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Monte Carlo Methods for Appraisal and Valuation: A Case Study of a Nuclear Power Plant

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Abstract:

Appraisals typically are conducted using four standard methods approved by the American Society of Appraisers. For large-scale, technically unique projects, such as chemical and power plants, and old industrial practices, these standard methods are insufficient. These types of projects contain political, technical, and economic risks that are not accounted for in standard valuation methods. To include these risks in an appraisal, a Monte Carlo simulation method can be used. Probability distributions are used to model the appropriate uncertainty. Modeling future decisions that may have to be made concerning the project can also be included to add insight to the risk involved. A case study of a nuclear power plant is presented. The use of Monte Carlo methods and the modeling of future decisions decreased the worth of the plant by 28% as compared to a standard income capitalization method.

Keywords: Appraisal, Capital Budgeting, Nuclear Power, Risk Analysis, Simulation, Valuation

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INTRODUCTION

Appraisals are conducted to find the fair market value of a given property for a wide variety of purposes, including insurance coverage, taxation, and sale. Appraisals to determine value are typically conducted using four approaches: net book value, comparable sales, reproduction or replacement cost, and income capitalization [Appraisal Institute, 1996].

Net book value is defined as the original cost of the asset, adding capital additions and subtracting capital retirements, and then deducting allowable depreciation. This appraisal method is generally used by accountants to calculate the gain or loss when an asset is sold. *Comparable sales* can provide an indication of fair market value when asset markets are competitive and liquid and when there have been many similar assets sold in a non-distress situation by a willing seller to a willing and knowledgeable buyer. Residential real estate, for example, is usually appraised using the comparable sales methodology.

Reproduction cost is the estimated cost to construct, at current prices, an exact replica or duplicate of the object being appraised, using the same materials, construction standards, design, layout, and quality of workmanship, and embodying all the deficiencies, superadequacies, and obsolescence of the subject asset. *Replacement cost* is the estimated cost to construct, at current prices, a property with utility equivalent to the original property being appraised, using modern materials and current standards, designs, and layout. The reproduction or replacement cost may be reduced by depreciation classified by physical deterioration, functional obsolescence, and by some factor related to risk. Many personal items, including machinery, tools, jewelry, and art, are evaluated using reproduction or replacement cost methods.

The *income capitalization* approach is based upon the "no arbitrage" hypothesis that the fair market value of a property is directly related to its discounted future net cash flow. The higher the net positive cash flow (*i.e.,* the difference between revenues and costs), the more valuable the project. The calculated value of a property using an income capitalization approach is the present worth of all rights to the tangible benefits to be derived from the property in the future. This method is only applicable to projects producing cash flow streams.[1] For example, the theory specifies that the buyer of a process plant producing a product for sale would pay no more than the value of the expected future cash flows, discounted to current dollars.

These methods are adequate for most common properties; however, complex industrial properties present appraisers with unique challenges (*e.g.*, Weber [1997]). These types of properties are large scale, unique, usually politically sensitive, and have inherent risks affecting future cash flows. Examples are oil refineries, old factories and old industrial facilities, chemical plants, and power plants. When appraising these properties, the typical valuation methods are inadequate. Very few of these projects are sold or rebuilt. Even if these properties are sold, sales data are generally confidential. Additionally, the replacement cost approach is often not applicable since very few equivalent plants are constructed. A simple income capitalization approach does not include uncertain future outcomes that could impact cash flows (*e.g.*, many of these projects will have significant environmental legacies). Now the question becomes: what is the appropriate method to value these unique properties?

The method proposed by the authors involves the use of a Monte Carlo simulation technique to model the stochastic process underlying the cash flows, thus enabling the income capitalization approach to incorporate the impact of many types of uncertainty. The probabilistic cash-flow modeling approach allows political, technical, and market uncertainties to be incorporated into the appraisal methodology. In fact, the benefits of the simulation approach have been recognized by the appraisal industry (*e.g.*, Appraisal Institute [1996], Li [2000]). Gain [1990] goes as far as labeling the simulation approach "one of the best methods available for estimating the value of income-producing properties." Adding uncertainty into an appraisal produces a result that implicitly recognizes the risk involved with these types of projects.

DEVELOPING A SIMULATION MODEL

The quantitative risk analysis (QRA) technique (Hertz [1964], Park and Sharp-Bette [1990], Birnie and Yates [1991], Jones [1991], Koller [1999]) is especially useful for valuing complex industrial facilities. For example, the nuclear power plant discussed in the case study later in this paper faced a number of unresolved technical, design, and licensing issues that increased uncertainty and negatively affected its fair market value.

The uncertainty surrounding the expected useful life of the facility adversely affected its capitalized income. QRA involves a comprehensive capitalized income calculation that simultaneously considers multiple project risks.

The development of a computer simulation model to be used for an appraisal starts with a typical cash-flow forecast or project *pro forma* financial statement. A *pro forma* states the net income from the project over the expected useful life of the project; the larger the difference between the costs and the revenues, the greater the net operating income and value of the property. All the variables that help to determine the costs and revenues of a project should be included in the detailed analysis, as well as all relationships between those variables. After the basic model is constructed, three types of risks are added: economic, political, and technical. This section will outline the core components of this modeling process.

