

## **MONTE CARLO SIMULATION AS A TOOL FOR TECHNICAL MODELLING AND PROJECT ANALYSIS**

by

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### **Abstract**

Coal preparation plant projects cost many millions of dollars to complete, so it is not surprising that project financiers want both the technical and financial risks to be properly examined. Conventional deterministic methods for “what-if” scenarios or sensitivity analyses can be not only tedious to undertake but presenting the results to decision makers can be challenging. Monte Carlo simulation provides a means to not only overcome the limitations of conventional methods but at the same time add levels of sophistication to the analysis that are not otherwise possible. One such advantage is the ability to use a variety of probability distributions to define the input variables to a spreadsheet model. Monte Carlo simulation involves running thousands of scenarios with a dozen or more variables varying simultaneously, to yield the key outputs as probability plots for ready presentation and interpretation. Modern computers and software tools now make it possible to prepare such models and present the results without the need for PhDs in mathematics, computer science and graphic art.

This paper presents the Monte Carlo simulation of a hypothetical case study. The simulation includes a simple yield model for the preparation plant, to quantify the effects of changing ROM coal quality on income. The outputs from the technical model are then combined with a discounted cash flow analysis to quantify the financial aspects of the project. The outputs are described and the benefits of the Monte Carlo approach over the more commonly used deterministic sensitivity analysis method are highlighted. The paper concludes with some references for further reading, including a list of potential sources for Monte Carlo simulation tools.

### **Introduction**

The coal industry, like any other business, uses a variety of tools to assist investment decision making. Given that most of these decisions involve risking many millions of dollars, it is not surprising that project financiers want both the technical and financial risks to be properly examined.

The conventional approach to project evaluation typically includes a technical model combined with a financial model which usually concludes with a discounted cash flow analysis. These models are then manipulated so that a series of “what-if” scenarios or sensitivity analyses are undertaken. For example, the individual may ask the questions: “What happens to project returns if input X increases by 10%”; “What if input X increases by 10% and input Y decreases by 25%?”. Given that a typical project evaluation may involve in excess of a dozen input variables, using discrete (ie. point value) spreadsheet modelling methods to assess the impact of so many variables can be not only tedious, but often presents considerable challenges when communicating the outputs to decision makers.

Savvakis (1994) provided a thorough outline of financial project risk analysis processes based on Monte Carlo analysis. A summary of the key considerations in project evaluation, as outlined by Savvakis is as follows:

- “The evaluation of project risk ... depends ... on our ability to identify and understand the nature of uncertainty surrounding the key project variables and ... having the tools and methodology to process its risk implications on the return of the project”
- Relying on single point values derived from expert opinion or even historical data can create biases in the project evaluation either as a result of the combination of conservative estimates or the unrealistic combination of values in a single scenario (eg. best case outcome for all inputs, or independent manipulation of dependent input variables, resulting in infeasible scenarios).
- Using single point (discrete) values for project inputs in an evaluation, even when best, expected and worst case scenarios are presented, implies that there is a degree of certainty in the forecast project performance that can mislead investment decision makers and certainly leaves them poorly informed about the probability or risk that the end result will be different from the expected result.

#### **The Monte Carlo method / Monte Carlo integration / Monte Carlo analysis**

The Wikipedia (Anon, 2006) explains that the name Monte Carlo method is a reference to the famous casino in Monaco, in so much as the method's use of randomness and the repetitive nature of the process are analogous to the activities in a casino.

In essence, Monte Carlo methods involve randomly and simultaneously varying the chosen inputs to a mathematical model (typically represented in a spreadsheet) to yield outputs as a range of possible outcomes, i.e. a set of probability distributions. The key to the method is that, even though the inputs are varied randomly, the set of random values for each input are constrained to fit a user defined probability distribution, which is intended to reflect the real world chance of a given value occurring. For example, many “natural” inputs, such as ROM ash content can be expected to fit a bell-shaped normal distribution. In contrast, artificial inputs, such as wage rates may have a much narrower and/or uniform (equal probability) distribution. Figure 1 illustrates this input sampling approach for the case where only 500 samples are used versus a much larger number. This highlights the requirement for Monte Carlo methods to be based on thousands of samples/iterations to ensure an adequate simulation of the intended probability distribution.

