Risk Analysis Using the Four-X™ Proteus Environment™

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Abstract

This paper describes a technique for analysing the risk factors associated with a mining operation, using the Four-X™ Proteus Environment™ user interface. The technique is based on a probabilistic approach that uses a set of inputs weighted with a probability to predict the probability of an output.

It is shown that the technique can quickly give an indication as to the possible value of a mining project using a range of NPV values rather than a single, possibly misleading, spot NPV estimate.

Introduction

Four-X has been used extensively within the mining industry to strategically plan, design and refine mining operations. Until recently, this process has been achieved using specialised text input files and the Four-X one dimensional user interface, however performing extensive risk analysis involved a great deal of work.

The Four-X Proteus Environment is a newly developed direct manipulation style user interface that provides users with a powerful set of tools for strategic mine design. It utilises the thoroughly tested and proven Four-X program as a behind-the-scenes engine, while allowing the user to quickly enter data via a graphical user interface.

Four-X forces the user to enter and re-enter large amounts of information, and requires the user to manage a large set of input and output files. The Proteus Environment manages all Four-X files for the user and provides default data wherever possible, therefore reducing the user's cognitive load.

To help navigate the large amounts of data needed for a Four-X run, the Proteus Environment uses a tree structure to graphically represent the inter-dependencies of the data. Selecting nodes on this navigation tree allows the user to browse the data associated with that node using a tab-book based interface.

The probabilistic risk analysis approach described in the following section makes extensive use of the Proteus Environment, relying on the interface to manage a staggering number of input and output files, allowing the user to focus on the true task of strategic mine planning.

Probabilistic Risk Analysis

The probabilistic approach to risk analysis is extremely useful as it gives not only a central NPV estimate, but also provides a range of NPV and the likelihood of the project falling within that estimate. This approach is preferable to producing a spot estimate of a project's worth, and using the Proteus Environment, risk associated with the assumed geological, geotechnical and operational limitations and environment can be evaluated together.

To study the concept, we will use a simple example that is derived from the Four-X tutorial data set. The simple example presented here only uses 27 tests, which provides very rough results. Tests of 125 or more are recommended if a reasonable estimate of the final distribution is to be made.

The first step in determining the risk associated with the operation is to determine the subjective probability distribution of each major risk factor, including the geological, geotechnical, and operational limitations/environment.

Geological Probability Distribution

The geological probability distribution is represented by multiple block models representing very conservative through to optimistic estimations of the size or average grade of the resource. Each of these block models is assigned a probability in relation to the other block models. These probabilities range between 0 (meaning impossible, will never happen) through to 1 (will always happen), and the sum of the probabilities assigned to the models should equal 1.

In this example, the block models were created by slicing away the lower sections of the block model. Other techniques for creating a range of block models include reducing and increasing the grades over the entire model, as well as completely re-producing the model using different constraints.

The first model (Model A) has had the lower 12 benches of the model removed (and turned to waste), representing a resource much smaller than anticipated.

The resource in the second model (Model B) was also cropped and had the lower 6 benches removed, representing the most probable resource. The Final model (Model C) was not modified at all, and represents an optimistic resource.

Each model is given a subjective probability relative to each other, the sum of which equals one. The probabilities assigned to each model are summarised in Table 1.

Model Name	Probability	Notes
Model A	20%	Last 12 benches removed
Model B	60%	Last 6 benches removed
Model C	20%	Complete model
Sum:	**100%**	

Table 1: Subjective Probability Distribution of the Block Model

These block models were then imported into the Four-X Proteus Environment and given meaningful descriptions. Figure 1 shows the imported block models in the tree as nodes with icons, a description and assigned probability.

Geotechnical Probability Distribution

The geotechnical probability distribution and the assumptions made about the competency of the rock being mined may be encapsulated by different slope constraints, representing very conservative through to optimistic estimations of the maximum safe slope angle possible. Like the geological distribution, each of these slope sets is assigned a probability in relation to the other slope set, and the sum of the probabilities will equal one.

In this example, only one slope region was used and only one slope angle used for each estimation. These estimations were given a subjective probability and are described in Table 2.