Representations of Uncertainty

Many levels of uncertainty affect the profitability of a complex industrial process. Whether or not an event will occur is the first level of uncertainty (*e.g.*, the passage of a new air pollution regulation). Then, secondly, *when* the event will occur must be estimated (*e.g.*, the date of passage). Given that the time the event will occur, *how long* the event will last is the third level of uncertainty (*e.g.*, time to meet compliance). The fourth and fifth levels, respectively, are the cost of the event and how effective the event will be (*e.g.*, the cost and the effectiveness of the pollution-control equipment). When working with an industrial process, uncertainty in each of these levels is common and should be considered for a complete assessment.

One of the most important analyses that must be completed before a discounted cash flow analysis can be performed is the construction of a *tornado diagram*. This analysis is performed to determine which variables contribute significantly to the project's value-assessment uncertainty. Identifying the key variables allows the appraiser to focus attention and effort on those factors/variables most likely to affect the asset's valuation.

A tornado diagram can be constructed in several ways. In Figure 1, the diagram is constructed by regressing the important input variables on the output (typically net present value or NPV). The values represented in the graph are the standardized beta coefficients from that regression, using the iterations from the simulation as the sample data. These values can be either positive or negative, depending on the direction of their influence. The implications found in Figure 1 include the fact that a one standard deviation increase in the Selling Price causes a 0.5 standard deviation increase in the project's NPV and that a similar increase in Fuel/Material Costs causes a 0.3 standard deviation decrease in the project's NPV. The variables that produce the largest change in the NPV are the most important to the project. Once identified, these variables should be thoroughly researched and methods to reduce their uncertainty should be considered.[2] It may be worth the effort to expand the most important variables by looking at the factors that affect *their* uncertainty (*e.g.*, for Selling Price: demand, competitor's price).

Variables that have little impact on the asset's NPV can be considered to be known (fixed at their most likely value) without affecting the simulation's results (or the final appraisal). Unfortunately, there is no simple rule as to which variables should be included and which should be simplified. Expert judgment needs to be applied and different thresholds may be appropriate for different problems. In this example, Selling Price, Fuel/Raw Material Costs, and Efficiency of the process should definitely be included as variables in the simulation.

[Figure 1]

Uncertainty versus Variability

Although an input many change or vary over time, a variable is not necessarily uncertain simply because it is changing. There is a difference between *uncertainty* and *variability*. For example, the cost of maintenance may vary from month to month even though the annual average is consistent from year to year. Even though the cost of maintenance varies, it does not mean that it is necessarily uncertain for all time scales. In some cases, future maintenance costs, although variable, may be forecast with almost complete certainty if risk-mitigation options are adopted (*e.g.*, long-term maintenance contracts).

Conversely, uncertainties are often inherent in such items as fuel prices, the effects of electric utility deregulation, and competition. In these cases, future events cannot be predicted with specificity. The price of fuel changes over time as the demand and supply change (both of which are uncertain). Even these uncertain variables can have opportunities for risk-reduction measures (*e.g.,* long-term fuel contracts or power purchase agreements).[3]

Correlations

To make a model of a facility more accurate, correlations between variables should be modeled. These correlations allow variables to be linked across time (*serial correlation*) or for one variable to be linked to another (*intervariable correlation*). A serial correlation is used to model the relationship of a particular variable from year to year (*e.g.*, the inflation rate). The inflation rate does not vary greatly from year to year; changes usually occur gradually. However, once a change has occurred, future rates tend to "persist" at that level for a time. Serial correlation allows the value for inflation to depend on the previous year's value. By including serial correlation, simulated forecasts of inflation rates appear as a smooth, rather than spiky curve. Intervariable correlation is used when there is a relationship between two variables. An example of an intervariable correlation is availability and unplanned maintenance expenses. A facility that has a high availability level generally has low unplanned maintenance expenses. As availability increases, it is likely that there are few unexpected repairs; thus, there is a negative correlation between these two variables. Other intervariable correlations can be the consequence of market economics. For example, if only a rival firm experienced higher costs, then the firm's sales should increase (as customers substitute one firm's products for the other's). In this case, there would be a positive correlation between a rival firm's costs and the primary firm's sales.

These correlation methods help to model the income streams of a project more realistically. More importantly, correlations can serve to either moderate (*e.g.*, the benefit of diversification) or exacerbate (*e.g.*, selling into a falling market) uncertainty. Thus, failure to attend to correlation can result in lost risk-reduction opportunities or potentially devastating hidden risks.

To find these types of correlations, a large amount of data is generally needed. For many variables, this data is not difficult to obtain. Most companies and management firms store large amounts of data on the operation of a project. For large, unique types of projects, government agencies may also record and file relevant data. Most data sources are in the public domain and are easily obtainable. If information that is needed is not given by plant-specific data, historical industry-wide data or expert opinion may also be used if then subjected to appropriate sensitivity analysis.