For those not familiar with probability frequency distribution diagrams, the x-axis gives the value of the variable and the y-axis is the probability that the variable will have that value within the set of samples or iterations taken. For example, in the desired normal distribution shown in Figure 1, the greatest probability is that the value will be 20% ash in ROM coal, or more specifically by looking at the area under the curve there is a 90% probability that the value will lie between 15.9 and 23.7% ash. Similarly, there is a smaller than 10% chance that it will be outside this range. Note the desired distribution has been defined as having a mean of 20% ash in ROM coal with a standard deviation of 2.5 percentage units around this mean and then truncated so values below 12.5 and above 25 do

not occur. This method of defining the inputs is relatively common across the various spreadsheet based tools available for Monte Carlo analysis.

Once the desired distribution has been defined the simulation will attempt to create this outcome by manipulating the otherwise random choices for values in each iteration. As a result the more iterations that are performed, the smoother the diagram becomes and the more closely it approximates the desired distribution.

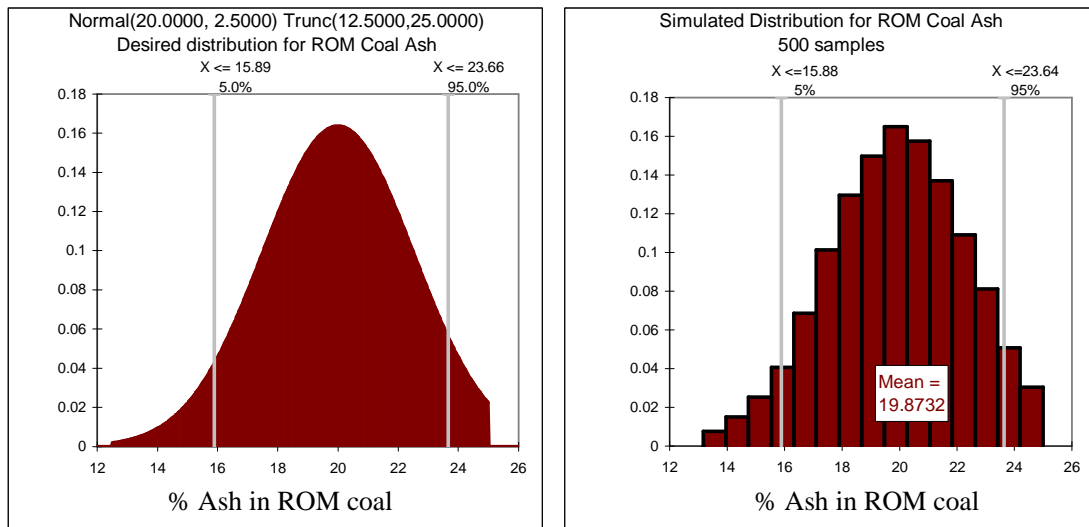


Fig. 1 Example of ash in raw coal as a Monte Carlo method input variable presented in probability frequency distribution form. The two plots contrast an ideal distribution with that based on a limited number of iterations.

The requirement for thousands of samples to accurately represent the desired input probability distribution for the inputs is one reason why Monte Carlo methods had not been widely used in project evaluation until the advent of sufficiently low cost computing power. Modern Monte Carlo simulation tools make it possible to run, in a matter of seconds, thousands of scenarios with dozens of variables varying simultaneously, to yield the key outputs as probability plots for ready presentation and interpretation. Similarly, there are now software tools that allow such models to be prepared and the results presented without the need for the user to have PhDs in mathematics, computer science and graphic art.

Figure 2 illustrates the basic structure of a typical spreadsheet based Monte Carlo simulation, as used for the example presented in this paper. The author has used this technique for models with in excess of 75 inputs, for both technical modelling and project financial evaluation.

