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APPLICATION OF ECONOMIC RISK ASSESSMENT TO HAZARDOUS WASTE REMEDIATION PROJECTS

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INTRODUCTION

The early stages of planning or conducting hazardous waste remediation projects generally involve considerable uncertainty in many factors. Most of these factors will eventually have an impact on the overall cost of the project, which may result in large cost overruns. While attempts can be made to estimate the potential range of cost outcomes, it is difficult given the complexity of many projects. The economic risk assessment methodology presented in this paper quantifies risks and uncertain factors into dollar amounts, thus providing a range for the financial liability associated with the project. It also allows selection of the optimum remediation technique and remediation path for each technique based upon expected cost, risk aversion criteria, taxation implications, and net present value costs. Economic risk assessment techniques have been used for more than 20 years for evaluation of large petroleum exploration and development projects to quantify risks and uncertainties in determination of expected cost and profitability outcomes. Data from actual case studies and hypothetical examples are presented to illustrate the methodology and its potential benefits.

An economic risk assessment can be used for a number of purposes. It can be used to provide a realistic range of expected cost outcomes to the owners or prinicipal responsible parties (PRP's) for the site. This allows for informed financial planning and decision making, while also averting the potential of large cost overruns at a later date in the project. The assessment also allows concerned parties to identify areas that may prove of greater liability than originally anticipated as the project progresses. It may also aid in the selection of options or approaches which will minimize some of the potential liability or uncertainty.

With an expected cost and net present value cost outcome at hand based upon probability analysis, settlements can be negotiated at an early stage with minor liable parties in order to simplify project management. For example, at one industrial waste contamination site presently in the early stages of remediation planning, the major responsible parties want to settle as soon as possible with more than 300 minor responsible parties in order to simplify project management. However, cost estimates for the remediation project range from below $40 million to close to $300 million. An economic risk assessment is being conducted to determine the mean cost estimate to be used for settlement negotiations.

There appears to be an increasing trend to have contractors negotiate a fixed price for their site remediation work, as compared to commonly used "cost plus" contracts. A fixed price passes much of the project risk onto the contractor. To quantify risks and uncertainties for their bids, contractors could use economic risk assessment techniques. Of a similar nature, major oil companies have used these techniques for at least 20 years to quantify risks and uncertainties in developing fixed bids for offshore petroleum leases. To minimize the time and cost involved in the assessment, it may be necessary to include only a few major risk or uncertainty items.

An economic risk assessment could also be used by the site owners or PRP's when evaluating fixed price bids from contractors for the remediation work.

The assessment will provide a probability distribution curve for the range of remediation costs which can be expected. A bid falling near the low cost end of the distribution indicates that the contractor will absorb a lot of risk unless he is unexpectedly efficient. In deciding whether to accept the low cost bid, the financial strength of the contractor to absorb this risk can be evaluated. If the contractor's financial strength is inadequate, he may fail to complete the work, or attempt to cut corners in order to save costs.

METHODOLOGY

Each of the steps composing a full economic risk assessment is detailed under their respective subheadings below. In general the approach requires review of all available literature pertaining to the site and conducting in-depth interviews with engineers and other responsible parties to define all potential project paths and cost component ranges. Decision trees are designed for each remediation scenario and probabilities assigned to all potential paths. Monte Carlo simulations are performed within the ranges of all significant cost and volume components. Total cost and net present value cost distributions are calculated for each path. The results are weighted in the decision trees to define both the expected project outcome and the distribution curve of potential outcomes. The optimum project path is selected based on cost and risk aversion criteria.

Specifically, an economic risk assessment consists of four key components:

- Financial Calculations consisting of cash flow and net present value (NPV) analysis to compare remediation paths in total cost and discounted value of money terms.
- Sensitivity Analysis to identify the relative effect different factors have on the overall project cost.
- A Decision Tree is developed for each major remediation method or scenario proposed. Each tree should portray realistic project schedules and probabilities for each significant event or cost component occurring.
- Distribution and Probability Analysis is used to generate probability distributions for total cost and NPV cost for each remediation scenario. The computer calculates total cost and NPV cost hundreds of times, using the Monte Carlo Simulation technique to select from distribution curves for most factors involved in each remediation option.