Market and Economic Risk

The market for different types of products can vary greatly across regions and over time. Electricity prices depend on demand, capacity, weather conditions, fuel availability, and other variables. Uncertainty about future inflation, interest rates, and competition with rivals will increase economic risk. The introduction of new processes or regulations can dramatically reshape a market and create significant uncertainty and risk. For the electric power industry, deregulation is such an example. In California, deregulation of electric utilities has shocked the entire system, while in Pennsylvania the transition has been smooth. The threat and occurrence of deregulation has led some utilities to close inefficient plants, terminate above-market power purchase agreements (PPAs), rapidly expand power-generation construction, and seek long-term fuel contracts. The value of existing plants has changed based on the region and the deregulation policies.

Technical Risk

Projects that depend on high-technology can a high degree of risk. These risks may be the result from new technologies that did not meet expectations or the premature obsolescence of adopted technologies. Over time, more efficient and environmentally benign processes may leapfrog over previously successful ones rendering older plants obsolete sooner than planned, resulting in a shorter estimated useful life (*e.g.,* equipment may not survive to its predicted useful lifetime). Capital investment projects with long payback periods can face significant technical and financial risks because of operating uncertainty in availability, maintenance, and production levels.

Political Risk

Political uncertainty is a characteristic of many industrial projects. Changes in regulatory issues (*e.g.*, new, more stringent air-quality or water-quality restrictions, site remediation requirements, or other environmental mandates) are difficult to predict. An election can change the underlying philosophy of a regulatory agency (*e.g.,* the EPA under a Gore administration versus a Bush administration). Additionally, public opinion can exacerbate the political risk (*e.g.,* the nuclear power industry). As demonstrated by the Three Mile Island and Chernobyl accidents and the recent deregulation problems in California, a series of events in one part of the country (or world) can change public perception overnight and, as a result, increase (or decrease) the risk for all commercial nuclear power facilities. Nuclear energy, lauded by the public in the 1950's and 1960's as a low-cost "clean" power source, fell into disfavor for decades because of two major accidents. During the 1980's and 1990's, the vast majority of the public opposed nuclear power over operating safety and spent-fuel storage concerns. Only recently has that view begun to change – and the change towards greater acceptance has happened with near-equal alacrity because of growing energy shortages [*Wall Street Journal*, May 2, 2001]. Additionally, public sentiment is often hard to predict (*e.g.*, why weren't there major protests in France when it adopted a large nuclear power-plant building program in the 1980s?). All of these political factors can greatly increase the uncertainty of future cash flows and, therefore, an asset's value.

Modeling Future Decisions

Many future uncertainties are beyond a manager's control. However, managers are invested with the responsibility of responding to these uncertainties to further the interests of the firm. Should an unexpected event occur in the future, we would expect a manager to respond by either limiting the firm's loss or exploiting newly available opportunities. Thus, representing choices taken at future decision points is an essential component of any multi-period simulation model.

The incorporation of *decision logic* into a simulation model has been widely advocated in the literature on real options [Trigeorgis, 1996; Amram and Kulatilaka, 1999]. Failure to incorporate prudent future managerial decision making means failing to incorporate the value of informed strategic action. For example, considering a scenario in which a firm continues to lose money period after period fails to take into account management's ability to simply halt operations, the so-called option to shut down.

The incorporation of a rational decision maker in a simulation model can substantially alter the value of an asset, depending on the discretion given to management and the degree of contingency presented by future uncertainties.

CASE STUDY: NUCLEAR POWER PLANT

To demonstrate the appraisal-via-simulation process described here, an actual valuation and appraisal of a nuclear power-generating facility performed in the early 1990s is presented.[4] The potential for greater current interest in nuclear power makes this analysis newly relevant. This particular facility was one of the first commercial nuclear power-generating facilities to be built and operated. The appraisal was performed 20 years after plant start-up to estimate the current value of the plant for the reason of property tax collection by the governing municipality. For taxation in this state, the fair market value of the facility is needed.

Construction of the plant began in the 1960s, and the plant begun electricity production in the 1970s. The original cost to construct the plant was approximately $150 million, and the plant is located in a rural area on a 500-acre site.

The plant was designed to produce approximately 750 MWs to be sold to its owner, a nearby utility. In previous years, this particular plant had experienced problems with its operations that resulted in it being put on the Nuclear Regulatory Commission (NRC) Watch List. The operating capacity and corresponding high operating costs of this facility were inconsistent with those of similar nuclear power facilities. Due to this historical information, the value of this plant could not be compared to other similar nuclear power facilities.

Variable Importance

The first step in the analysis is to identify the most influential variables in the appraisal of the plant. This is done using the tornado diagram shown below in Figure 2. In this appraisal, the prices paid for the electricity generated and the operating costs of the plant are the most important variables in the analysis.

[Figure 2]

Variability

Variability in day-to-day operations is also a characteristic of a nuclear power plant. There is both daily and hourly variability in electricity prices due to on- and off-peak rates and monthly variability in fuel costs. There is also monthly variability in the maintenance costs arising from scheduled maintenance periods. Because the focus of the analysis is the fair market appraisal of the plant over a 19-year period, only the yearly averages are modeled as variables. If more detail was needed for a higher resolution analysis, then the monthly, daily, or even hourly variables could be included. Yearly, these variables are relatively constant, with changes largely a result of industry trends.

