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A PROBABILISTIC COST MODEL WITH AN APPLICATION TO A GEOTHERMAL RESERVOIR AT HEBER, CALIFORNIA

G. Michael Ziman, Sue Campbell Jones, Lowell H. Orren

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

ABSTRACT

A financial accounting model that incorporates physical and institutional uncertainties has been developed for geothermal projects. Among the uncertainties it can handle are well depth, flow rate, fluid temperature, and permit and construction times. The outputs of the model are cumulative probability distributions of financial measures such as capital cost, levelized cost, and profit. These outputs are well suited for use in an investment decision incorporating risk. The model has the powerful feature that conditional probability distribution can be used to account for correlations among any of the input variables. The model has been applied to a geothermal reservoir at Heber, California for a 45MW binary electric plant. Under the assumptions made, the reservoir appears to be economically viable.

INTRODUCTION

Because the cost of developing a geothermal resource is intrinsically uncertain, no venture analysis technique can evaluate the cost or profit of a project with any degree of confidence without considering the uncertainties present. Partial accommodation of these uncertainties can produce results which are misleading. Probabilistic cost modeling, however, does provide the opportunity to properly incorporate these uncertainties into the final results. This paper describes one such model that has been developed at the Jet Propulsion Laboratory and discusses its application to a geothermal site at Heber, California.^{1}

The concept underlying probabilistic modeling is that the values for the model inputs are not known, but that their distributions can be estimated. A decision tree showing each possible sequence of events and the associated probabilities can then be constructed, and from this, project costs and other financial measures can be appropriately aggregated into probability distributions. By generating entire distributions, this model enables the inclusion of a decision-maker's risk preference into his investment decisions. The shaded area in Figure 1 shows that even though the expected cost of a new technology may be higher than the current cost of conventional technologies, there might be a considerable probability that the new technology is competitive with the existing technology. Likewise, there may be a significant probability that the cost of the new technology will reach unacceptable levels.

The most distinguishing feature of the Geothermal Probabilistic Cost (GPC) model is that it allows the outcome of one variable to be dependent upon the outcomes of the other variables. Conditional probability distributions can thus be used. For example, the probability distribution for the length of a development stage may be dependent upon the lengths of the stages that precede it or upon the depths of the wells that have to be drilled, none of which may be known at the beginning of the project. In this way, any correlation--either positive or negative--between characteristics can be considered explicitly and a joint probability distribution that has all existing dependency relationships factored into it can be constructed.

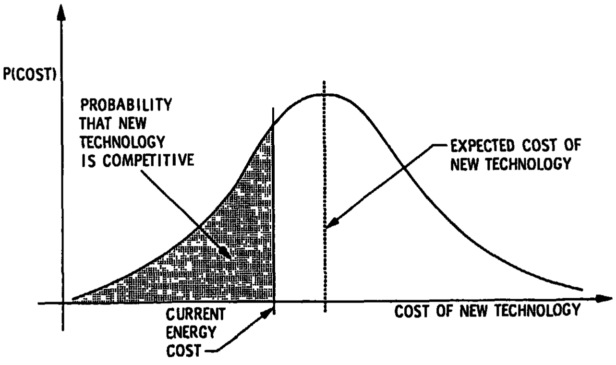

FIGURE 1 - Probability Density Function of Cost for a New Technology

THE MODEL: AN OVERVIEW

Many projects or processes can be considered as occurring in stages, with the cost of the activities for the project being dependent upon the duration of the stage in which they occur. In projects of this type with long time-horizons, it is often the case that the duration of at least some of the stages (and hence the cost of the activities in those stages) will be uncertain. Thus, final cost and profit will be sensitive to the length of time required to complete each of the stages. In addition to the stage durations, other variables that have an effect on cost, such as physical parameters, may also be uncertain.

The model described in this paper deals with these uncertainties by considering individually all permutations of times (for the stage durations) and values (for the uncertain physical variables). From each such permutation of times and values, a 'scenario' is constructed and then analyzed.

