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# Baley Gold Project Optimisation with Whittle Four-D and Beyond

## Joe Bosworth & Tamer Dincer

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B Sc Degree in Mechanical Engineering, Purdue University, Indiana, USA.

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Worked for several international mining and metals companies as Corporate Manager of Engineering, Corporate Chief Engineer, Project Manager, Construction Manager and Project Engineer for both operating companies and engineering companies.

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B Sc and M Sc Degrees in Mining Engineering, METU, Ankara, Turkey.

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Consulting Mining Engineer with experience in numerous open pit planning projects for gold, nickel and coal operations. Worked for Snowden Associates (including Baley Gold Project) prior to establishing Mining Solutions Consultancy in May 1998. Has also worked for WMC Mt Keith Operation as a Strategic Planning Engineer and held research and lecturing positions in various universities including WASM.

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## Introduction

The Baley Gold Project is owned by Armada Gold Corporation and is located in the Chita Region of Siberia, Russia. The mining study was completed as a part of the Bankable Feasibility Study being carried out for the development of an open pit mine and gold processing plant to be located at one of Russia's past productive underground gold mines.

An iterative approach was adopted throughout the mining study in order to achieve the best utilisation of the Taseevskoe deposit's mineralisation. The planning cycle included pit optimisations, staged pit designs, cut-off grade optimisations, detailed production scheduling, equipment selection, capital and operating cost estimates and financial analysis stages. Whittle Four-D was used extensively for mine modelling while a **Fifth Dimension**, the capital and operating costs of the proposed mine and processing facilities was used to find the optimum size of the project to maximise the financial returns to Armada.

The Baley Project Feasibility Study is an outstanding example of the integration of

the specialist mine engineer and the mine planning process using Whittle Four-D software, with an owner's team and their objective of planning a project that brings the best project financial returns for a specific set of conditions.

## Project Background

During the first detail phase of the study in early and mid 1997, four relatively large mining stages were designed based on the pit optimisation results. These mining stages were planned to deliver 28.2 million tonnes of ore averaging 3.23g/t gold grade. Cut-off grade optimisations were carried out prior to production scheduling to optimise the mining and milling rates and the resultant operating cash flow. The final production schedule was based on a mill capacity of processing 1.75 million tonnes of ore selected from a maximum mining rate for high and low grade ore and waste of 25 million tonnes per year.

With the gold prices continuing to fall during the remainder of 1997, the study was revisited in the first quarter of 1998 and further refined in order to optimise financial returns. This second detail phase study identified two smaller high grade pit stages which were selected for mining 3.1 million tonnes of ore at 7.1 g/t. Accordingly, a start-up project with a mill capacity of 0.5 million tonnes per annum was chosen. Considering the upside potential for the project, this pit development strategy allows

for further expansion of the open pit as planned in the first phase of the study once gold prices recover to suitable levels.

Baley has been one of Russia's historic mining areas with two gold mines immediately adjacent and several other mines in the vicinity. Baley is located east of Lake Baykal in south eastern Siberia as shown on Figure 1. The town is on the Unda River a few kilometres south of the Trans-Siberia Railway.



Figure 1: Baley Project Location in Siberia, Russia

Modern mining at Baley dates from the late 1920s when exploitation of the large Baleykoe Deposit on the west edge of town commenced. The Taseevskoe Deposit south of town was discovered in the 1940s, underground mined until the late 1980s with an open pit mine started over the underground workings. Poor economic results due to unsuitable mining and processing methods resulted in mines on both deposits shutting down by 1994.

There are innumerable parallels between Baley today and Kalgoorlie as it was about 20 years ago.

Armada Gold through a wholly owned Cyprus company first earned interest over the Taseevskoe as well as other nearby gold deposits commencing in 1995. Armada now has direct control over 85% of the Taseevskoe deposit, (Russian interests hold the other 15%). Armada has agreements in

place that will allow it to control 95% once they are exercised.

Preliminary and Base Line studies for project development took place between 1995 and 1997. A bankable quality Feasibility Study was completed in October 1997 and a supplement to that study completed in August 1998.

This paper concentrates on the Taseevskoe deposit mining study completed as a part of Bankable Feasibility Study being carried out for the development of an open pit mine and new processing plant. The open pit is planned as an expansion of the existing pit over the underground mine. It presents the iterative planning approach used in the mining study to improve the project value through various phases involving pit optimisations, designs, cut-off grade optimisations and production scheduling.