Economic and Market Uncertainty

The economic competitiveness of nuclear power, as compared with other means of generating electricity, depends on the cost and financial risk of operating nuclear power plants. Both cost and risk can be lowered through improvements in the technology and reductions in fuel and other operating costs. The cost and risk associated with individual nuclear power plants varies substantially. Therefore, it is imprudent to correlate industry data to a facility without complete analysis of a specific plant and the regional economics.

Other market risks connected with the plant are the regional power-generation capacity and the industrial power-market demand. The U.S. is divided into electricity producing regions. The region in which this particular plant is located contains many fossil-fueled electric generating stations, primarily fueled by coal but with several newly constructed gas turbine combined-cycle plants. Therefore, the regional power market is currently linked to the cost of production from coal power plants, but at the time of the appraisal, it was anticipated that gas turbine combined-cycle plants would become an increasingly important. These regional fossil-fuel plants generally have lower production costs than the nuclear power plant. In addition, the local industrial market demand was changing with several large industries reorganizing and cutting back production and electricity consumption. Because of these factors and due to increased competition in all areas of business, industrial customers actively sought the lowest cost electricity, which was not produced by nuclear energy in this region.

In addition to the above market risks, discussions and uncertainty about sweeping deregulation of electric utilities was a major concern. Theoretically, if consumers can pick their electricity provider, the demand for low-cost electricity production will sharply increase. This may lead to many of the inefficient, high-cost nuclear plants to close.

Political Uncertainty

There are two main political uncertainties associated with this plant. First, at the time of the assessment, nuclear power had a very negative image in the United States. Many Americans believed that nuclear power was dangerous to human health and therefore, unacceptable for widespread use. These opinions shaped a negative social climate regarding the technical and environmental hazards associated with the plant. The growing media coverage of environmental risk in general and nuclear risk specifically highlighted these concerns. Throughout the U.S. (and in this region), organized opposition to industrial siting was so prevalent that new names were created: NIMBY (not in my backyard) syndrome and BANANA (build absolutely nothing anywhere near anyone). For nuclear power, the situation was exacerbated by widespread opposition to the siting of a permanent repository to store the large and growing volumes of nuclear waste. On balance, because of power needs, the public was unwilling to rule out the nuclear option completely (unless another major accident occurred), but was opposed to any expansion of this option (several nearly completely plants were never commissioned).

The second political problem is that the spent fuel storage pools at the facility were becoming full and an alternative method to store the irradiated fuel had to be found. The method of on-site dry cask storage had been proposed by the plant's owners to solve this problem. However, not everyone agreed that this is the best method. The governing state's Attorney General had challenged the use of dry cask storage, and local papers had described how radioactive wastes would end up polluting nearby lakes. At the time of the analysis, the plant's plan was to have the casks remain on-site until the Department of Energy began to take receipt of spent nuclear fuel for permanent storage at the federal repository targeted to be Yucca Mountain, Nevada. For this study, the availability of Yucca Mountain was estimated to be no earlier than the year 2010 after the plant had retired.

Based on a review of local newspaper articles and interviews with experts familiar with the history of dry cask storage and the political opposition to this storage alternative, it was estimated that the likelihood of action against this storage option would be strongest in 1993, and would reduce in subsequent years. Because of the uncertainties involved (*e.g.,* disagreement among experts in predicting the strength of public opposition), the probability of this occurrence in any given year was estimated using beta distribution. It was assumed that if spent fuel storage was going to be a problem, half the time the plant would have to shutdown permanently (the state legislature would bar the dry cask storage option) and half of the time money would be spent to remedy the problem. In instances where the storage problem was resolved, the NPV is calculated by a *pro forma* modified to reflect the expense of repairs and lost income due to extended downtime. It was assumed that implementing a new storage system would on average cost $10 million and take three months to complete.

Technical Uncertainty

The technical uncertainty in this project involved pressurized thermal shock (PTS) to the reactor pressure vessel (RPV). The RPV houses the nuclear fuel and control equipment for the operation of the plant. Key weld areas of the RPV had become embrittled by the continuous exposure to neutron radiation from the nuclear fuel. Under certain temperature and pressure conditions, normally encountered during plant startup, shutdown or during certain potential accidents, these weld areas could be subject to cracks, known in engineering terms as PTS, resulting in a possible rupture of the RPV. Although vendors were, at the time of the appraisal, researching methods of annealing RPVs to relieve the stresses induced by the neutron exposure or simply to mitigate the risk of PTS, the NRC had yet not sanctioned any method of repair.

A process called annealing might resolve the RPV issue. With annealing, the entire RPV is raised to high temperatures for a duration of time to renew any weak or brittle welds. At the time, this process had never been performed in the United States. The annealing process would require the facility to be off-line for no less than six months, and possibly much longer, resulting in lost generation sales. Moreover, without a proven annealing process prior to shutdown, the annealing process could be a failure, leading to permanent shutdown and decommissioning. This issue represented the single largest liability to the continued operation of the nuclear power facility.