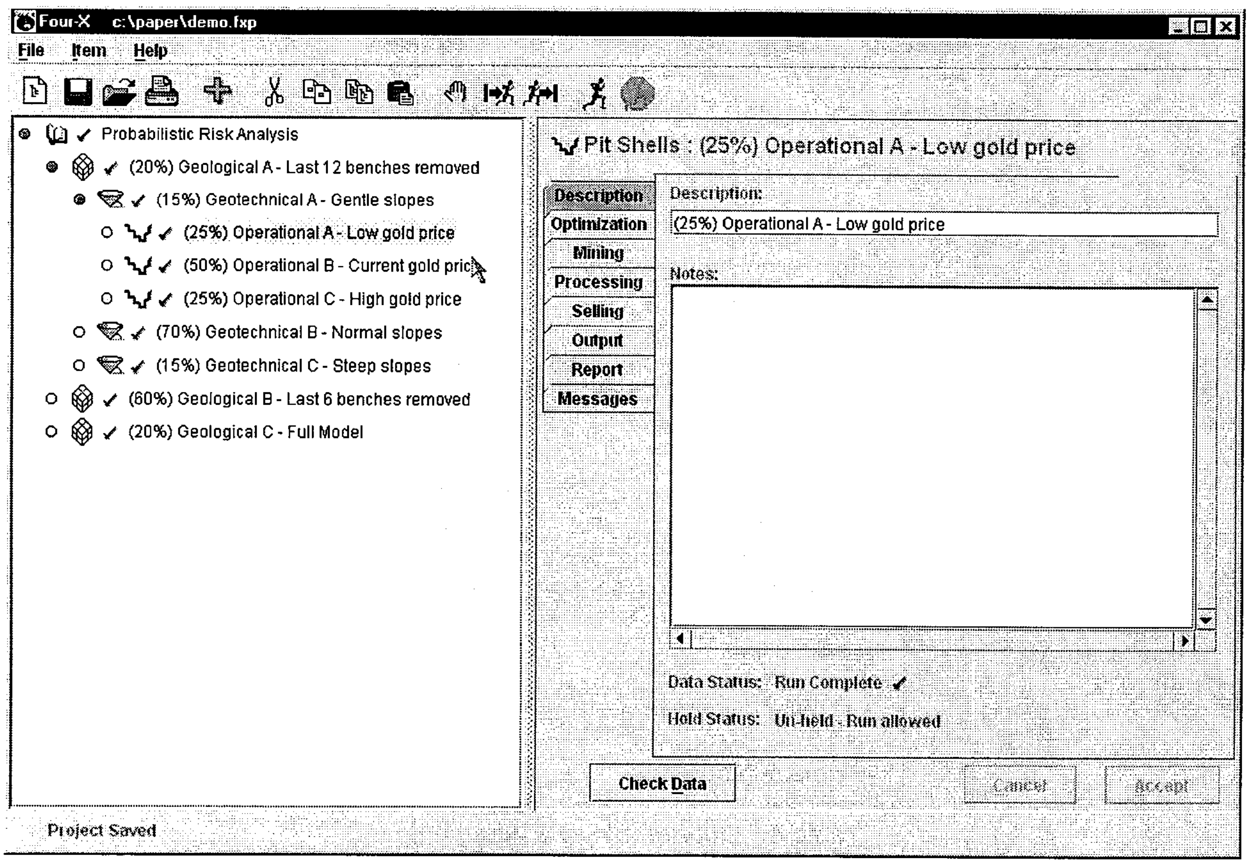

Figure 1: Probabilistic Risk Analysis Using the Four-X Proteus Environment

Slope Name	Probability	Notes
Geotechnical A	15%	Flat slopes, 41°
Geotechnical B	70%	Normal slopes, 45°
Geotechnical C	15%	Steep slopes, 49°
Sum:	**100%**	

Table 2: Subjective Probability Distribution of Geotechnical Risk Factors

These slope sets were then entered into the Four-X Proteus Environment and given meaningful descriptions. Figure 1 shows the slope sets in the tree as nodes with icons as well as the description and assigned probability.

Operational Limitations / Environment Probability Distribution

The various operational and economic environment assumptions are also represented by a subjective probability distribution.

Like the other distributions, each of these factors is assigned a probability in relation to the others, and the sum of the probabilities will equal one.