The project started with Whittle Four-D pit optimisations using initial input parameters to determine the size of a preliminary ultimate pit and a staged pit development strategy. Although pit optimisations provided a basis for the size and development sequence of the pit reserves, it did not answer the fundamental questions of what should be the optimum processing plant and mine capacity. Another important aspect of the study was to determine a cut-off grade policy that would meet the project expectations determined by the Armada's financial optimisation programmes.

Since operating and capital costs, project size, equipment requirements, cut-off grade and reserves were all inter-related in a mining project, an iterative approach was necessary in order to optimise the overall mine operation. Cut-off grade optimisations were critical to determine the optimum size of the project in this iterative planning process. Using the preliminary production schedule derived from the pit development sequence, the cut-off grade study and the analysis of capital expenditure requirements provided the **Fifth Dimension** to the project analysis.

With the computer tools available today, it has been possible to perform the iterative planning cycle effectively and quickly throughout the project. In the following sections of this paper this computerised iterative approach is discussed together with the major outcomes. Particular emphasis is given to the **Fifth Dimension**, which is the determination of the optimum mining and processing capacities for the operation utilising full plant capital and operating cost estimates.

### Iterative Planning Cycle

The classical cyclic relationship between major variables in a mining project is well known and introduced in mine planning textbooks (SME, 1992).

Figure 2 summarises the variables and the cyclic relationship between them in the

planning process. The cycle starts with the determination of initial economic parameters used in the reserve estimates. Based on the reserve estimate, the production schedules are prepared leading to the determination of the equipment requirements. With the selection of the equipment fleet, the project costs are revised and new economic parameters can be defined which will require a new reserves estimate. Hence, the planning cycle starts again producing a solution approaching to the optimum with the completion of each cycle.

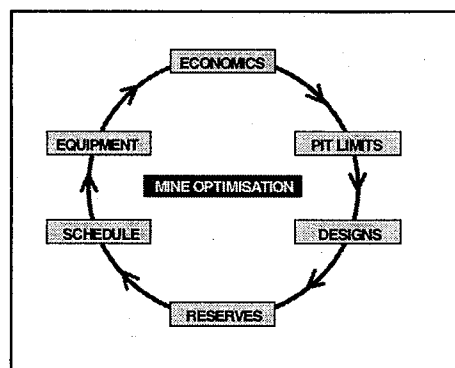


Figure 2: Iterative Planning Cycle

Computer tools available today largely facilitates this cycle by introducing shortcuts and making possible detailed evaluations with additional inputs at various stages of a project. Pit limit and cut-off grade optimisations are the tools widely used for this purpose. Integrated with other computer tools, such as pit design and production scheduling software, the iterative planning cycle can be executed effectively and efficiently. These mine planning tools can be integrated with project capital, (capex) and operating cost (opex) estimates in sophisticated financial models to determine the optimum Net Present Value and Internal Rate of Return for a project.

The flow chart in Figure 3 is an example for such an integration of open pit mine planning with capex and opex estimates as used in Baley Project Feasibility Study.

Three basic project development phases can be identified in Figure 3 without compromising the iterative nature of the planning process. Although the distinction between them is not well defined, these phases can be referred as (1) initial, (2) progressive and (3) final phases.

### Phases of Cycle

The initial phase includes the pit optimisations, initial pit stage designs (pushbacks) and preliminary production schedules using the parameters mainly defined in the pre-feasibility study. It provides a starting point for the feasibility study with the accommodation of further information and data gathered before the

commencement of the study.

In the progressive phase, the relationships between the project variables are investigated in order to maximise the return from the operation. The progressive phase is the critical phase of the study since it requires making major decisions with the contribution of various groups involved in the project. Some of these inter-related decisions include the size of the operation, cut-off grade policy, pit development strategy, equipment selection and cash flow requirements. At the end of this phase, the variables are optimised together in line with the company policy and the project becomes ready for the final evaluation phase.