Aside from the possibility of permanent shutdown, because the length of time that the plant would be offline is unknown, the technical uncertainty creates an economic exposure in the project. The longer the plant is shut down, the greater the economic loss. The uncertainties associated with annealing extended to when it might be required, how long it would take to complete, how successful it would be (if at all), how expensive it would be, and the probability it might fail. Therefore, all types of uncertainty described in the introduction are associated with the annealing process for this plant.

Modeling a Future Decision

The combinations of the above uncertainties and the timing at which they could occur require that a rational decision-making process be integrated into the model. Obviously, future decision would greatly influence the plant's cash flows. For example, if eight years into the future, the NRC requires that annealing be done or the plant shutdown permanently, then the plant owner must decide what to do. At the time of the decision, does annealing make economic sense? At that future decision point, the expected future earnings of the plant and the expected cost of annealing must be compared to the cost of retiring the plant.

Developing a model for this future decision involves uncertainties from all levels of the problem. It was assumed that if the NRC would require annealing, they would do so during the period from 1998-2002, with 2001 and 2001 being the most likely years. The probability of the NRC requiring annealing for a given year was determined using professional judgment based upon review of the then-available industry and NRC data. Our model used beta distributions for these yearly probabilities to reflect the uncertainty inherent in NRC's annealing decision timing. See Figure 3 for the distribution for 2002 given that it had not occurred previously.

[Figure 3]

The expected value associated with plant shutdown (because of RPV embrittlement) is calculated by determining the shortfall in the decommissioning account for each year and then discounting this amount into the appropriate year's dollars. If, however, the RPV is annealed and the plant returns to normal operations, then the expected cash flow is calculated on a separate *pro forma* modified to reflect the expense of repairs and lost income due to the extended downtime. The cost of repairs is assumed to average approximately \$45 million and is modeled using a truncated normal distribution with a lower limit of \$10 million and an upper limit of \$100 million (see Figure 4). It is also assumed that the repairs will require the plant to be down for an average of 11 months. The shutdown time is modeled using a general probability distribution ranging form 6 months to two years (see Figure 5).

[Figure 4]
[Figure 5]

In this model, the decision on whether or not to anneal the RPV is made based on strictly economic factors. The NPV resulting from the modified *pro forma* is compared to the cost of terminating operations and decommissioning the plant. If the NPV with annealing is greater than the cost of ceasing operations and decommissioning, then the RPV is annealed, and it is assumed that the plant will operate without further PTS problems for the rest of the license period through 2010. If the owners determine that annealing is not economically justified, then the plant will permanently shutdown. By adding this logic, the modeling task becomes more complex, but it is significantly more realistic reflecting what would really happen.

Catastrophic Failure

Lastly, a small probability of catastrophic failure was also modeled. An example of such an occurrence is the Three Mile Island, Unit II, incident. During this incident, there was radioactive leakage and, although there was no harm to the public or property outside the plant's fence (suggesting that the use of the term "catastrophic failure" was inappropriate in some sense), the incident led to the closing of the facility.[5] Though nuclear power-plant systems and components are designed and constructed to operated such that they will not experience catastrophic failure at a rate more frequently than 1 in 100,000 events in any year, human factors and the plant's "safety culture" can increase or decrease these risks. Again, a beta distribution was used to model this uncertainty in the yearly probabilities.

A Scenario Example

The quantitative risk analysis (QRA) for this model consists of two probabilistic steps. First, a sequence of major yearly events is randomly generated (*e.g.,* normal operations, spent-fuel storage problem, annealing required, catastrophic failure) creating a "scenario." (There were, in fact, 286 different possible scenarios.) Then, for each year in this scenario, using the distributions of costs and revenues previously discussed, a specific cash flow is determined. This two-step process is then repeated many hundred of thousands of times, to generate the overall distribution of cash flows for the plant over the next 19 years. Each iteration of the two-step process defines a complete *pro forma* spreadsheet. In this type of analysis, hundreds of uncertain input parameters in the model (*e.g.,* inflation rate in 1997, maintenance cost in 2002, fuel price in 2000) are randomly varied simultaneously, not just one at a time as in typical sensitivity analyses, and the values for each variable are drawn from their entire distribution, not just their upper and lower values.

Table 1 shows an example of one scenario (of the possible 286) that could occur in the model. This is one of the more probable scenarios. As shown, there are "Normal Operations" for 17 out of the 19 years, a successfully resolved spent-fuel storage problem in 1993, and successful RPV annealing in 2002. For each year in the scenario, a net revenue value is determined and discounted back to present value (PV) in 1992 dollars. The sum of these PVs is the NPV ($146.7 million) for this one iteration of this one scenario.

[Table 1]

To demonstrate the variability of the NPV of a scenario, this one scenario was simulated 1,000 times, generating 1,000 NPVs. This distribution of NPVs is shown as a cumulative distribution function (CDF) in Figure 6. This type of graph allows a decision maker to determine the probability that the plant's value will be more (or less) than a specified amount. For example, in the graph below, there is a 50% chance that the plant is worth $110 million or more. It is interesting to note that even with the same sequence of yearly events that the NPV of the plant could be as low as -$100 million or as high as $350 million depending on the randomly draw input values.