A scenario thus represents one possible path through a decision tree. Specifically, each scenario is defined by four attributes:

(1) a set of durations specifying the length of each of the stages;

(2) a set of values for any uncertain physical parameters;

(3) the probabilities that each stage and each physical parameter will take on the value specified for it in (1) and (2); and

(4) the dollar value costs for all cost-accounts in all stages.

To avoid the enormous information costs of acquiring (1) - (4) for each scenario, the model makes use of a Reference Scenario. A Reference Scenario is defined as the most likely path through the decision tree. Cost-accounts are input into the program for only this Reference Scenario. For all other scenarios, only their stage times, physical parameter values, and the associated probabilities are input: their cost-accounts are derived within the program by modifying the appropriate Reference Scenario cost accounts for any differences in the length of the stages or for any differences in the values of the physical parameters. Thus, as described below, the Reference Scenario is really a baseline case from which all other scenarios are derived. As a result, the lengthy and difficult task of providing detailed cost accounts for the site under study has to be performed only once (for the Reference Scenario).

To illustrate the procedure, if in the Reference Scenario, Stage J is assumed to take 10 years, then a time-dependent cost account in Stage J is estimated based upon the 10 year duration.[2] If, however, Stage J in another scenario lasts 20 years, then that time-dependent cost account in Stage J would be doubled to reflect the now longer stage time. Additionally, if a particular cost account is affected by an uncertain physical variable, the model would make an adjustment through the use of appropriately defined scaling functions.

In a like manner, the cost-accounts for each of the other scenarios are derived. Because the lengths of the stages are different from scenario to scenario, the occurrence of the cost-account expenditures in each scenario will be staggered. The model accounts for the staggered time frames by appropriately accounting for time differences when the financial analysis is performed. The financial subroutine in the model calculates levelized energy cost, life-cycle cost, and profit for each scenario. With the probability of occurrence for each scenario (and thus of their outputs) having been input[3] as part of the scenario description, a complete set of values and their probabilities are obtained for levelized energy cost, life-cycle cost, and for profit. From these, separate probability functions for both of the cost categories and for profit can be constructed.

HEBER RESERVOIR SITE STUDY

The Geothermal Probabilistic Cost model was used to evaluate the economics of a geothermal reservoir at Heber, California, to supply fluid for a 45MW (net) binary-cycle electric plant.[4] The Heber Binary Plant, which is not modeled here, has been proposed as a demonstration project to prove the feasibility of a large scale binary plant.

BRIEF DESCRIPTION OF HEBER

The Heber field would consist of 13 production wells ranging in depth from 4000 to 10,000 feet. These wells would deliver approximately 7 million pounds of 360°F water per hour, with the flow rate increasing as temperature degrades over time. Fluid would be injected back to the reservoir using 7 wells at depths from 4000 feet to 10,000 feet. All wells are pumped. The project has a proposed production lifetime of 30 years.

For analysis by the GPC model we have divided the project into four stages. The first stage, resource proving, consists of acquiring leases to the land, exploring the field, and proving the existence of a viable reservoir. The second stage, permit processing, consists of performing all required environmental assessments and obtaining all permits required to fully develop the resource. The third stage, developing the resource, consists of drilling all production and injection wells, and installing pumps and all required surface facilities. The last stage, operating the reservoir, consists of delivering fluid to the binary plant, performing required O&M activities, and redrilling wells as required. Table 1 is a summary of the costs by stage. For a complete breakdown of these costs by year and tax status, see Reference 1.