To illustrate one of the many possible applications for Monte Carlo analysis, this paper presents the analysis of a project to build a new coal preparation plant at an existing mine site. The simulation includes a yield model to quantify the effects of changing ROM coal quality on the product coal, which is then combined with a discounted cash flow analysis to quantify the financial aspects of the project.

### **Techno-financial model**

The coal preparation plant model used in this analysis consisted of the following worksheets:

- Inputs (26 in total, for both technical and financial parameters. Only 9 of these inputs were varied for the analysis illustrated in this paper, to simplify presentation of the study)
- A simplified specific yield model, i.e. yield relative to the moisture and ash free coal content. More complex models to account for the yields of the different coal recovery circuits, based on a variable sizing envelope for ROM coal can also be implemented but were not used in this example.
- Operating/maintenance cost estimations
- Capital cost estimates
- Financials, including discounted cash-flow (DCF) worksheet and internal rate of return (IRR) calculations.

The input probability distributions used were based on the authors' experience. This is the aspect of the modelling where expert knowledge is required ... otherwise the axiom "Garbage in = Garbage out" will apply as it does to any spreadsheet modelling exercise. A hurdle rate of 15% was assumed, i.e. the after tax internal rate of return must be greater than 15% for the project to be considered worthwhile by the project proponents and their financiers.

The general modelling approach is illustrated in Figure 2. The input distributions included a normal distribution for % ash in ROM coal, a uniform distribution for product coal price (to allow direct testing of the influence of this variable on the project outcome), truncated normal distributions for the capital cost functions, and finally uniform distributions for the debt finance ratio and loan interest rate (again in recognition of the arbitrary nature of these variables).

The capital cost estimates in this case study assume the choice of a two stage DMC coarse circuit, spirals for fine coal recovery, Microcel flotation cells with a nominal capacity of 1000 tonnes per hour of ROM coal, plus stacker reclaimers in the ROM and product coal stockpiles. This assumption was made to simplify the analysis; however it is possible, with sufficiently sophisticated spreadsheet or external models, to include a changeable flowsheet design in the Monte Carlo simulation process. The ability to use discrete value distributions in Monte Carlo simulations is useful in this respect, to allow distinct plant flowsheet options to be simulated.