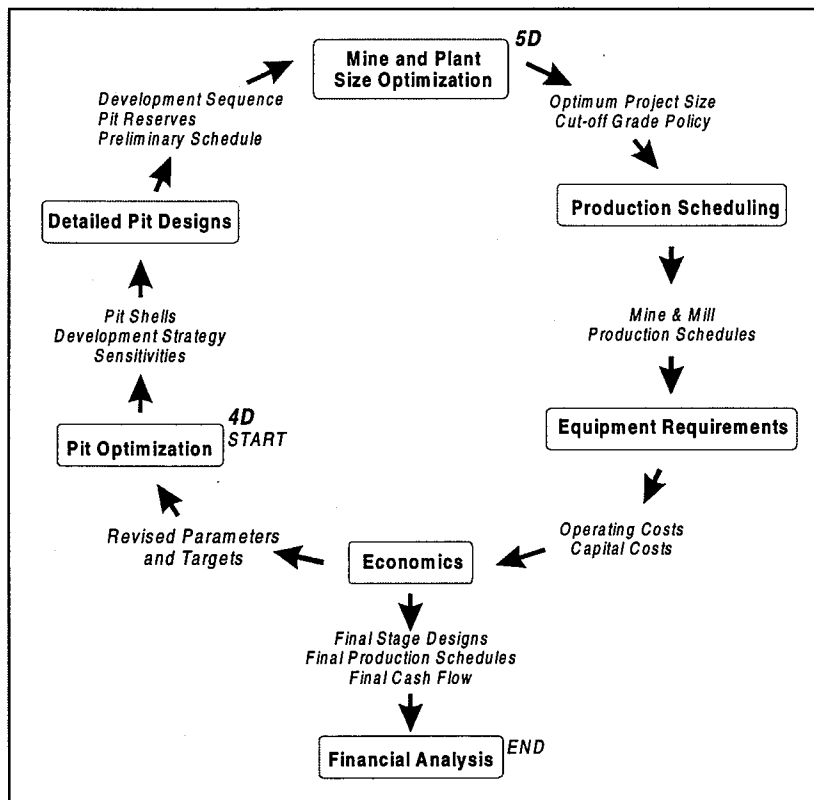


Figure 3: Baley Project Planning Cycle

The final phase requires a review of the project outcomes and reconciliation of parameters and methodology used in conjunction with the end results. The pit designs, production schedule, equipment requirements and cash flows are finalised

during the preparation of the final project report.

Table 1 summarises the processes involved in each phase of the Baley project mining study.

PHASE	PROCESSES	PARAMETERS
Initial (Start-up)	Pit Optimisations Initial Designs Preliminary Schedules	From pre-feasibility study Updated resource model Initial objectives
Progressive (Iterative evaluations)	Pit optimisations and sensitivities Cut-off grade optimisations Production capacity optimisation Pit design options Detailed production schedules Operating cash flow analyses	Refinement of operating costs Capital cost estimates Incorporation of additional data Results from other studies Redefined study objectives Financial requirements Armada Gold company policy
Final (Reconciliation and reporting)	Final pit designs Final production schedule Final cash flow Low gold price scenario	Finalised parameters, project size Achieved objectives Change in gold price

**Table 1: Baley Project Mining Study Phases**

With the confirmation of the decline in the gold price in the first quarter of 1998, the study was revisited in the reporting stage. How the mining study evolved in each phase with changing parameters and the outcomes is discussed in the subsequent sections.

**Initial Phase**

The initial phase of the project started with Whittle Four-D pit optimisations using an updated resource model and refined parameters from the pre-feasibility study. Based on the pit optimisation results and ultimate pit selection, seven mining stages were designed in order to develop two

parallel main orebodies, the Taseevskoe 1 and Taseevskoe 3 deposits.

Following the reserve calculations, preliminary production schedules were prepared and the initial cash flows were determined. The outcomes from the initial phase of the study have been summarised in Table 2. Processing rate and the mining rates were the main parameters with the implications on the operating costs and the ore reserves development in the initial phase.

Parameter	Value	Notes
Reserves	38.8Mt @ 2.55g/t	0.80g/t cut-off
Processing rate	2.5Mtpa	US\$385/oz price
Mining Rate	20-26Mtpa	Fixed mill cut-off
Operating Cost	US\$225/oz	
Operating Cashflow	US\$431M	
Op. NPV @ 10% DCF	US\$217M	

**Table 2: Initial Project Definition**

### Progressive Phase

After the initial phase of the study, the stage designs and the production schedule were reviewed together with the equipment requirements. The processing cost was increased by approximately 10% to allow for additional operational factors. As a result of this review, it was concluded that four mining stages would be more favourable than the originally identified seven stages with the reduction in the size of the open pit quantities. Please note that the cash flows and operating costs presented in Table 3 and Table 4 are calculated in the

mining study operating cash flow context only and further revised in the detailed financial analysis stages of the project by Armada subsequently.