[Figure 6]

Results

This random sampling of scenarios and input parameters results in a complete distribution of the plant's possible value measured by its NPV. Figure 7 shows the CDF for 250,000 different scenario/iteration combinations. Examples of questions that could be answered from this graph include: (1) What is the average NPV for the operating the plant over the next 19 years? *Approximately $185 million.* (2) What is the likelihood of having a negative NPV? *Approximately 15%.* (3) What is the range of possible NPV outcomes? *Approximately $1 billion (-$300 million to $700 million)*.

[Figure 7]

Table 2 shows how the different levels of the model's complexity affect the valuation of the plant. In the table, a standard deterministic income-capitalization analysis (what would be typically done), a simulation analysis (a Monte Carlo Approach), and a simulation analysis with a rational decision process (a Monte Carlo Approach with Real Options) are compared. The median values are displayed because they are a good representation of the project's fair market value (*i.e.,* there is equal probability that the actual NPV would greater or less than the median value). Compared to the standard approach, the median NPV is almost $70 million less when important uncertainties are modeled. However, if a rational decision maker is allowed to close the plant when operations are likely to be highly unprofitable, the median NPV increases by more than $30 million to $204.7 million. These differences are significant.

[Table 2]

The impact that increasing the sophistication and realism of the valuation model will have on the NPV of a facility will not necessarily follow this trend (lower with uncertainty, higher with real options). Depending on the project, adding uncertainty to the model may increase the NPV. Stopping short of a complete model can result in dramatic over or under valuations.

CONCLUSIONS

From the example shown above, unique, large-scale technical projects need more than just standard appraisal techniques. These types of projects contain risks that most other projects do not. Political, technical, and economic risks all play an important role in their valuation. Inclusion of these risks is necessary when conducting an appraisal. Cumulative probability distributions present the results from an analysis in a manner to relate all possible changes in the worth of a project. The use of this method of display can quickly and clearly show the potential risks of a project.

Monte Carlo techniques are appropriate for the valuation of a project. These techniques provide a method to include uncertainty into the evaluation by the use of probability distributions. The modeling of future decisions is necessary to full understand all risks associated with a particular project. Probability distributions alone cannot predict future happenings. The use of these techniques can change the result of an appraisal by as much as 28.3%.

From the example presented and the information given above, clearly the methodology present is valid for the appraisal of large-scale, unique, technical projects. The methods described present a new approach to valuation for a more complete appraisal.

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Figure 1: Sample Tornado Diagram

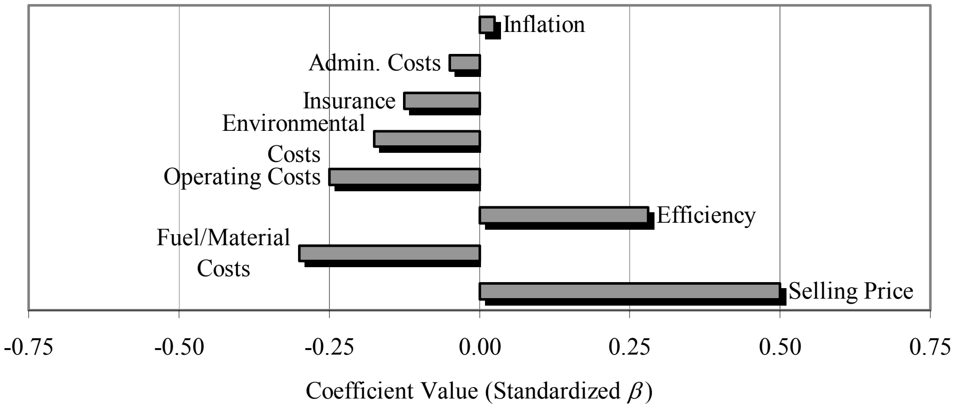

Figure 2: Tornado Diagram for Nuclear Plant Appraisal

Sensitivity of Plant Value (NPV) to Input Variables

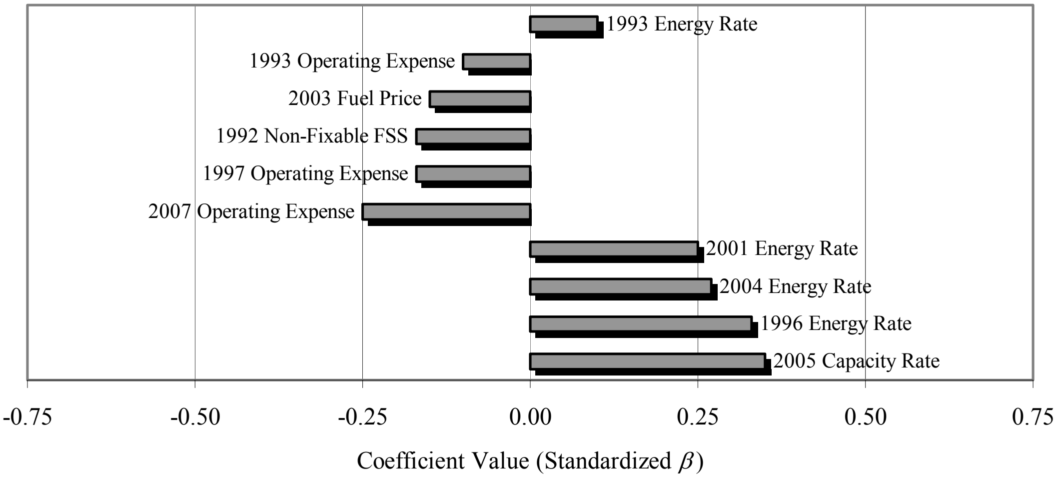

Figure 3: Probability of Anneal Occurring in 2002 Given That Annealing Will Occur