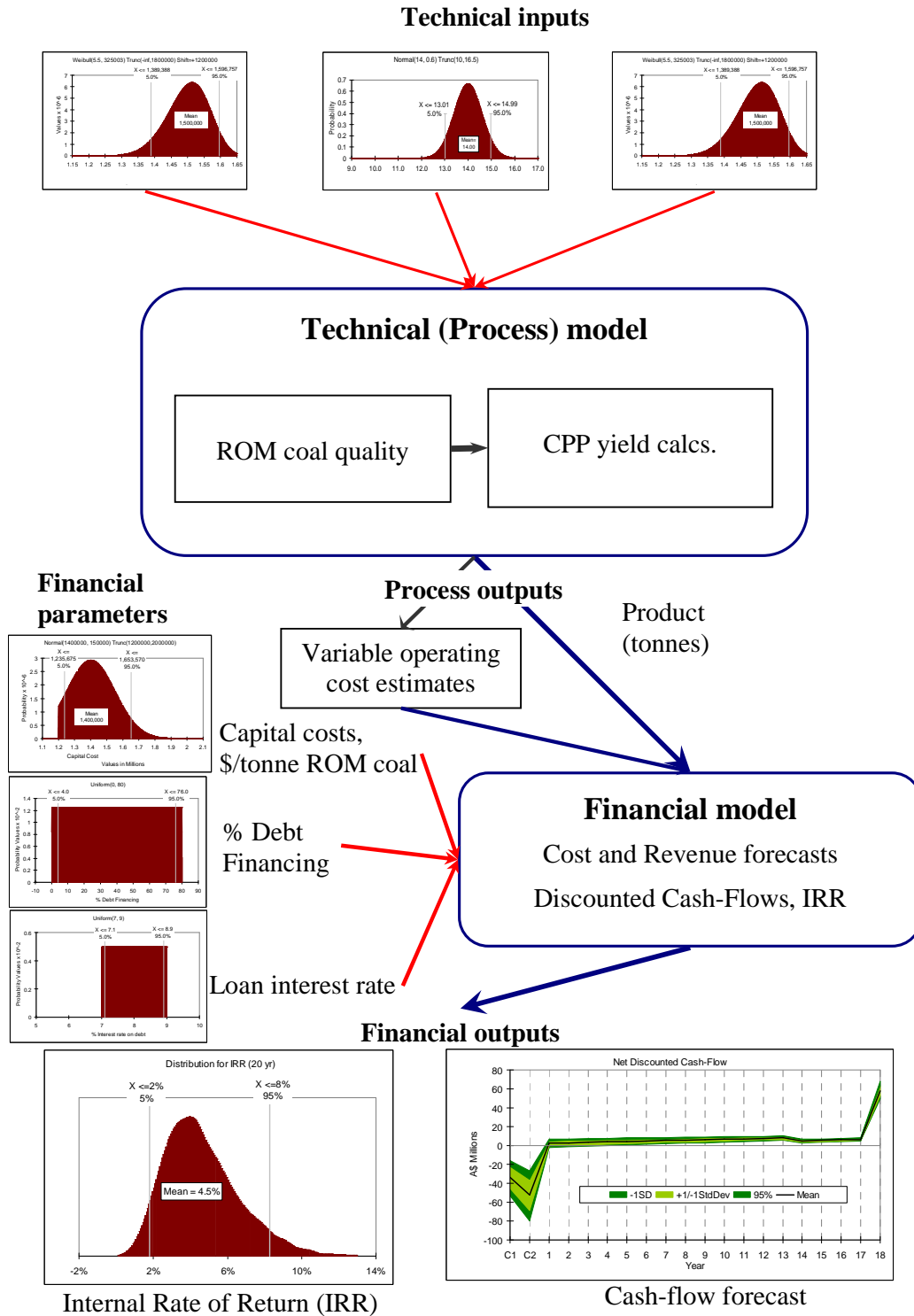


Fig. 2 – Outline of the Monte Carlo Procedure

## Results and Discussion

The spreadsheet model took approximately four hours to prepare from scratch and debug. The subsequent Monte Carlo analysis took under an hour to implement, with a 10,000 step simulation taking under a minute to run on a standard laptop PC.

The results of the analysis are presented in Figures 3, 4 and 5.

