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Application of Monte Carlo Simulation for Determining IRR and Cash Flow of a Geothermal Project

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ABSTRACT

Geothermal investment is full with risk and uncertainty that requires to careful considerations of the project. An investment analysis method which can accommodate those uncertain variables is therefore needed.

We have developed a Monte Carlo Simulator for IRR (internal rate of return) and cash flow behavior of geothermal projects. The method is based on Gaussian distribution that continuously generates outputs for all the parameters in the given geothermal datasets.

The simulated variables include project cost, well cost, well output, steam fraction, reinjection capacity, drilling duration, energy price, price escalation, inflation, load factor, operating and maintenance cost. The set of answers are then grouped to yield a set of IRR. The IRR spectrum allows us to view a broader perspective of possible outcomes.

Significant factors that are sensitive to the output can also be examined. The answers with the error taken into account are very helpful for project management to be able to anticipate the worst and the best case.

1. INTRODUCTION

Economic assessment of geothermal projects is usually carried out using a single flow calculation. The economic review is then carried out by simulating one parameter and fixing the other parameters to examine the possible results. Therefore, in practice, the real behavior is often far from the nature. This weakness can be fixed on the basis of Monte Carlo implementation to IRR and cash flow simulation (Raharjo, 2004). This paper describes the usage and the results of the method.

2. MONTE CARLO SIMULATION

The Gaussian distribution is a collection of samples, where its distribution can be drawn as a normal bell-shape function. The peak of the shape represents the average value while the flanks show how the rest of the populations behave compared to the average value. Analytically, the shape states that 68.3% of the samples are situated within the range of x $\pm\Delta x$, where Δx represents one standard deviation, or the square root of one variance, σ. In a wider boundary, e.g. two standard deviations ($\pm 2\Delta x$), 95.4% of the samples are taken into account, while at a three-standard-deviation condition ($\pm 3\Delta x$) 99.7% acceptance is required. In a more advanced requirement, e.g. six sigmas ($\pm 6\sigma$), only one error is accepted from a million events. In this paper the normal bell-shape is considered.

Suppose we consider a multiplication of two numbers $\alpha \times \beta = \gamma$. If α and β are simply two single numbers, the result is then straight forward γ. However, when α and β are collections of two samples, such as ($\alpha \pm \delta\alpha$) and ($\beta \pm \delta\beta$), the result is also a collection of ($\gamma \pm \delta\gamma$), as shown in **Figure 1**. One should notice that the combined error, $\Delta\gamma$, is much larger due to the error propagation effect. In general the total error propagation ΔF from a function of F(x1,x2,…,xn) takes the form of :

$$\Delta F = \Sigma \left| \left(\partial F / \partial x_n \right) \right| \delta_{xn} \tag{1}$$

where $\partial F / \partial x_n$ represents the derivative of F from each contributing variable x, and δ_x is the respective error. For a simple problem in a linear equation, the solution is very handy. However, when the problem is non-linear, complex, or feedback, often it requires a herculian effort to find the solution.

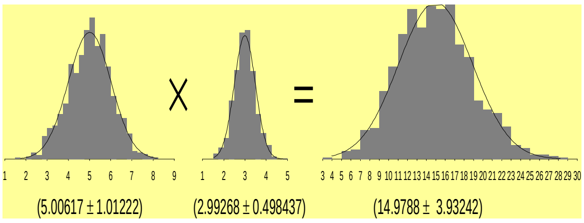

Figure 1: An example of two Gaussian datasets multiplication from a thousand trials. Note that the combined error is much larger than each contributing error.

A method called Monte Carlo has been introduced to overcome such a non trivial analytic solution. So, instead of deriving the formula analytically, the method lets the computer 'throw a dice' continuously on the basis of a Gaussian distribution. On the basis of the forward operator, each 'throw' is converted into the variable of the problem and we observe the result. All results are then collected into a set of answers. The method has become inexpensive, as a result of advanced computing technology. For a complex problem, Monte Carlo often becomes a handy solution.

3. IRR MONTE CARLO SIMULATION

Internal Rate of Return is defined as the annualized effective compounded return rate which can be earned on the invested capital (wikipedia). Or we could say that IRR, for an investment, is the discount rate that gives the NPV (net present value) of the series of cash flow equal to zero. The formula for the NPV is simply:

$$NPV = \sum_{t=1}^{r} \frac{Ct}{(1+r)^t} - Co \tag{2}$$

Where C is the cash flow series as a function of time t, while r is the compounded interest. **Table 1** shows the example of a cash flow with the respective NPV at different interest.