For this example, the price of gold per ounce was considered to be the major risk factor, and so was varied (see Table 3).

Other operational and economic constraints were kept constant to reduce compute time and keep the example simple (see Table 4).

Name	Probability	Notes
Operational A	25%	Low gold price (US$300/oz.)
Operational B	50%	Current [1] gold price (US$400/oz.)
Operational C	25%	High gold price (US$500/oz.)
Sum:	100%	

Table 3: Subjective Probability Distribution of Operational Limitation / Environment Risk Factors

Constraint	Value
Mining limit	None
Milling limit	1.0 m tpa
Capital expenditure	None
Time related costs	None

Table 4: Operational and Economic Factors Used in the Example

This information was entered into the Four-X Proteus Environment and given meaningful descriptions, however unlike the previous probability distributions, this information is entered as three separate nodes in the tree. These nodes are the Pit Shells node, the Operational Scenario node and an Analysis node.

Figure 1 shows the Four-X pit optimisation step in the tree as nodes with icons and are called Pit Shell nodes. The Pit Shell nodes have their respective gold prices entered, and all have only a single revenue factor set to 1.0. This creates only one pit (which will be optimal for the stated gold price) and simplifies the collection and presentation of the data.

Figure 2 represents the Operational Scenario node in the tree with a icon. The gold price for this node was set to the gold price of the parent node and the mill limit of 1.0 m tpa was set. The discount rate was set to 10%. This rate was not risk adjusted, as risk factors are being accounted for in the probability assigned to the node.

An Analysis by Grand Total node (represented by an icon in Figure 2) was added to each scenario, and the required output variables selected (NPV in this case).

[1] The current gold price indicates the price at the time the Four-X tutorial data set was created, not the current gold price at the time of writing.