The data for the assessment is obtained through reviewing available literature, and conducting in-depth interviews with engineers and other responsible parties involved, to define all potential project paths and item cost ranges. Much of the data obtained is of a subjective nature. As each of the above four components is refined, the results are entered into the others in order to further refine those and to determine where additional emphasis for the study should be directed. Each of the four key components is described below.

Financial Calculations

Cash flow and NPV calculations are used to determine the relative cost for the most likely path(s) for each proposed remediation method or scenario. Initially these are calculated from original engineering cost estimates. Later they are refined using most likely estimates from distribution ranges defined for major items.

The cash flow analysis shows the client the expected allocations of money over time, both on a before and after tax basis. From this a total cost for each path is easily calculated.

The NPV analysis has the advantage over total cost estimates of taking into account the time value of money for the PRP's. Changes in project scheduling can have a significant effect on NPV cost estimates. Careful selection of the discount rate to be used can be important since it can determine the relative economics of engineering and management decisions.

Sensitivity Analysis

The purpose of a sensitivity analysis is to identify the specific factors subject to risk or uncertainty which have most effect on total project cost or NPV cost. The identified factors warrant close management attention and/or additional review. Potential highly sensitive factors include:

- Changes in regulations or their interpretation
- Permitting delays
- Extent of contamination
- Cleanup levels
- Number and depth of wells to be drilled
- Weather related delays and rainfall effects on hazardous liquid volumes
- Labor costs
- Proximity of contaminants to a property boundary, the public and/or public facilities

The sensitivity analysis is performed by changing values for individual items or categories of items, and re-estimating the total cost or NPV cost. A number of methods of sensitivity analysis can be employed. One method is to have the computer change categories of items by increments. Then graphs can be generated comparing the sensitivity of the NPV cost of the project scenario to the incremental changes. As individual items are changed, the sensitivity of the project scenario to those individual items can be evaluated.

To determine the upper and lower limits of the total project cost and NPV cost for each remediation scenario, the set of "extreme" values (maximum and minimum) for all significant components are used. This provides an estimate of the maximum and minimum potential cost for each remediation option.

Decision Tree Analysis

A decision tree is constructed for each major remediation method or scenario proposed. It is designed to portray realistic project schedules and probabilities for each potential path or branch. The total cost, NPV cost, and probability is calculated for each major path and compared in order to identify the most economic and most probable paths.

The NPV cost estimate for each branch is multiplied by the probability of occurrence to provide a weighted NPV. The weighted NPV costs are then totalled, resulting in the expected NPV cost estimate for each major remediation scenario. This process highlights the most economic path for which to strive. However, it more importantly shows the path which has the greatest probability of occurrence.

An expected NPV cost for the entire project can also be calculated by combining the results from the individual scenario decision trees. This requires the assignment of probabilties to the occurrence of each remediation alternative. These probabilities are then used to weight the expected NPV cost estimates, which are then totalled.

The probabilities assigned are usually by necessity subjective in nature. However, this detracts little from the benefit of their application. The research and interview process involved in estimating the probabilities is also generally very beneficial to all participants. Quantification of risks and uncertainties requires confronting many external and internal factors which could effect the project, some of which management may have ignored or been unaware exist.

Figure 1 is designed to illustrate an application of a decision tree. It shows a simplified decision tree for remediation of a hypothetical lead contamination site. There are many such metal contamination sites in or near old mining towns in the inter-mountain regions of the western U.S. Management for many of these sites will be confronted with the issues included in this example as remediation planning for the sites progress.

In this case the decision tree for each of the three remediation scenarios have been weighted by probability of the scenario's occurrence and combined to provide an overall project decision tree. The prime difference in the three scenarios is the geostatistical level of confidence for contaminant removal. The confidence level determines the volume of material which must be removed.

In developing the first scenario the geostatistics consultant has argued that remediation to a 99.0% confidence level and excavation to an average depth of 6 inches should be an adequate level of remediation. This would provide a 1.0% chance of any remaining block of material being contaminated. In other words, after remediation by demolishing buildings, excavating and hauling away the contaminated soil, the new topography for the site could be divided into 10,000 blocks, each with x sq ft of surface area. If all of these blocks were to be resampled, probability dictates that the mean number of contaminated blocks remaining would be 100.