In order to arrive at the optimised project definition (Table 3) and to address the issue of determining the optimum project size, the preliminary schedule obtained from the pit development sequence was subjected to cut-off grade optimisations using OGRE software. This, with the inclusion of various gold price, discount rate and capex/opex scenarios, provided the **Fifth Dimension** to the project.

Parameter	Value	Notes
Reserves	28.2Mt @ 3.23g/t	0.90g/t cut-off
Processing rate	1.75Mtpa	+10% processing cost
Mining Rate	25Mtpa (Max)	US\$385/oz price
Operating Cost	US\$201/oz	Improvement in designs
Operating Cashflow	US\$454M	Reduced ramp width
Op. NPV @ 10% DCF	US\$268M	After Fifth Dimension

**Table 3: Optimised Project Definition**

### The Fifth Dimension

The approach used for the optimisation of project size is summarised in Figure 4. Operating costs and capital costs depend on the project size and have direct effects on the reserves development and the production schedules.

Likewise, the expected gold price to be realised from the project directly affects the mining cut off grade. This directly affects the size and metal grade of the reserve that in turn indirectly affects the processing plant throughput rate.

Operating cash flows based on the ore to be processed after making cut-off grade optimisations are developed using different processing rates. For each processing rate, the necessary mining rate is determined providing continuous mill feed at the optimised cut-off grades. The capital expenditure was included into the analysis separately after cut-off grade optimisations to determine the best operating cash flow strategy.

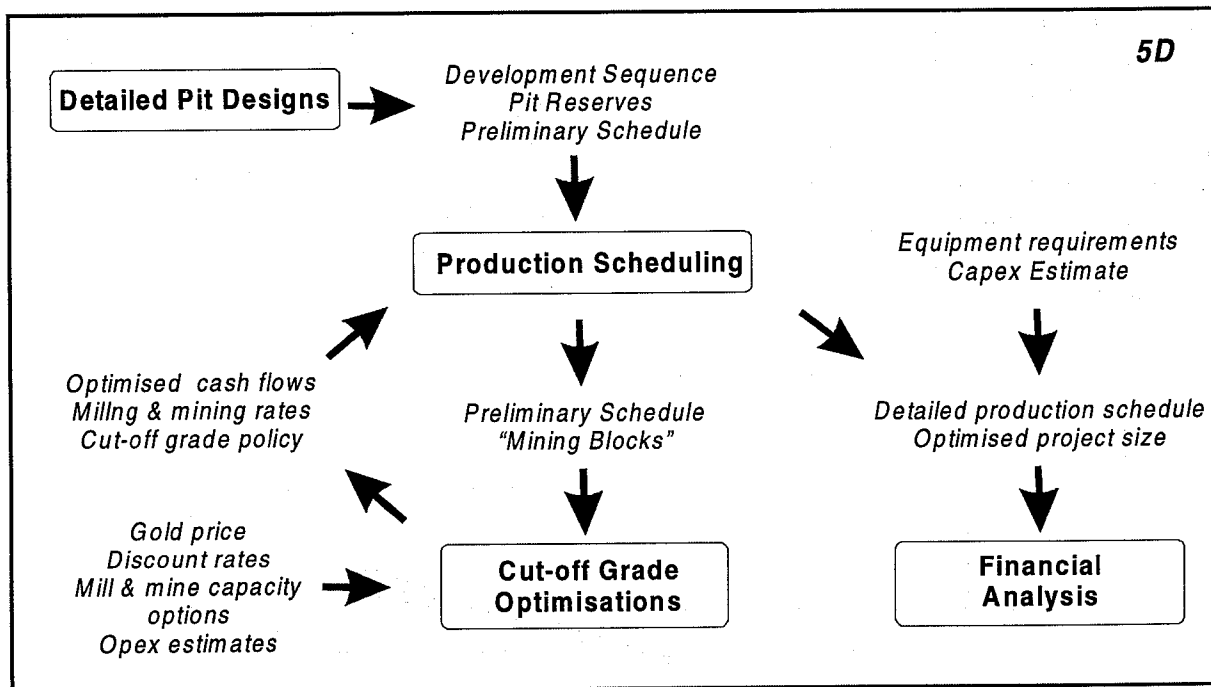


Figure 4: Project Size Optimisation

### Capital Cost Estimates

For Baley, we were fortunate in having a well detailed capital cost estimate made during the Base Line Study. That estimate was for a mine and processing plant capable of processing 2.5 million tonnes of gold bearing ore per year.