TABLE 1 - Reference Scenario Cost by Stage[5]

	1980$, thousands
STAGE I - Resource Proving	
Rent	$ 75/year
Permits	25
Exploration	3680
G&A	100/year
Lease Acquisition	325
Surface Occupancy	60
Contingency	406
STAGE II - Permit Processing	
Rent	$ 75/year
Environmental Assessment	200
G&A	100/year
Contingency	38
STAGE III - Developing the Resource	
Rent	$ 75/year
Well Drilling	18,954
Surface Installation	9,400
G&A	100/year
Contingency	513
STAGE IV - Operating the Reservoir	
O&M	$ 2,093/year
Pumping costs	514/year (start)
Redrilling of Wells	19,920 (year 15)
Contingency	209/year

TABLE 2 - Financial Assumptions[5]

Energy Price	17.5 mills/kWh
Required Rate of Return after Tax	15%
Debt/Equity Ratio	0
Royalty Rate	10%
Federal Tax Rate	46%
State Tax Rate	10%
Local Tax Rate	1%
Investment Tax Credit	10%
Royalty Rate	10% of gross revenue
Depletion Allowance	15%
Depreciation Method	Sum of years digits
Escalation of Energy Price	10%
General Inflation	9%

The set of data and assumptions listed in Tables 1, 2, and 3 is referred to as the Base Case Set. The Base Case Set consists of 54 scenarios (3x2x1x3x3), each with a specific probability of occurrence, plus all cost and financial assumptions. The Reference Scenario is the particular scenario whose cost accounts are shown in Table 1 and whose uncertain variables take on the values indicated in Table 3. Other scenarios are treated as perturbations from the Reference Scenario, with a calculable probability of occurrence. (The scenario with stage lengths of 3 years, 1 year, 2.5 years, and 20 years, and flow rate of 1035 GPM would have probability .2x.8x.2x.2 = .0064.)

RESULTS

Results for the Base Case Set of assumptions and for sensitivities are shown in Table 4. The cumulative distribution function for profit is shown in Figure 2.

TABLE 3- Density Functions of Uncertain Inputs[5]

Variable	Value	Probability
Stage I	3 yrs.	.2
	5.5 yrs.*	.6
	8 yrs.	.2
Stage II	1 yr.*	.8
	1.5 yr.	.2
Stage III	2.5*	1.0
Stage IV	20 yrs.	.2
	30 yrs.*	.7
	35 yrs.	.1
Well Flow Rate	1035 GPM	.2
	1380 GPM*	.6
	1725 GPM	.2

*Reference Scenario Value

For the Base Case Set, the expected profit is -$1.61 million and for the Reference Scenario the profit is $.60 million. This profit is the present value of profit at the assumed start of the project in 1980 and it does allow a payment to equity capital of 15% after taxes. The profit is clearly sensitive to changes of assumptions in the Base Case Set. Profit is dramatically sensitive to changes in the price of energy sold. A 2.5 mill/kWh increase over the original price of 17.5 mill/kWh increases the expected profit approximately $4.5 million. The expected profit is not greatly sensitive to the investment tax credit, as a change from 10% in the Base Case Set to 25% increases profit approximately $1 million. The increase in ITC would have had a larger effect had not such a large percentage of costs been expensed as indirect drilling costs (75% of wells and 50% of surface installation). Energy escalation, the rate of increase of price of the fluid sold, has a great impact on the profit. An increase from 10% to 11% causes expected profits to rise approximately $6.5 million. The effect of a shorter well life, 10 years as compared to the Base Case Set assumption of 15 years, is substantial, as expected profits fall by almost $5 million.

The costs shown in Table 4 are only for the Reference Scenario. They are the first year real levelized costs[6] at the beginning of Stage IV, which occurs 9 years after the start of the project. For the Base Case Set this cost is 40.93 mills/kWh. This cost will grow at 10%, the rate of escalation for energy. Nine years after the start of the project the energy price will have grown from 17.5 mills/kWh to 41.26 mills/kWh. Then comparing the first year real levelized cost to the energy price at that time, we see there is a profit of .33 mills for each kWh of fluid sold. There will also be a positive profit in each of the remaining years of the operating period as both the price and real levelized stream will grow at 10%. As expected, the costs are sensitive to changes of assumptions from the Base Case Set. When energy price