With this scenario providing by far the lowest expected NPV cost estimate, at $35 million, economics indicates that attempts should be made to obtain approval for this level of remediation. This will require convincing the authorities that the potentially remaining contaminant poses no more than 1 in a million long term chance of serious injury to the population. This is a very difficult argument to defend, no matter how high the confidence level for remediation is set.

The tree shows that there is higher probability (50%) that remediation to a 99.9999% confidence level will be the settlement negotiated with authorities. This will require removal of the surface materials covering a considerably greater area and excavation to an average depth of 2 ft. This would provide a 1 in a million chance of any remaining block of material being contaminated. The expected NPV cost for this level of remediation is calculated to be $70 million.

The figure shows that for all three remediation scenarios, off-site disposal is most likely to be required. This is due to emotional and political factors rather than engineering parameters. If on-site disposal is approved, local clays are unlikely to prove suitable for the bottom lining and cap for the disposal vault. Therefore, a greater probability is shown for purchase of clay from a distant source at considerably greater cost. For off-site disposal, a decision must be made as to whether the project management will attempt to develop and permit a disposal site nearby or truck the contaminants to a distant third party administered disposal site.

The overall expected NPV cost for the project based on weighting of probabilities for the three scenarios is $55.5 million. This gives management a best estimate to use in discussions, decision making, government reports, or reports to the PRP's stockholders.

Distribution and Probability Analysis

Distribution and probability analysis is used to generate probability distributions for total cost and NPV cost for each remediation path. Based upon the research and interviews conducted, low, most likely and high estimates are developed for each significant item or factor for each year of the project. These estimates are used to define individual probability distribution curves within the computer program for each item.

The Monte Carlo simulation technique involves randomly selecting from distribution curves for each item. For each of the simulations, annual cash flows, then total cost and/or NPV cost for the project are calculated. By combining the estimates calculated from hundreds of simulations (i.e., each simulation has a different, randomly selected set of inputs), a probability distribution curve of total cost or NPV cost is generated for the project path. In general, 500 simulations is adequate to define the resultant probability distribution curves.

The distribution curves defined for individual items by the low, most likely and high estimates are usually skewed curves. Although a lognormal distribution may be used to model these, a triangular distribution has a

number of advantages. A triangular distribution gives greatest weight to the most likely estimate, which is typically by far the best estimate the analyst has available. In defining a lognormal distribution only the low and high estimates are utilized, while estimates of confidence levels are also required for these values. Use of the triangular distribution does not require asking the engineer the conversation killing question of what the confidence limits are for the maximum and minimum cost or volume estimates which he has just pulled out of the air. However, when in doubt, 95% confidence limits can usually be applied successfully in defining lognormal distributions.

Additionally, the Monte Carlo simulation technique can be modified to reduce the randomness of selection for specific items. This allows levels of dependency between similar items to be simulated, and the amount of change from year to year to be retarded. For example, although the cost of excavating a cubic yard of material may be allowed to vary from year to year, the probability for a large amount of change to occur can be reduced. Estimates for levels of dependency are generally subjective in nature.

The Monte Carlo simulation is repeated for each significant project path. Typically the resultant distribution curves will be skewed slightly towards a low cost, with a tendency for a tail to develop for the high cost end. From these distributions the mean (expected) NPV cost and and mean total cost is calculated for each path. With a skewed distribution, the mean value will not represent the mode (most likely) value. However, it should be used as the expected value (best estimate) in additional calculations, or for reports, since it takes into account both the probability of occurrence and magnitude of project cost estimates.

The expected (mean) costs and cost distribution curves should be compared for each of the remediation paths evaluated using the Monte Carlo simulation technique. This aids in determining the preferred path for which to strive. The expected costs are then returned to the decision trees for recalculation of the decision tree analysis. When the results are finalized, the decision tree provides the expected NPV cost and total cost for each scenario based upon the means from the simulated distribution curves.

Through weighting the values contained in the total cost and NPV cost distribution curves by the path probabilities contained in the decision tree, it is possible to develop NPV cost and total cost distribution curves for each remediation scenario and for the project as a whole. These curves provide the probability of the remediation cost falling within any given range.