Table 1: Example of simple cash flow series and the NPV.

	a	b	c	d	e	f	g
discount rate	0%	3%	6%	9%	9.6%	12%	15%
series	-300	-300	-300	-300	-300	-300	-300
	120	120	120	120	120	120	120
	120	120	120	120	120	120	120
	120	120	120	120	120	120	120
NPV	60	38	20	3	0	-11	-23

From the given example in **Table 1**, we can see that the IRR for the cash flow [-300, 120, 120, 120] is 9.6%.

Pertamina Geothermal Energy has developed such a program (Raharjo, 2004). The program is written in Fortran95 where the Gaussian behavior and the root finding described in Press et.al. (1992) are used. The programs are available for download both in binary executable file and in FORTRAN source program. Hopefully people can use the program, fix bugs, and share among others, and the link is www.pgeindonesia.com at geothermal article part.

The usage of the program is simple, where we only need to prepare the parameters in one text file, and feed the file into the program. **Table 2** is an example input file.

The program can be run by calling the executable file MCarloIRR.exe and a Console window will appear as shown in **Figure 2**. Once the name of the input file is fed, the program yields the result as shown in **Figure 3**. The results are the simulated cash flow and the IRR's. The cash flow consists of a series of C's with the respective ΔC's. Keep in mind, from the given example we see the the ΔC_5 is quite significant since this point is located at the boundary between last year of investment and the first year of income. So the simulation at this spot is swinging between negative and positive values.

For illustration purposes, we have the IRR values ranging from about 8 to 17 %, with the peak located at about 13%. We can also convert this pdf (probability distribution function) into cdf (cumulative distribution function). The conversion can be carried out analytically or numerically. And for this paper we developed the numerical solution, since the program already had the matrix containing the cdf. Three selected cdf's are shown by the program, e.g. at cdf=10%, 50%, and 90%. We geothermal people treat cdf in positive way. So saying that P10=11%, this means that we 90% sure we would have this change. On the other hand P90=15%, we say that the chance to get this IRR is very remote, only 10%.

The Monte Carlo Simulation uses random numbers to generate a bounded value parameters. When the number of trial is small, a Gaussian shape may not be well developed. Our experience with this technique suggests five thousand trials to obtain a Gaussian behavior for the mean and standard deviation. Fifty thousand trials typically results in a smoother distribution, and eighty thousand trials typically give an extremely smooth Gaussian shape.

4. CONCLUSION / RECOMMENDATION

We have implemented a Monte Carlo scheme for economic assessment of geothermal projects. The program is extremely useful for investigating the amount of risk involved in geothermal investment. By quantifying the variability of the results of the investment, it allows us to properly portray the real nature of the investment. The program uses Gaussian distribution, and we can access the validity of the algorithm by looking at the final answers of the IRR yielding a Gaussian distribution also.

The source code is public and therefore we would like to receive improvements from other users also. The next plan is to include the calculation of Hurdle rate, so that it will accommodate this specific requirement. Constructive comments are welcome.

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Table 2: Montecarlo IRR simulation input parameter.

INPUT FILE	UNCERTAINTY VALUE			FIXED VALUE
POWER PLANT SECTIONS				
Instaled Capacity (MW)				110
Steam Constanta (t/h/MW)				8
COD (months)				36
Fine				0,75
Tax				0,34
DRILLING SECTIONS				
Site preparation & drilling bid (months)	10	12	14	
Cost of the site preparation (million USD)	-9	-10	-11	
Drilling Success Ratio				0.9
Expected Output Production Wells (MW)	8	10	12	
Steam Fraction of the wells	0,2	0,25	0,3	
Expected Capacity of Reinjection Wells (t/h)	250	275	300	
Drilling Duration (months)	1,8	2,2	2,6	
Cost/ Well (million USD)	-4	-5	-6	
Number of Rig (default in the mean time)				2
ABOVE GROUND CONSTRUCTIONS				
Design fabric, construction, commissioning (months)	22	27	32	
Construction cost	-220	-250	-300	
INCOME SECTIONS				
Project Life in Years				30
Energy Price (USD/kWh)	0.05	0.06	0.07	
Price Escalation	0.015	0.02	0.025	
Inflation	0.02	0.03	0.04	
Load Factor	0.95	0.97	0.99	
O&M Cost (million USD)	8	8.2	8.4	
Simulations Section				
Simulations (80000 max)				50000
nclass (50 max)				35
IRR Guess min-max	-0,4		0,25	
Accuracy Root Finding				0,000001