During the Initial Phase of the feasibility Study we became certain that the fall in gold prices which had started in early 1997 would not provide for an income that would justify the Base Line Study size plant.

In order to use the **Fifth Dimension** we needed to determine the capital costs for alternative size plants. Exponential methods of relating different size plants are commonly used by plant cost estimators and others planning process plants. An early reference to this method was written in *Chemical Engineering*, December 4, 1967. One of your authors has been regularly using the method since about that time.

The exponential method is based on the principle that different sizes of plants for the same process have their capital costs, (C1

and C2) related by an exponential relationship of their throughput. Thus the capital cost of two plants with throughput of Q1 and Q2 are related as follows:

$$C2 = C1 * (Q2/Q1)^n$$

The exponent n is a factor known by experience. Depending on the industry and process involved, n can be from a low of about 0.4 to a high of about 0.85. Mathematically, the closer that n is to unity, (1), closer that the capital costs vary directly by throughput.

Your author has found that gold plants, (using similar process routes), of differing throughputs inevitably compare with n exponents of between 0.55 and 0.65. In fact, if two plants of known size and cost don't back calculate to having exponents in this range it is useful to dig deeper and find out why not. A logical answer is almost always forthcoming

This relationship can be shown graphically in Figure 5. As you can see from this graph, the estimated capital cost of plants within the range of about half to two times the size

of a known capital cost plant is not very sensitive to applications of n factors between 0.55 and 0.65.

More specifically, for applying the Fifth Dimension to the Baley study we used a factor of 0.60 to the base line plant capital costs for a 2.5 million tonne per year processing plant. The capital costs used are

as shown in Figure 6 as follows. You may observe that these capital costs are high compared to your expectations. Two things come into play, one is the cost of constructing a plant in Russia and the other is that pressure oxidation of the ore was chosen as the best processing route.