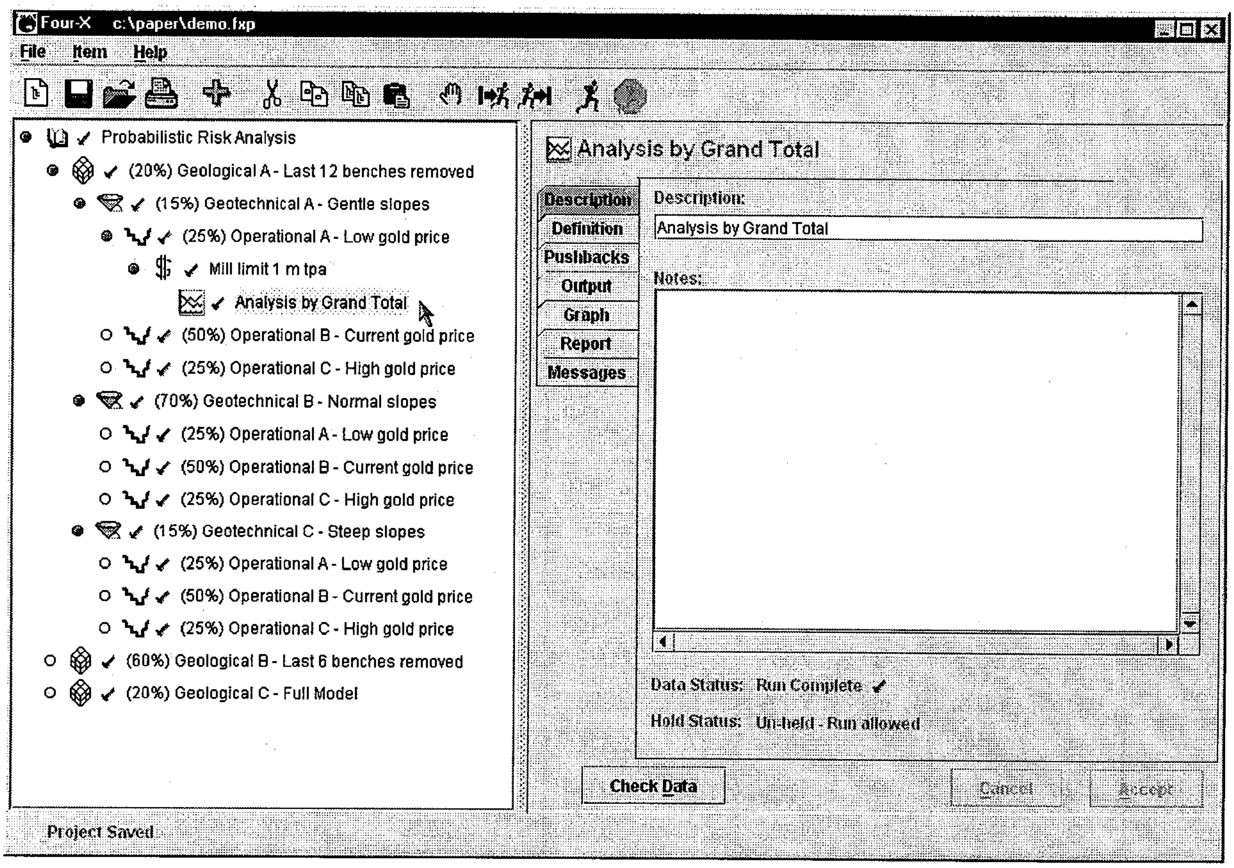

Figure 2: All Items entered into the Proteus Environment.

Producing Results

After the three variations for each risk factor are entered, all possible combinations can easily be created by using the Proteus Environment *Copy Branch* and *Paste* functions, and all NPVs can be calculated by pressing the *Run All* button ( ).

The probability of each result is calculated by multiplying together the subjective probabilities of each node that contributed to the result. For example, the first branch shown in Figure 2 consists of a Block Model (20%), a Slope Set (15%) and the Pit Shell/Scenario/Analysis combination (25%) giving a probability for the result of 0.75%.

The probability of each result, and the NPV result itself was entered into a spreadsheet from which the weighted mean and standard deviation can be calculated (see Table 4). The weighted mean was calculated by summing the product of each NPV result and its associated calculated probability. The standard deviation was calculated using Equation 1.

Model		Slope		Shell		Probability	NPV
A	20%	A	15%	A	25%	0.75%	1,854,112
A	20%	A	15%	B	50%	1.50%	6,728,951
A	20%	A	15%	C	25%	0.75%	13,549,467
A	20%	B	70%	A	25%	3.50%	2,198,445
A	20%	B	70%	B	50%	7.00%	7,191,437
A	20%	B	70%	C	25%	3.50%	14,273,192
A	20%	C	15%	A	25%	0.75%	2,778,454
A	20%	C	15%	B	50%	1.50%	8,025,486
A	20%	C	15%	C	25%	0.75%	15,113,010
B	60%	A	15%	A	25%	2.25%	1,854,817
B	60%	A	15%	B	50%	4.50%	8,301,057
B	60%	A	15%	C	25%	2.25%	17,595,504
B	60%	B	70%	A	25%	10.50%	2,537,029
B	60%	B	70%	B	50%	21.00%	9,491,156
B	60%	B	70%	C	25%	10.50%	19,547,780
B	60%	C	15%	A	25%	2.25%	3,512,997
B	60%	C	15%	B	50%	4.50%	10,862,145
B	60%	C	15%	C	25%	2.25%	21,304,165
C	20%	A	15%	A	25%	0.75%	1,854,817
C	20%	A	15%	B	50%	1.50%	7,930,154
C	20%	A	15%	C	25%	0.75%	18,180,942
C	20%	B	70%	A	25%	3.50%	2,537,029
C	20%	B	70%	B	50%	7.00%	9,244,672
C	20%	B	70%	C	25%	3.50%	20,420,282
C	20%	C	15%	A	25%	0.75%	3,485,860
C	20%	C	15%	B	50%	1.50%	11,260,590
C	20%	C	15%	C	25%	0.75%	22,432,589
						Mean:	9,804,498
						Std Dev:	5,940,272

Table 5: Subjective Probability and Calculated NPV

Equation 1: Standard deviation for infinite population.

$$\sigma = \sqrt{\sum (X^2 p(X)) - \overline{X}^2}$$

Graphing the cumulative probability versus NPV produces an unusual curve (see Figure 3) that does not look much like the classic S curve for cumulative normal distributions. The strange shape of the curve is due to the small number of NPV results and because of the discrete form of the input variables.

