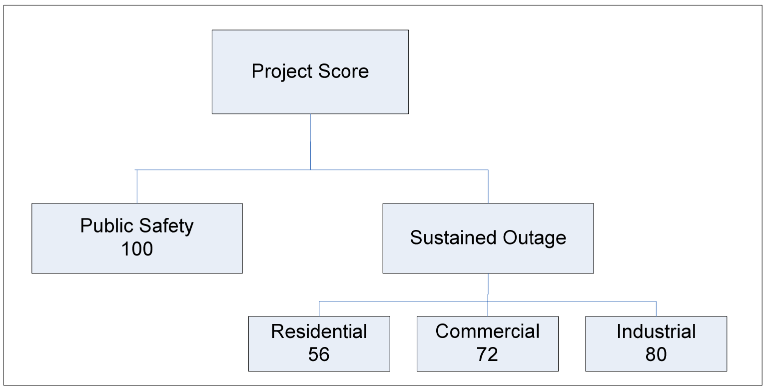

Figure 7
Attribute Hierarchy With Terminal Attribute Weights

Weights represent the relative importance of changes brought about by projects via the project attributes.

P^{2}V – RISK CONSIDERATIONS

A common misconception is that risk is a separate project attribute similar to other attributes such as monetary impacts, safety, and environment. In fact risk is an inherent aspect of each attribute and the design of the value model must take this fact into account. A simple example illustrates the point.

Suppose a specific project will solve a potential overload of a circuit. If the project is deferred, there is a chance that the circuit will become overloaded and fail, resulting in a power outage. Suppose there are two possible outcomes if the project is delayed: (1) no overload and no outage and (2) a significant overload and an outage of 10 hours. If the likelihoods of these two events are 80 and 20 percent respectively the expected outage duration is 2 hours.

The fact that outage is uncertain impacts the value of a project designed to solve the outage problem. If the 10 hour outage will happen for certain, there is no risk. There is just the 10 hour outage event if the project is not done. The question is how do you value projects that solve uncertain and thus risky situations?

To illustrate, if the value scale used to convert different duration outages is linear using the expected value of possible durations provides a valid measure of project value. However if the scale is non-linear using expected value duration (a natural unit) does not provide a valid measure of value. In this situation the scaled values must be used to compute the expected value of the project.

The scale function shown in Figure 8 illustrates the problem. For our example the value of the expected value duration (2 hours) is 0.95. If deferring the project has a value of 0.95, doing the project creates net value of 0.05 (1.0 - 0.95).However because of the non linearity of the value function and the relatively high cost of long outages the actual value achieved by doing the project is much greater. The correct value of not doing the project is 0.8

(0.8 x 1.0 + 0.2 x .0) and value achieved by doing the project is 0.2 (1 - 0.8). This example illustrates that risk can have a significant impact on the value of doing a project – in this example correctly accounting for risk increases the value of doing the project by a factor of four.

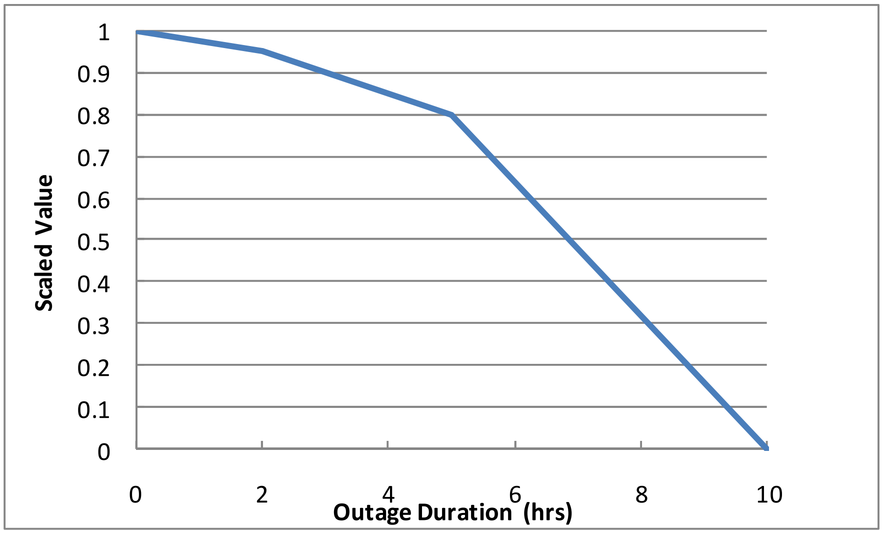

Figure 8
Example Value Scale for Outage Duration

P^2V – SOFTWARE CONSIDERATIONS

Many companies view the software selection decision as the lynch pin to P^2V success. This is a serious mistake. Value model design, testing, training and corporate commitment are critically important. Software is important but insufficient absent the other elements. However software is required and there are important considerations and question when choosing software.