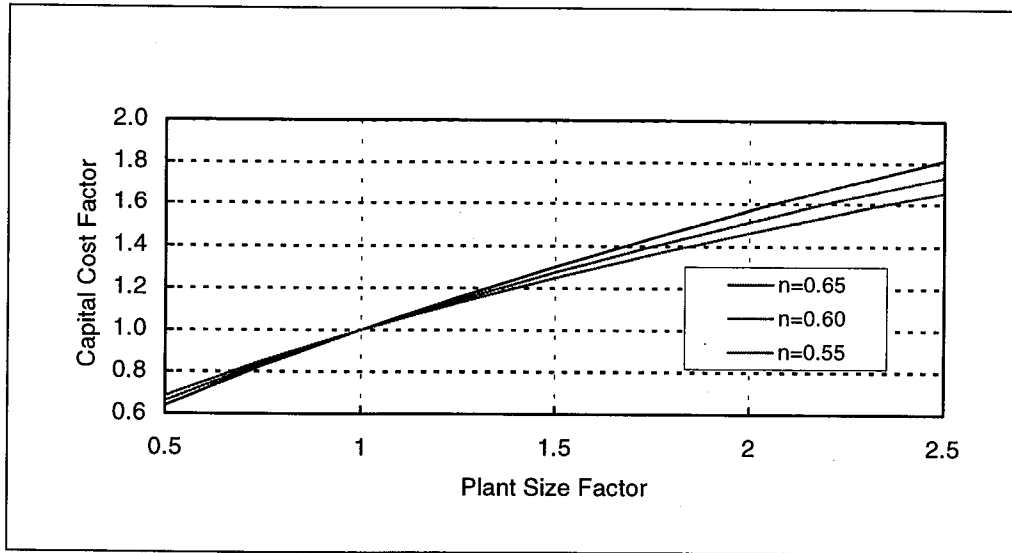


Figure 5: Plant Size v. Capital Cost Using Exponential Method

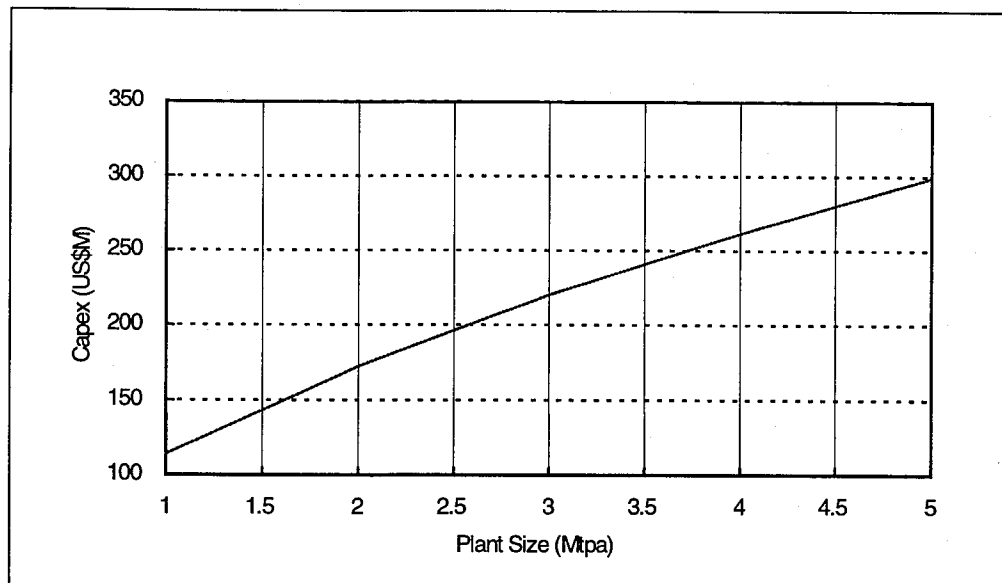


Figure 6: Estimated Direct Capital Cost, Mine and Mill Using Exponential Method, n = 0.60



### **Operating Cost Estimates**

Operating costs need to be separately analysed for Operating costs need to be separately analysed for the mining and processing portions of the project.

For mining, the most important variable is the size of the equipment able to be effectively used for mining, hauling and feeding the process plant. Experience has found that when mining rates change such that larger/smaller equipment needs to be selected that the cost per tonne of providing ore to the plant decreases/increases by up to 30 percent. However, when analysing costs over moderate ranges of mining rates that the cost per tonne varies in the range of a maximum plus/minus 15%.

Over the operating range of 1.25 to 1.75 million tonnes of annual ore throughput analysed in detail for Baley, mining costs were held at US\$1.05 per tonne average varying by mining depth.

The processing plant operating costs generally model as annually fixed costs, variable by tonnage throughput and a mix of the two. Annually fixed costs are primarily in the way of administration that includes supervision, accounting and purchasing personnel and outgoings such as insurances.

Tonnage variable costs are primarily for chemicals and other reagents, electrical, power and water.

The major cost that is a combination of being time dependent as well as tonnage dependent is plant maintenance.

Over the operating range of 1.25 to 1.75 million tonnes of annual ore throughput analysed for finding annual mine production for Baley, operating costs were held at US\$9.25 per tonne.

### **Financial Modelling and Analysis**

Armada developed an interactive spreadsheet financial model for analysing the data developed in the mine model and incorporating the opex and capex for several

alternative plant size options. Armada's model is shown in the Appendix at the end of this paper.

The major input to the model was the mine schedules and production plans prepared with Whittle Four-D, (with OGRE used for cut-off grade optimisation). After approximating the likely range of best project sizes, mine model and production schedules were run for annual mill production rate increments of 0.25 M TPA over the selected range. We found that we were able to get fast and reliable information for the Armada financial model using the Whittle software.

The Armada financial model was arranged so mine production schedules from Whittle Four-D could be easily combined with alternative gold prices, opex and capex information. The major output of the model is after-tax project cash revenue after providing for debt repayment on a leveraged project. An early decision was made to include the after-tax affects so as to emulate the full financial affect of the project alternatives.