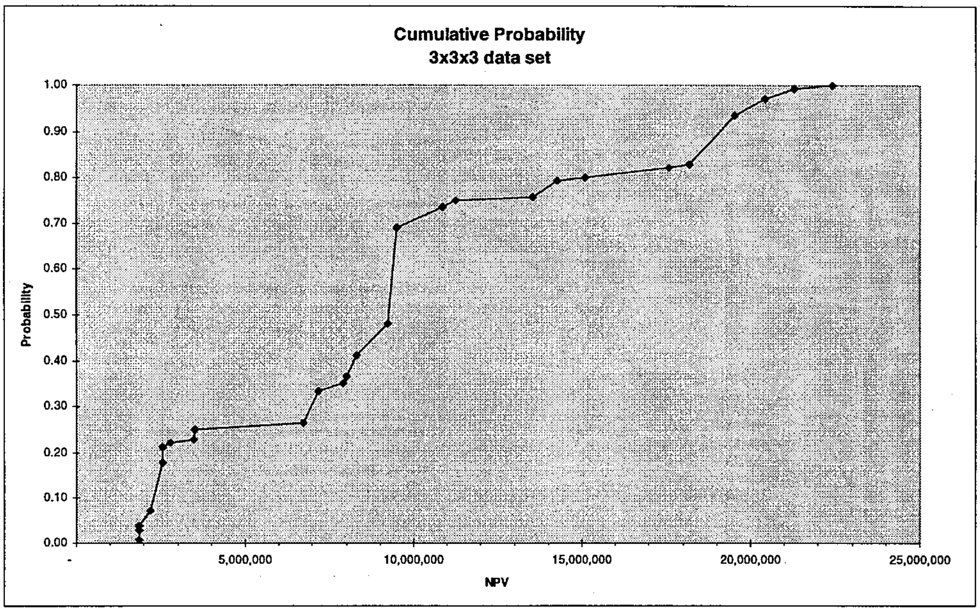

Figure 3: Cumulative Probability for Simple 3x3x3 Data Set (27 Data Points)

A more advanced test was conducted which consisted of five block models, five different slope sets and five different gold prices, producing a total of 125 NPV results. This test produced a very interesting cumulative probability curve (see Figure 4) that clearly has five smaller curves combined with a skewed cumulative S curve. To highlight the underlying S curve, the data was smoothed by extracting the mid point of each sub curve and fitting a curve to the result (see Figure 5).

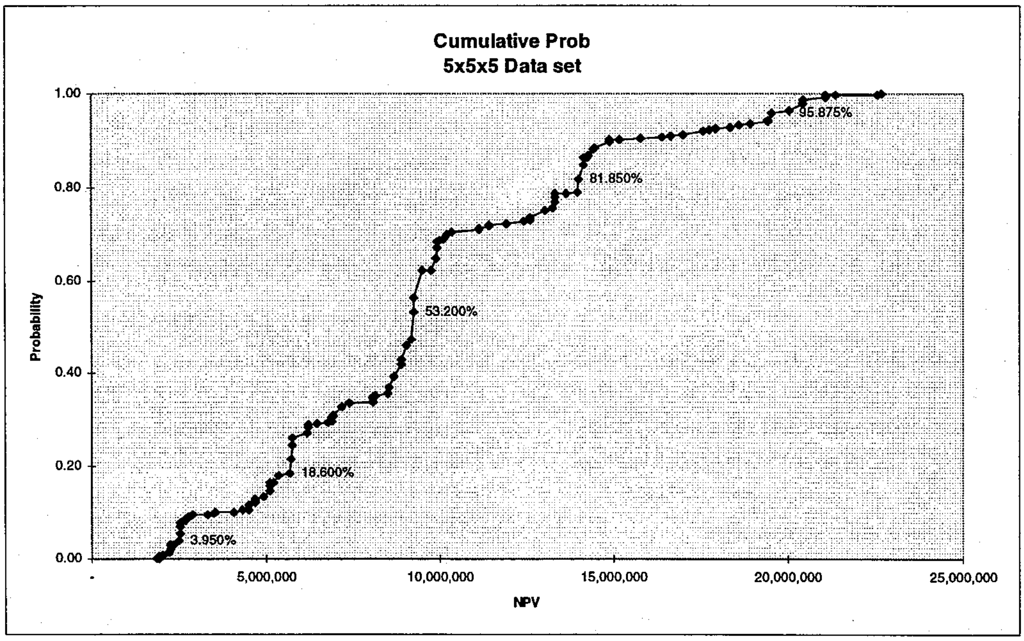

Figure 4: Cumulative Probability for More Complicated 5x5x5 Data Set (125 Data Points).