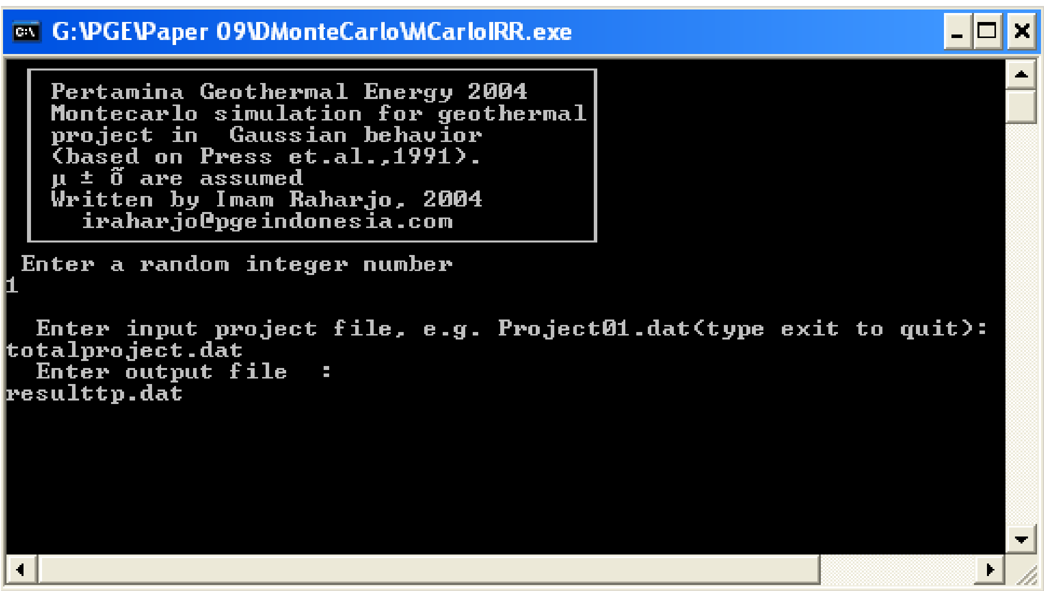

Figure 2: The Monte Carlo IRR program showing the inquiry for input and output files. The program reads text ASCII files.

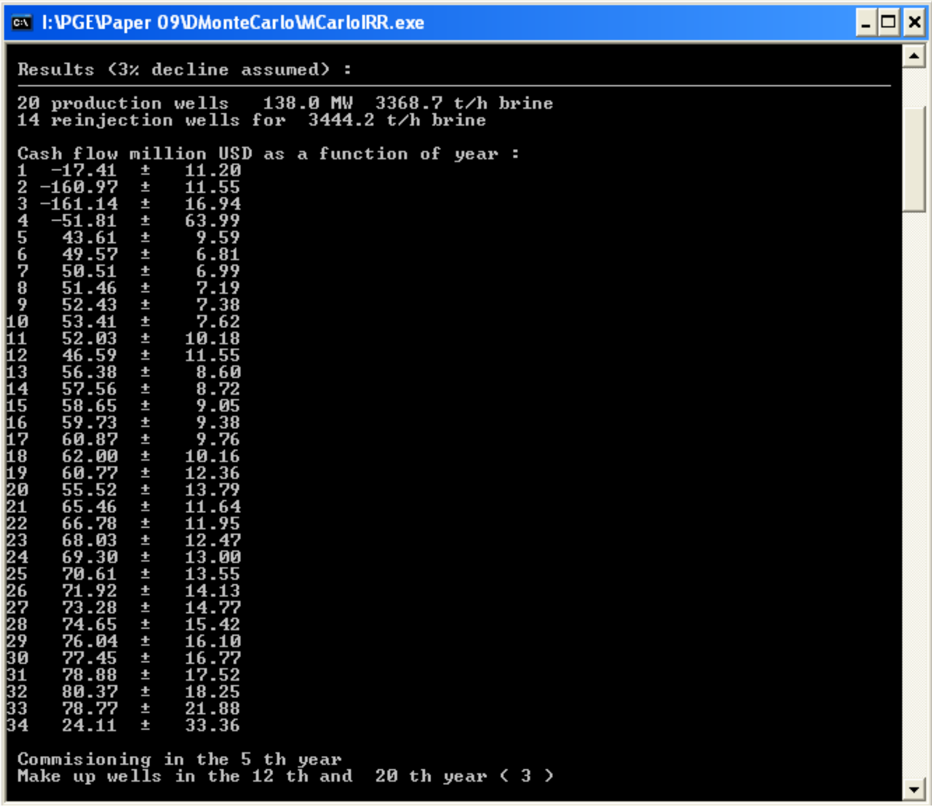

Figure 3: The result of IRR simulation and cash flow within the period of 35 years. Commissioning in the 6th year, then make up wells in the 13th and 21st year. The makeup wells in the 35th year can be omitted.