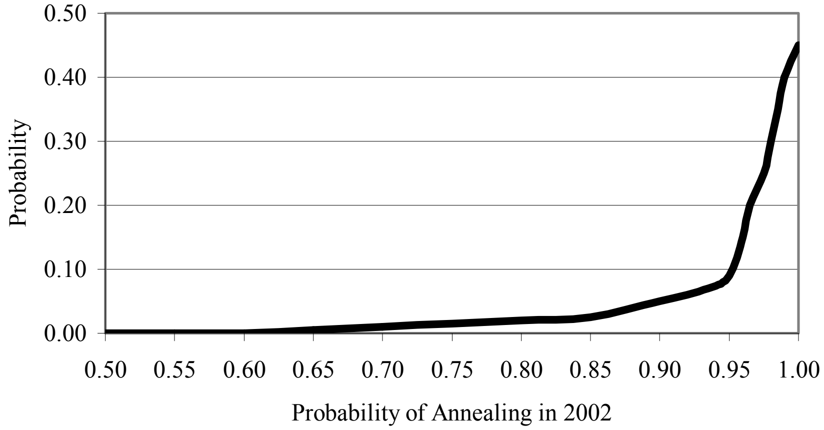

Figure 4: Probability Distribution of the Cost to Anneal

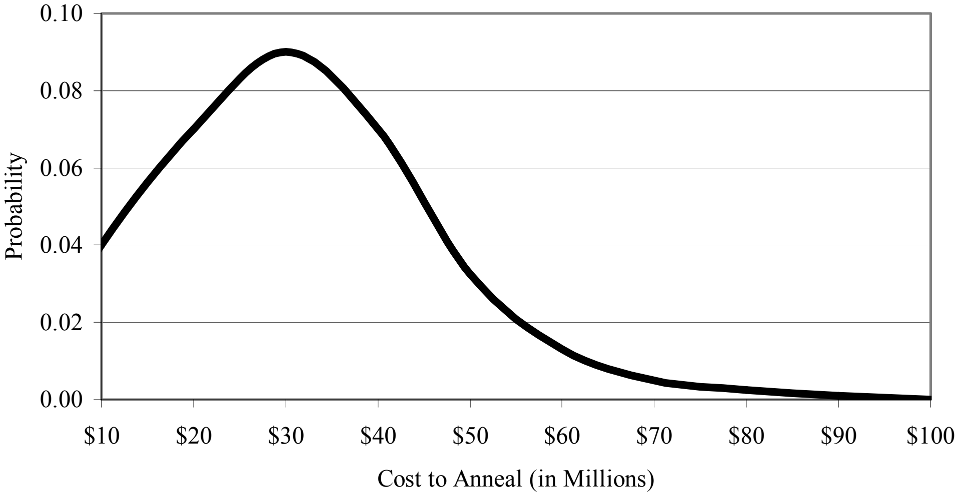

Figure 5: Probability Distribution of the Length of Time Needed to Anneal

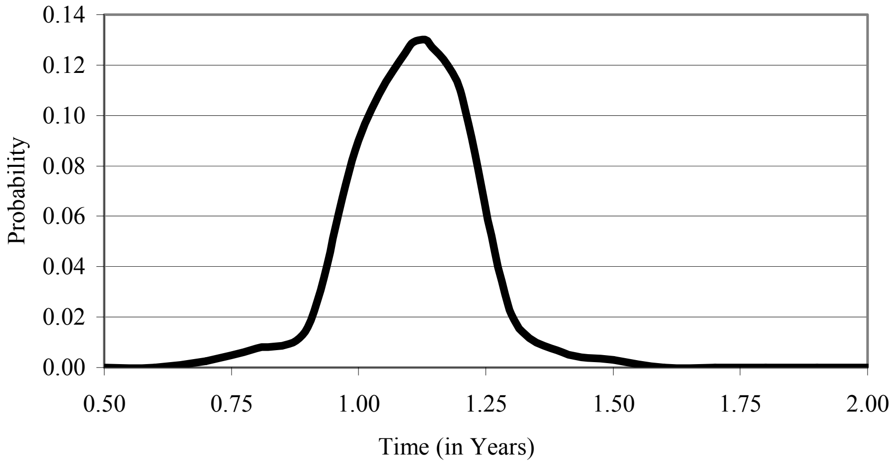

Figure 6: Cumulative Probability Distribution for NPV of One Scenario

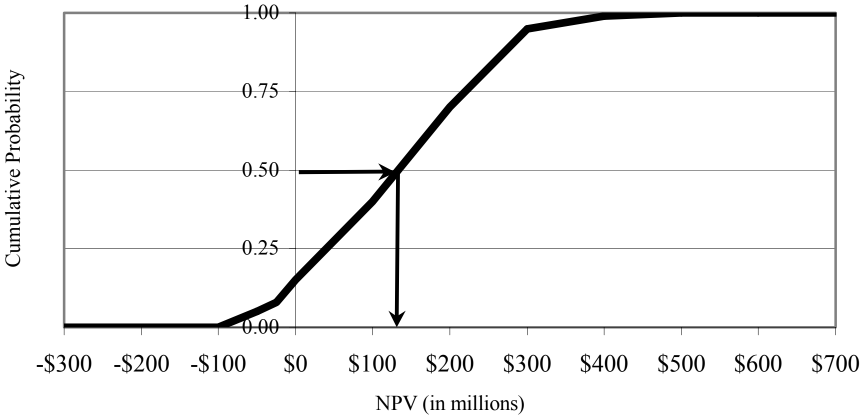

Figure 7: Cumulative Probability Distribution of NPV Including All Uncertainty and Decisions

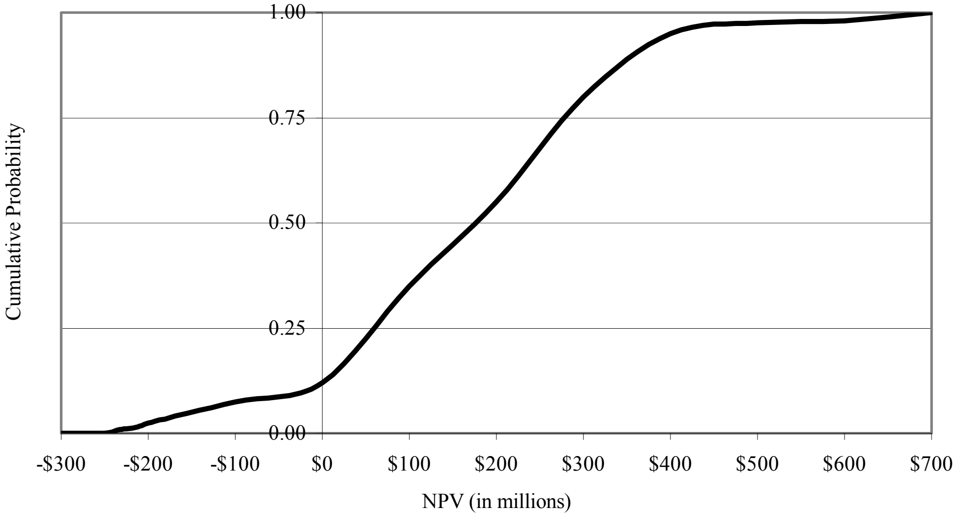

Table 1: Scenario Example ($ millions)

Year	Outcome	Net Revenue
1992	Normal Operations	$45.6
1993	Spent-fuel Storage	$23.5
1994	Normal Operations	$38.9
1995	Normal Operations	$46.4
1996	Normal Operations	$43.2
1997	Normal Operations	$44.5
1998	Normal Operations	$41.2
1999	Normal Operations	$40.3
2000	Normal Operations	$37.4
2001	Normal Operations	$46.9
2002	Repair RPV	($49.0)
2003	Normal Operations	$45.1
2004	Normal Operations	$42.8
2005	Normal Operations	$38.1
2006	Normal Operations	$40.5
2007	Normal Operations	$37.4
2008	Normal Operations	$38.9
2009	Normal Operations	$35.3
2010	Normal Operations	$38.6
1992 Net Present Value *14.6% Discount Rate*		$136.70

Table 2: Plant NPV (1992 $ million) Using Different Models

Appraisal Method	Median NPV
Standard Income Capitalization Method	$240.7
Monte Carlo Analysis	$172.6
Monte Carlo with Real Options	$204.7

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[1] Even if no earnings are present currently, there will (presumably) be at least a liquidating distribution at some future point. In many respects, all assets can be valued with this approach (since the asset's sale could be considered a liquidating distribution). If the liquidating date is sufficiently far into the future or surrounded by too much uncertainty, however, one of the other methods may be more appropriate.

[2] Tornado diagrams can also be constructed using (rank) correlations or by varying each input parameter individually and measuring the absolute effect on the output of interest.

[3] The recent volatility of the California power market has highlighted the value of some of these options. Consumers with locked-in prices for power have been able to resell their contracts for significant profit.

[4] Events and values presented in the case study are given from the perspective of an appraiser in 1996 assessing the plant's value as of 1992 (due to certain legal issues in the case). For the most part, this perspective does not play a role on this paper's illustration of the general modeling process. At the same time, it serves to highlight the importance of incorporating uncertainty. Specifically, almost no one in 1992 or even 1996 would have predicted that nuclear power would be given the type of serious consideration it is receiving today. In such cases, simple "point estimates" would have been grossly in error. However, simulation through the combination of input distributions can (and did in this analysis) capture these future events.

[5] Additionally, the Price-Anderson Act expires in 2002.