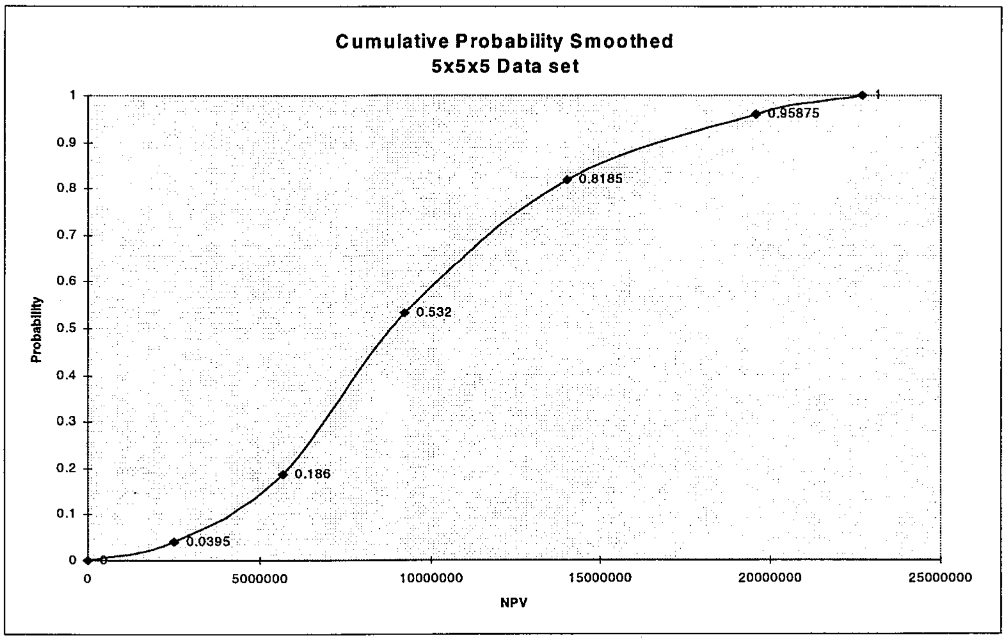

Figure 5: Smoothed Cumulative Probability of 5x5x5 Data Set

Using the Results

Once a curve like the one presented in Figure 5 has been plotted, rough estimates as to the risk involved in the project may be made. Our sample shows a mode of approximately $9m, with NPV values 25% either side of the mode of $6m and $13m. Such a range is much more useful than a spot estimate when comparing projects.

Conclusion

Probabilistic risk analysis is a useful technique that can quickly give a rough indication as to the possible value of a mining project using a range of NPV values rather than a single, possibly misleading, spot NPV estimate.

However, the results of this technique can only be used as a guide, as significant error is introduced by the subjective assignment of probabilities, the discrete approximation of continuous distribution input variables, and the smoothing of the resultant distribution.

The new Four-X Proteus Environment user interface greatly assists in the implementation of this technique, relying on the interface to manage the large number of files needed by the Four-X engines, as well as exploiting the copy and paste facility to quickly fill out the entire probability space.

For the example presented in this paper (using 27 tests), entering the data, computing the NPV for each test, extracting the data and placing in a spreadsheet took a little under an hour to accomplish. The Proteus Environment created and/or managed approximately 300 files (including parameter files, log files, print files, result files, structure arc files, spread sheet definition and output files, etc.), consuming 98 MB of disk space.

The more complicated example of 125 tests took around two hours to complete, with the Proteus Environment creating and/or managing over 1,300 files, consuming 677 MB of disk space.

Both tests were conducted using an early development version of the Four-X Proteus environment on a 333 MHz Pentium 2 machine with 128mb of RAM (mid range machine).