TABLE 4 - Results for Base Case Set Assumptions and Sensitivities

		Present Value Profit (1980$, millions)					Reference Scenario Levelized Energy Cost (Mills/kWh)
		Expected Value	Standard Deviation	Minimum	Maximum	Reference Scenario	
Base Case Set		- 1.61	2.83	- 7.23	5.66	.60	40.93
Energy	15	- 6.10	2.52	-11.46	- .016	- 4.14	37.70
Price	20	2.87	3.16	- 3.41	11.33	5.34	44.15
(mills/kWh)	25	12.00	3.87	3.26	22.69	14.82	50.59
ITC	25%	- .31	2.76	- 5.59	6.92	1.84	40.23
Energy	11%	4.84	3.76	- 2.73	13.70	7.70	40.89
Escalation	9%	- 6.61	2.31	-11.10	- .84	- 5.14	41.24
Well Life	10 yrs.	- 5.64	3.05	-12.25	1.77	- 3.42	43.19
	30 yrs.	2.25	2.61	- 3.21	9.10	4.25	38.87
Correlated Events		- 1.55	2.81	- 7.23	5.66	.60	40.93

changes, cost changes because income tax and royalty payments change.

The correlated event case is the Base Case Set modified by the assumption that the distribution of well flow rate depends on the length of time it takes to prove the resource, or the length of Stage I. The relationship assumed is shown in Table 5. As shown in Figure 2, the profit in the Base Case Set is probabilistically dominated by the distribution of profit in the correlated event case. With only the assumption that an investor is risk adverse, we may conclude that an investor would prefer a project with the correlated event over the project with the Base Case Set assumptions. The ability to handle correlated events is a powerful feature of the GPC model.

TABLE 5 - Flow Rate Correlated to Stage I

Outcome of Stage I	Possible Value	Probability
3 years	1035 GPM	.1
	1380 GPM	.1
	1725 GPM	.8
5.5 years	1035 GPM	.15
	1380 GPM	.35
	1725 GPM	.50
8 years	1035 GPM	.2
	1380 GPM	.6
	1725 GPM	.2

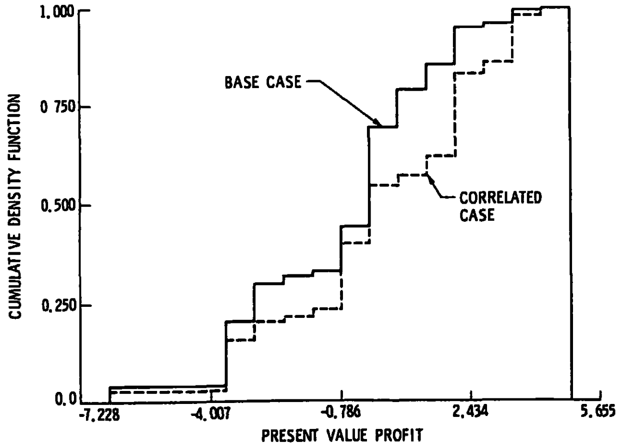

FIGURE 2 Distribution of Profit in Base Case Set and Correlated Events Case Set

NOTES

1. For a fuller discussion of the model and site study see Reference 1.
2. Cost accounts are identified as either time-dependent or time-independent. Time-independent cost accounts remain unchanged by differences in stage lengths.
3. Actually, only the conditional probabilities for the stage length times and physical parameter values are input. Their product, calculated in the program, yields the probability of occurence for each scenario and its output.
4. The model can be applied to any process with uncertainties whose distributions can be estimated, not just geothermal or energy projects.
5. See Reference 1 for detailed sources.
6. Levelization is discussed in Reference 2.

REFERENCES

1. Orren, L. H., et al, Geothermal Probabilistic Cost Study, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, February 1981.
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