In order to illustrate the application of the Monte Carlo simulation technique, results from an on-going project are used. In 1985 the prime contractor estimated the total before tax cost of remediation, closure certification and post-closure maintenance to be $8.9 million. The remediation and closure was planned for completion by early 1987. The following economic risk assessment was performed in 1985.

Relevant cost estimation documents were examined and interviews conducted in order to determine the range of outcomes for all significant factors. The data was then entered into the economic evaluation and simulation computer program. The results derived suggested that the project would likely have a cost considerably higher than that estimated by the prime contractor.

Based upon most likely estimates, the total before tax cost for the project was estimated to be $13.6 million. After tax the most likely cost was estimated to be $7.2 million, due to the advantage of corporate profits external to the project being available from which the project tax losses can be deducted. At an 8% DCFROR (constant purchasing power), the after tax NPV cost was calculated to be $6.1 million.

Using sensitivity analysis, the set of minimum estimates for all items was used to estimate the limit for the minimum total cost, then the set of maximums to estimate the limit for the maximum cost. This produced an estimate for the minimum total before tax cost of $8.1 million and maximum before tax cost of $32.9 million. The respective after tax NPV costs were calculated to be $3.7 million and $15 million. However, the probability of these limits occurring, was estimated to be negligible.

Figure 2 shows the after tax NPV cost results from the Monte Carlo simulation, with a mean of $8.0 million. Five hundred simulations were used. The top graph shows the histogram for the distribution curve as slightly skewed from that of a normal distribution curve. The lower graph is a cumulative probability curve produced using equal increments of NPV cost. Total before tax cost distribution curves were not calculated at that time. However, from the before tax NPV cost curves shown in Figure 3 and knowledge of the project cash flow profile, it can be estimated that the mean total cost would have been $15 million to $15.5 million. The lower graph in Figure 3 is a cumulative probability curve based upon equal increments of percentage probability, which by definition must graph as a straight line.

At the time of writing (March - April, 1988), the remediation process has not yet begun. Approximately $3 million has been spent in the intervening 2.5 years for site investigations and permitting, this being one-third of the prime contractor's original total project cost estimate. Fixed price bids received from contractors to conduct the remediation are in the range of $5.5 million to $14 million. Quality assurance and quality control, prime contractor fees, other overhead and contingencies can be expected to add up to 40% or more to these remediation costs. Closure certification and post closure costs are not included. Deflating the bids to October 1985 would reduce these by less than 10%, providing a range of costs for the remediation phase of the project of aproximately $7 million to $18 million.

Overall, to date the results from the economic risk assessment appear to be on target with actual outcomes, whereas the prime contractor's cost estimate has suffered a major overrun. This illustrates the effectiveness of the economic risk assessment approach in quantifying risks and uncertainties. Some items which have occurred, driving up the project cost from the prime contractor's original cost estimate, are:

- Time delays
- Permitting problems
- A considerable increase in the area to be remediated due to recalculation of the level of remediation
- Drilling of deep monitoring wells - none of which were included in the original estimate
- Clay for the bottom liner and cap of the landfill will most likely be purchased from many miles away, instead of using on-site clay.

All of the above items, except for time delays, were well represented in the economic risk assessment. However, in hindsight, the upper estimates used to define some item distributions have proved inadequate to encompass the events which have taken place. Experience gathered on other projects similarly suggests that one should not be cautious in estimating the maximums that cost or volume items can reach, since maximum estimates are often exceeded.

A closing observation or suggestion seems deserved for this case study. Before accepting one of the fixed price bids, it would appear advisable for the PRP to have an updated risk assessment performed to estimate a cost distribution curve for the remediation portion of the project. This would aid in evaluating which bid to accept. For example, if the $5.5 million bid falls near the low cost end of the distribution it indicates that the contractor will absorb a lot of risk unless he is unexpectedly efficient. The financial strength of the contractor to absorb this risk can then be evaluated. If the contractor's financial strength is inadequate, he may fail to complete the work, or attempt to cut corners in order to save costs.

CONCLUSIONS

The economic risk assessment approach is an effective method for quantifying the risks and uncertainties involved in hazardous waste remediation projects into an estimate of the mean and range of total costs and NPV costs. It is effective in providing a realistic range of estimates even at an early stage of site investigation and remediation planning. The total cost and NPV cost estimates developed are substantially more realistic and accurate than total cost estimates developed by engineers from most likely estimates of component costs.