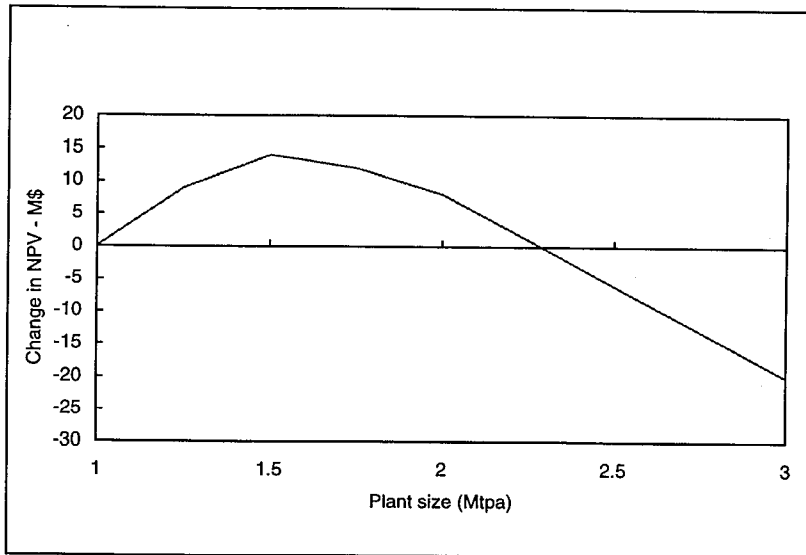
The cash revenues over the life of the project were re-stated as project Net Present Value, (NPV), and Internal Rate of Return, (IRR) for each project size option.

It was expected that the model would yield NPVs for various size options that would yield an option with a superior NPV and that project sizes either smaller or larger than the best would provide lower NPVs. As NPV is sensitive to discount rates used for determining the NPV, the model was designed so that discount rate could be easily changed and discounts of 10%, 17% and 25% were run.

The model was created with sufficient logic that various input data such as discount rates and gold prices as well as alternative opex and capex could be entered at a single point in the model and the model would make the correct outputs instantaneously and automatically.

To ease analysis, a graphical representation of the model output was created.

A typical graph is enclosed as Figure 7 below.



**Figure 7: Project Size Optimisation Mine Model @ 10% DCF including Capex**

### Final Phase

For Baley Gold a “best project” was identified in June 1997 at between 1.25 and 1.75 million tonnes of ore processed per year. Lower gold prices and higher discount rates tended to indicate that projects at the lower end of the range were optimum. Higher gold prices and lower discounts indicated that the projects at the higher end of the range were best.

Armada chose to develop a project of 1.75 million tonnes per year. Subsequently gold prices continued to fall. By the end of 1997 it was apparent that gold prices were going

to be in the sub US\$ 300 per ounce for the foreseeable future.

The optimisation process was re-run and a very high grade pocket was identified for exploitation. This pocket comprised of 3.1 million tonnes of ore grading 7.1 g/t (Table 4). A decision was made to process this ore at the rate of 0.5 million tonnes per year. Among the factors considered was that this provides six years of production. It is expected that in such a time frame gold prices will firm again to the point that the 1.75 million tonne per year plant can be developed.

Parameter	Value	Notes
Reserves	3.13M @ 7.09g/t	1.20g/t cut-off
Processing rate	0.5Mtpa	US\$320/oz
Mining rate	6Mtpa	Higher processing cost
Operating cost	US\$139/oz	Higher mining cost
Operating cash flow	US\$103M	Two smaller pushbacks
NPV @ 10% DCF	US\$70M	

**Table 4: Effect of Reduced Gold Price**

## Conclusion

It has been possible to optimise the overall Baley Project production strategy by using the available software tools (such as pit optimisation, cut-off grade optimisation, pit design generator and production scheduler) and the iterative planning approach,

After pit optimisations using Whittle Four-D, we choose to call the project size optimisation process described in this paper as the **Fifth Dimension**, with due respect to Whittle Programming Pty Ltd.

Contribution of the cut-off grade optimisations to the Baley Gold Project has been significant due to the relatively high variability of gold grades within the resource model.

The pit stage designs have been identified as particularly important in a project development with the direct effects on production schedules, cut-off optimisations and final cash flow.

With a low gold price scenario, the Baley Project is still viable with likely project expansion in future depending on the gold price levels.

## References

SME, 1992. *Open Pit Planning and Design*. Mining Engineering Handbook, Second Edition, Volume 2, Littleton, Colorado, pp 1274-1297.



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