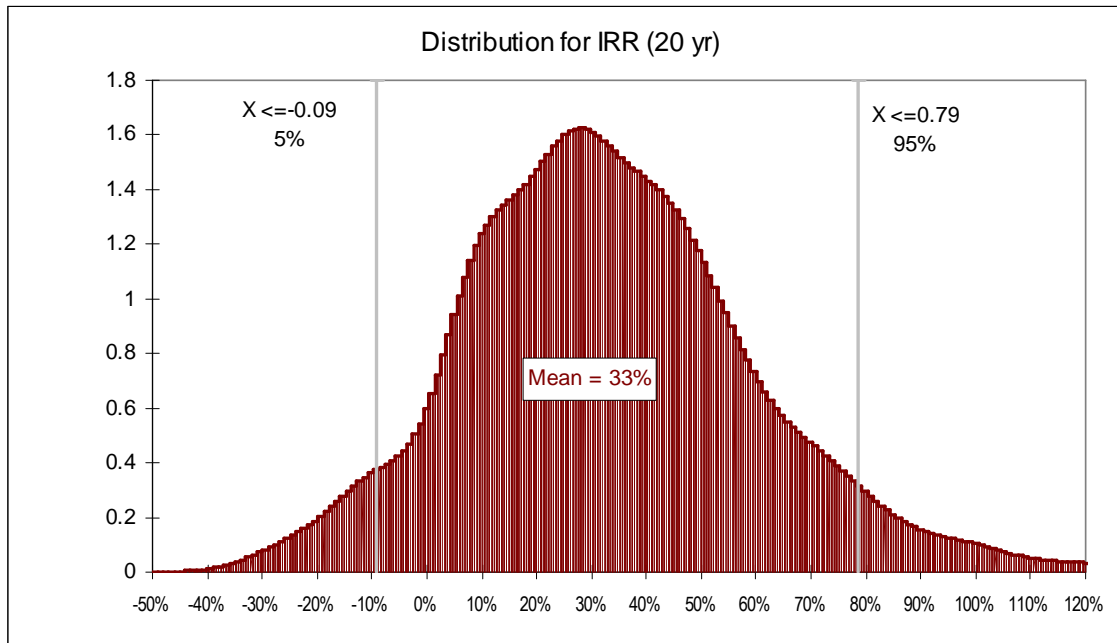


Fig. 3 – Forecast Rate of Return

Based on the results illustrated in Figure 3 the forecast internal rate of return (IRR) shows a rather broad 90% confidence interval of -9% to 79% with an expected (mean) outcome of 33%. The possibility of negative returns is roughly one in ten, but returns in excess of 120% are also possible. Overall the predicted return is well above the 15% hurdle rate required for the project to proceed. The primary source of potential negative returns can be investigated by a sensitivity analysis.

Figure 4, illustrates a sensitivity analysis using a Tornado plot. The Tornado plot is generated by the software using a multiple regression analysis of IRR against the input variables. This helps to highlight which of the key inputs are influencing the variability of the project IRR and thus which aspects deserve attention. In Figure 4 the bars with positive values indicate a positive rate of change of IRR with that specific input. Similarly, negative values indicate a negative correlation between IRR and those inputs (eg.. mine operating costs and ash in ROM coal etc.). The magnitude of the bars represents the relative influence of the inputs on IRR. Tornado plots are generated by all of the commonly used commercial Monte Carlo analysis tools.