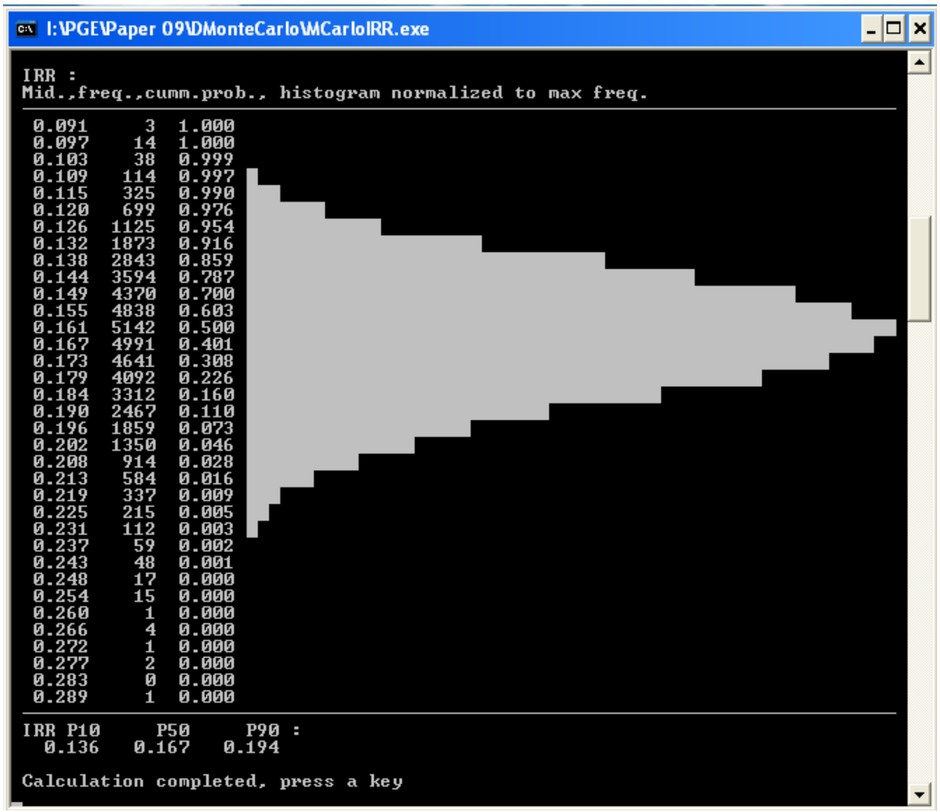

Figure 4: The result of Monte Carlo simulation with 50.000 runs divided into 35 classes.

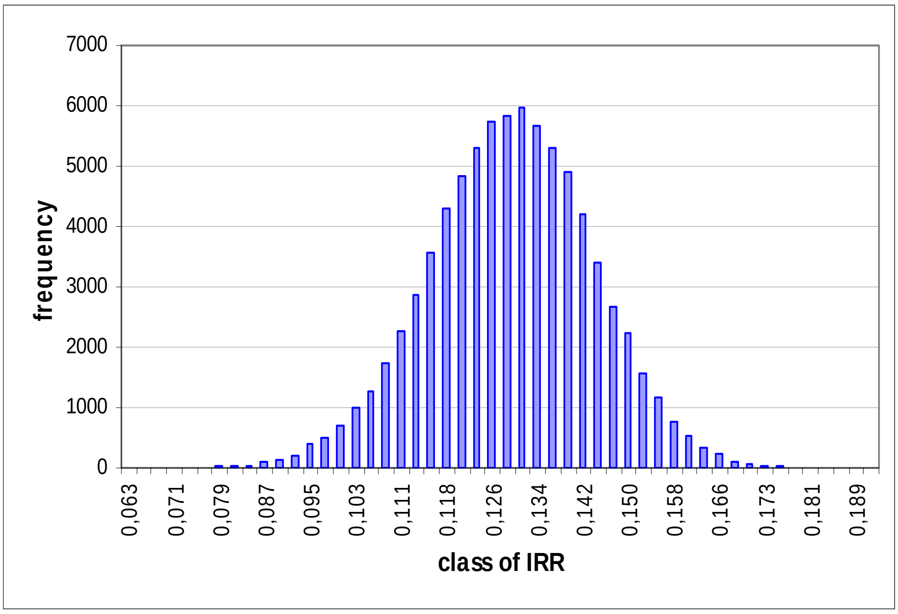

Figure 5: The result of IRR distribution by Monte Carlo IRR simulations. It gave 10.8% for P10, 12.7% for P50, and 14.6% for P90.