A thorough economic risk assessment is composed of the following four integrated components: financial calculations; sensitivity analysis; decision tree analysis; and distribution and probability analysis.

A well developed economic risk assessment provides management with a realistic range of project costs and annual cash flows for which to budget, and realistic optimum remediation paths for which to strive based on risk aversion criteria.

Estimation of an expected NPV cost which encompasses the probability of occurrence of all remediation scenarios, provides the PRP's with a single dollar amount upon which to base early settlement negotiations.

The highlighting of factors with large risk or uncertainty ranges provides an opportunity for additional review, preparation and management decision making. That is, it provides for a proactive rather than a reactive approach.

NPV cost estimates are a better tool than total cost estimates for comparing the economics of various remediation alternatives, because NPV cost estimates take into account the time value of money.

The economic risk assessment approach can be used by contractors to develop realistic fixed price bids for hazardous waste remediation while minimizing the financial risk inherent in performing the work.

Similarly, the PRP's for the site can use an economic risk assessment to aid in evaluating which fixed price bids to accept from contractors for hazardous waste remediation. If a bid falls near the low cost end of the distribution it suggests that the contractor will need to absorb a lot of risk, possibly leading to failure to perform the work.

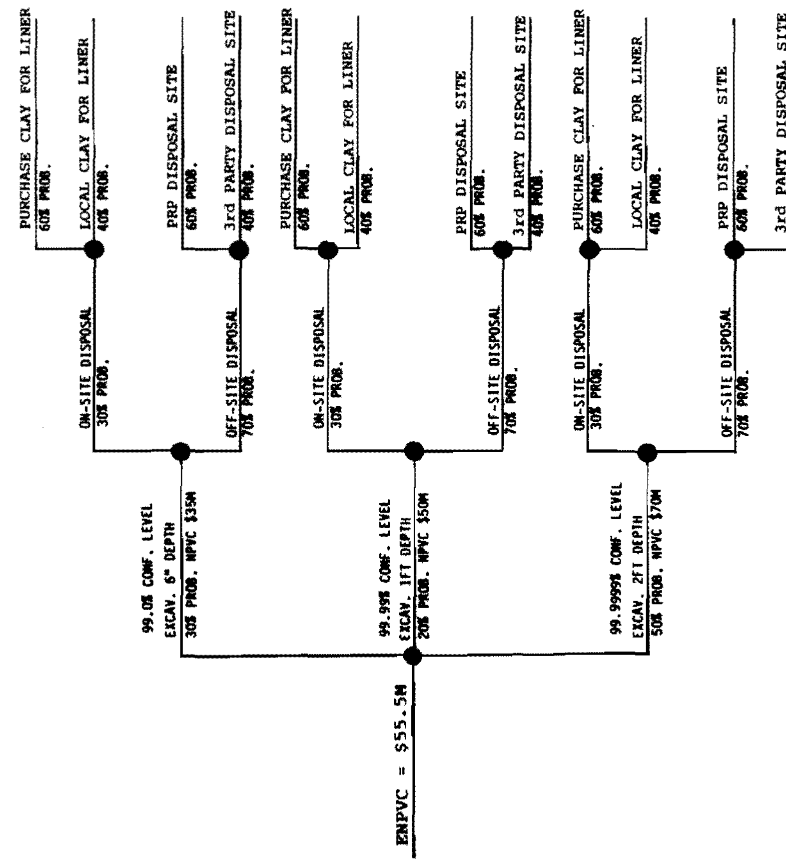

Figure 1. Decision Tree Analysis

The Expected Net Present Value Cost of the lead contamination remediation, taking into account the probabilities of the alternatives is $55.5 million.