Good P^2V software will have three components

1. A data management component for collecting, storing, and retrieving the information that serves as the foundation for project portfolio decision making.
2. A decision component for (a) converting project induced changes into measures of project value, and (b) using project value to identify value-maximizing portfolios.
3. A reporting component that displays the results.

There are several questions that should be considered when choosing software. These include:

- Is the supplier set up to handle both the IT and value modeling support that is required for success?
- Is the system designed to support implementation of value models based on a credible methodology for quantifying value (i.e., multi-attribute decision analysis)?
- Can the implementation of the tool be easily modified without the help of the supplier and without writing code? In other words, is the system flexible in its setup and modification or does it have a pre-specified set of project attributes that require software coding in order to be modified or expanded?
- Does the system have a data management system that allows ease of collecting, storing and retrieving information, including remote data entry and analysis?

- Does the software allow remote data entry via a client-server environment?
- How are reports generated and can the user create customized reports?
- Can the system export data to other corporate databases? Likewise can required data be imported into the system?

P^2V – AN IMPLEMENTATION CHECKLIST

A good implementation strategy benefits from a check list. At a minimum the list should include the following:

- Get the necessary corporate commitment
- Organize for P^2V and create the internal expertise to effectively use the system
- Create a credible valuation tool through rigorous design and testing
- Implement the system in a multi-user software environment.

Corporate Commitment: Implementing a formal quantitative P^2V system requires a commitment of significant internal resources in a corporation. Both managers and engineers must be committed to the design of the system and its adoption as the analytic tool for project and portfolio valuation. Resources and change management can only come from the most senior management in a company.

Organizational Change: Experience has demonstrated that to effectively implement a P^2V system necessary organization elements include:

- An executive sponsor, representing senior management's commitment to implementing the Project and Portfolio Valuation system
- A system administrator with the authority to administer the P^2V system including perform analysis and work with project sponsors and functional managers to get data and review project scores. The administrator must have accountability for the credibility of the analysis process.
- Project sponsors, typically engineers, in the functional organizations that are committed to the system and to working with the system administrator.
- Cross-functional support and participation from the various functional organizations – maintenance, engineering, construction, and operations – as well as management for the implementation of a comprehensive and sustainable P^2V program.

Design and Testing of the System: The success of a P^2V system depends upon a rigorous and credible analytic methodology for performing analysis of project and portfolio value. For the design phase: (1) use multi-attribute decision theory as the underlying methodology, (2) hire an expert in this field to facilitate the design and testing of the system, (3) budget at least six months for the design and testing phase, and finally (4) make it your objective to create a system that produces, for all stakeholders, credible project values and rankings.

CONCLUSIONS

This paper makes two arguments:

1. Electric utility asset management requires solving two problems: managing individual assets and managing multiple assets together.
2. These problems are about decision making under uncertainty and can benefit from the application of methods from the "science of decision making."

The first asset management problem, managing individual asset, can be solved by first recognizing that there are three classes of assets. Solving the repair/replace problem for two of the classes requires integration of diagnostic testing options with repair/replace options in a decision analysis framework. A one period decision model is used to illustrate the framework. This is followed by an argument that multi-period decision models are required for solving real world problems. Multi-attribute models are required because of the dynamic nature of the condition of assets over their life and the need for the key decisions, diagnostic testing and repair/replace, to respond to the condition dynamics.

The second asset management problem, managing multiple assets together requires the application of multi-attribute decision analysis. The decisions and objective associated with this second problem are:

- Given a budget constraint, which projects should be done in the current year and which can be safely deferred to a future year?
- Which projects do you choose to do in the current year so that the value of the set of projects done over time is maximized?

This paper summarizes the key aspects of the multi-attribute methodology that allows projects and portfolios to be valued including how projects changes are converted to values using scales and weights and how project risk potentially affects project value. There is also a discussion of software considerations and there is an implementation checklist.