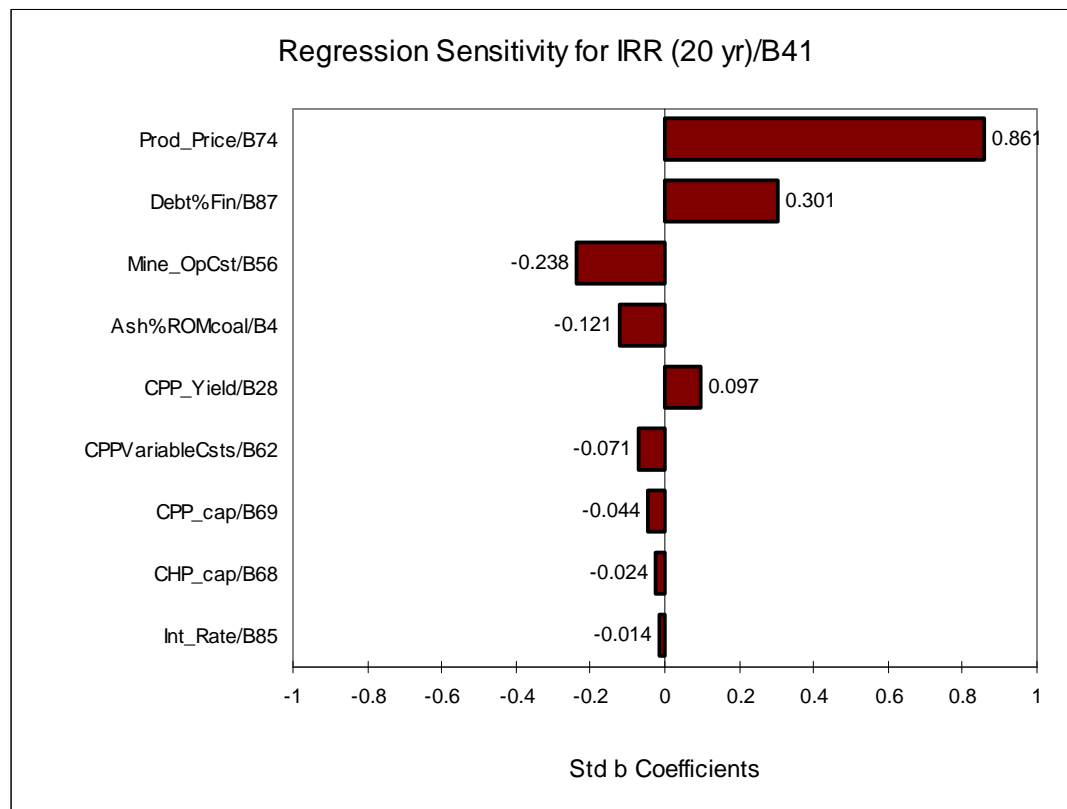


Fig. 4 – Sensitivity analysis (Tornado plot)

Figure 5 gives a time series probability plot for net cash flow. This indicates that the cash flow of the project is expected to rise above zero in the first year of operation of the plant (yellow line); however, there is a 5% chance that it will be less than zero for the first fourteen years.

Figure 5 also shows that the owner's equity (ie. funds outlaid during the two construction years) is very variable; which is as expected because this results from the varying of the debt financing ratio. Obviously, debt financing reduces exposure of the equity owners during the initial period of the project, but the primary benefit is that debt is "cheaper" than equity funds.

Total capital outlays were estimated to be of the order of \$300M for the installation of new CHP and CPP equipment on a greenfield site at an existing mine, given a nominal capacity of 1000 tonnes per hour of ROM coal.

### Conclusions

For the worked example, it is evident that the project is most strongly influenced by the price of the product coal, followed by the debt financing ratio, the ash percentage in the ROM coal and plant yield. After that the significance of other factors, such as capital costs, and debt interest rate is relatively small.

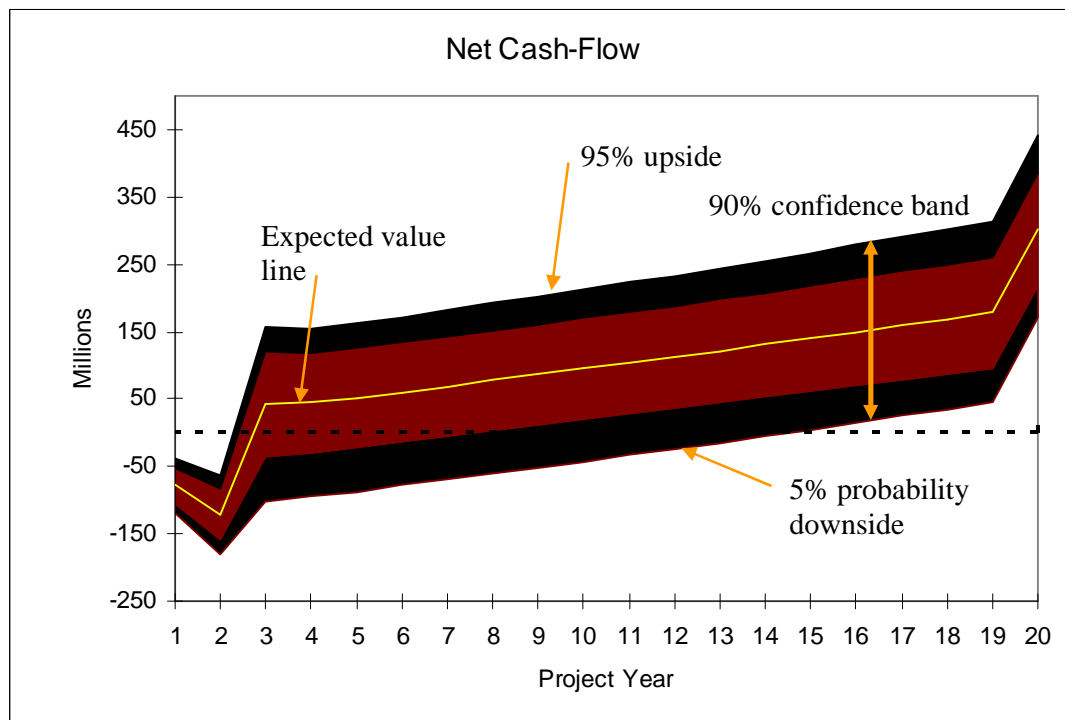


Fig. 5 – Forecast Net Discounted Cash Flow

The importance of the product coal price in project economics is perhaps obvious but serves to highlight the worth of coal marketing and the price security of forward contracts in justifying a coal preparation plant project.