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RISK ANALYSIS with  500 Iterations of NPV ANALYSIS AFTER TAX
@ Discount Rate   8.00%
on PROJECT BASIS
with CONTINUOUS COMPOUNDING   of CONSTANT PURCHASING POWER  cash flows

EXPECTED COST -- MEAN/WEIGHTED AVERAGE ($000) =      7976.27
STANDARD DEVIATION ($000) =        909.65


                         *** HISTOGRAM ***

             NPV COST
              ($000)                 % PROBABILITY
            IS GREATER 0    10   20   30   40   50   60   70   80   90  100
  PROB         THAN    +----+----+----+----+----+----+----+----+----+----+
   1.8%      10210.94  |#
   2.8%       9675.76  |#
   5.8%       9140.59  |###
  12.4%       8605.43  |######
  20.4%       8070.25  |##########
  26.8%       7535.09  |#############
  16.6%       6999.92  |########
  10.0%       6464.76  |#####
   3.0%       5929.58  |##
    .4%       5394.41  |
                       +----+----+----+----+----+----+----+----+----+----+


                   *** CUMULATIVE PROBABILITY ***
                      EQUAL INCREMENTS OF COST

             NPV COST
              ($000)                 % PROBABILITY
            IS GREATER 0    10   20   30   40   50   60   70   80   90  100
  PROB         THAN    +----+----+----+----+----+----+----+----+----+----+
   1.2%      10478.51  |#
   1.8%      10210.94  |#
   2.8%       9943.35  |#
   4.6%       9675.76  |##
   7.4%       9408.18  |####
  10.4%       9140.59  |#####
  15.4%       8873.00  |########
  22.8%       8605.43  |###########
  31.2%       8337.84  |################
  43.2%       8070.25  |######################
  55.6%       7802.68  |############################
  70.0%       7535.09  |###################################
  78.6%       7267.51  |#######################################
  86.6%       6999.92  |###########################################
  92.4%       6732.33  |##############################################
  96.6%       6464.76  |################################################
  98.4%       6197.17  |#################################################
  99.6%       5929.58  |##################################################
 100.0%       5662.00  |##################################################
                       +----+----+----+----+----+----+----+----+----+----+
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Figure 2. Monte Carlo Simulation for Project After Tax NPV at 8% DCFROR

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RISK ANALYSIS with  500 Iterations of NPV ANALYSIS BEFORE TAX
@ Discount Rate   8.00%
on PROJECT BASIS
with CONTINUOUS COMPOUNDING   of CONSTANT PURCHASING POWER  cash flows

EXPECTED COST -- MEAN/WEIGHTED AVERAGE ($000) =      14334.48
STANDARD DEVIATION ($000) =       1649.37


                         *** HISTOGRAM ***

             NPV COST
              ($000)                 % PROBABILITY
            IS GREATER 0    10   20   30   40   50   60   70   80   90  100
  PROB         THAN    +----+----+----+----+----+----+----+----+----+----+
   1.4%      18587.12  |#
   3.0%      17595.60  |##
   5.2%      16604.10  |###
  10.8%      15612.59  |#####
  19.8%      14621.07  |##########
  26.0%      13629.57  |#############
  18.6%      12638.07  |#########
  11.8%      11646.55  |######
   3.0%      10655.05  |##
    .4%       9663.54  |
                       +----+----+----+----+----+----+----+----+----+----+


                   *** CUMULATIVE PROBABILITY ***
            EQUAL INCREMENTS OF PERCENTAGE PROBABILITY

             NPV COST
              ($000)                 % PROBABILITY
            IS GREATER 0    10   20   30   40   50   60   70   80   90  100
  PROB         THAN    +----+----+----+----+----+----+----+----+----+----+
   5.0%      17267.24  |###
  10.0%      16474.45  |#####
  15.0%      16003.65  |########
  20.0%      15614.51  |##########
  25.0%      15375.96  |#############
  30.0%      15065.13  |###############
  35.0%      13462.86  |##################
  40.0%      14617.83  |####################
  45.0%      14412.79  |#######################
  50.0%      14205.00  |#########################
  55.0%      14020.79  |############################
  60.0%      13813.26  |##############################
  65.0%      13679.60  |#################################
  70.0%      13493.42  |###################################
  75.0%      13214.66  |######################################
  80.0%      12946.95  |########################################
  85.0%      12620.68  |###########################################
  90.0%      12363.07  |#############################################
  95.0%      11726.75  |################################################
 100.0%       9663.53  |##################################################
                       +----+----+----+----+----+----+----+----+----+----+
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Figure 3. Monte Carlo Simulation for Project Before Tax NPV at 8% DCFROR