The positive influence of debt financing in this instance is directly as a result of the cost of debt capital being less than the cost of equity (ie. the equity owners have higher expectations for financial return on funds invested, i.e. 15%, than the lending institutions).

Interestingly the role played by up-front capital costs in overall project return was relatively small, suggesting that project development efforts are best put into coal sale contracts and the optimisation of the mining operations than focussing on the installed cost of the CHPP.

The Monte Carlo analysis method outlined here has illustrated the ease with which a spreadsheet model can be used to rapidly analyse and present the outcomes of a project evaluation. The example was a coal preparation plant project, however, the method can be equally well be applied to technical applications such as the examination of mining operations, coal preparation plant flow balances, site water use management etc.

#### **Recommendations for further reading on Monte Carlo analysis**

For further reading on the application of Monte Carlo techniques the following resources are recommended:

Introduction to Monte Carlo simulation. This reference is provided by Microsoft Corporation and has specific instructions on how to use Monte Carlo methods in MS-Excel®. <http://office.microsoft.com/en-au/excel/HA011118931033.aspx>

Savvakis Savvides, Risk Analysis in Investment Appraisal, Project Appraisal Journal, Vol. 9, No. 1, March 1994. Available at SSRN: <http://ssrn.com/abstract=265905> or DOI: 10.2139/ssrn.265905

The resources supplied by Monte Carlo Simulation software providers are also very useful. A selection of the commonly used Monte Carlo simulation software tools is as follows:

- @Risk by Palisade Asia-Pacific Pty Limited. A suite of fully featured Monte Carlo Simulation and decision support packages for Microsoft Excel®. See [www.palisade.com.au](http://www.palisade.com.au) .
- CrystalBall by Decisioneering Inc. A suite of fully featured Monte Carlo Simulation and decision support packages for Microsoft Excel®. See [www.decisioneering.com](http://www.decisioneering.com) .
- GoldSim by GoldSim Technology Group. One of very few non-spreadsheet based modelling and Monte Carlo analysis software packages. Not recommended for first time or casual users of Monte Carlo methods. See [www.goldsim.com](http://www.goldsim.com) .
- Lumenaut by Lumenaut Ltd. An intermediate cost Monte Carlo simulation add-in for Microsoft Excel®. See [www.lumenaut.com](http://www.lumenaut.com) .
- Riskamp by Structured Data, LLC. A low cost but well featured Monte Carlo simulation add-in for Microsoft Excel®. Approximately one tenth the licence cost of the fully specified decision support packages such as @Risk or Crystal Ball but well suited to standard Monte Carlo analysis. See [www.riskamp.com](http://www.riskamp.com) .
- RiskEase by Master Solutions Ltd. An intermediate cost Monte Carlo simulation add-in for Microsoft Excel®. See [www.riskease.com](http://www.riskease.com) .
- w3mcsim – An online Monte Carlo simulation tool for scientists provided by the University of California. The authors do not recommend this tool as spreadsheet based tools will suit most users best. Located at [www.biocyb.cs.ucla.edu/montecarlo/montecarlo.html](http://www.biocyb.cs.ucla.edu/montecarlo/montecarlo.html)

## References

**Anon.** (2006). Monte Carlo Method. Wikipedia, 14 December 2006, Wikimedia Foundation, Inc., 14 December 2006, [http://en.wikipedia.org/wiki/Monte\\_Carlo\\_method](http://en.wikipedia.org/wiki/Monte_Carlo_method)

**Savvides, S.C.** (1994), Risk Analysis in Investment Appraisal, Project Appraisal Journal, Vol. 9, No. 1, March, 30p.