Cut-Off Grade Sensitivity Analysis Using Opti-Cut

Ricardo Palma

Qualifications: B Eng Sci, Universidad de Chile, 1974
Civil Mining Engineer, Universidad de Chile, 1977.

Experience: Chief Engineer Projects Dept, Codelco Chile, División Salvador.

Currently: Project Manager, NCL Ingenieria y Construcción SA, Santiago, Chile.

Introduction

For a long time, the "Optimum Cut-off Grade" has been a mystery to metal miners all over the world. In later times, the "Opportunity Cost" theory has given us a new theoretical approach to the definition of such values, when the optimisation of NPV is one of the objectives of the company.

The typical variables associated with the cut-off grade (COG) definition are technical parameters and an economic scenario. Implicit to this simple definition are a number of variables that influence the COG values to be used in the exploitation of the same deposit.

In the process of designing and planning the exploitation of a mine, lots of effort is put into the correct definition of the most typical variables, like forecasting of commodities prices, estimation of mining and processing costs, metallurgical recoveries, general expenses, etc. In many cases, COG definition is considered a simple exercise, based on the well-known marginal analysis.

This paper analyses the influence of other "non-typical variables" in COG definition, using the Opportunity Cost approach. Variables like mine capacity, pre-stripping tonnage and discount rate are analysed. Such variables, which may be called "strategic variables", have, in most of the cases, a more relevant role in the COG values than the price of the commodities or some of the key technical factors.

This paper shows the results of some investigations developed by NCL Ingeniería y Construcción SA in relation to COG definition strategies.

Presentation of the Problem

One of the first things to do when planning the exploitation of a new deposit is to define an overall strategy to carry out the mining of the deposit. This strategy means to define, amongst others, the following terms:

- Final Pit.
- Mining Phases.
- Plant Capacity.
- Mine Capacity.
- Waste Dumps Location and Filling Strategy.
- Pre-stripping Tonnage.
- Stockpile Treatment.

Some of the above-mentioned items are easy to define for a specific technical-economic scenario. Most projects are quite clear in terms of Final Pit and Mining Phases as well as Plant Capacity and Waste Dumps Location and Filling Sequence. The remaining three items mentioned, Mine Capacity, Pre-stripping Tonnage and Stockpile Treatment are not so clearly definable and depend on several variables, both technical and strategic.

Mine Capacity, in terms of total tonnage of material to be moved per unit of time, is frequently set as the minimum required to

ensure the supplying of ore to the plant for a defined COG.

The definition of the pre-stripping tonnage is a more complicated one. A minimum tonnage is easily definable using Opti-Cut, doing runs increasing the pre-stripping tonnage, up to the moment when the program can reach the minimum plant feeding required, using the marginal COG. No maximum limit exists for pre-stripping and it should be searched for iteratively during the mine planning process. In any case, any reasonable tonnage will only affect the initial years of the project (which may produce some important variations in NPV if using a high discount rate).

Stockpile Treatment is another variable to be considered at the moment of setting a planning scenario. Usually a mine site allows some room for stockpiling but this is, in most of the cases, restricted to a limited capacity, so the adequate use of it in time may become a real problem.

The problem then is how to select the better mining strategy, using an opportunity cost approach to define the COG profile.

Once this scenario is selected, an additional sensitivity analysis can be performed to test the sensitivity of COG to variations in different variables and get an idea about the "risk level" associated to the selected scenario.

The present paper suggests a methodology to select mining scenarios when mine capacity, pre-stripping tonnage and stockpile size are not defined. The approach is based on the use of Opti-Cut as an analysis tool. Additionally, some examples are given, based on real situations.

Methodology

Unfortunately there is not an automatic way to obtain the better mining strategy for a specific deposit. The only methodology to achieve the better solution is to analyse as many scenarios as possible and make a selection. Under this approach, the use of Opti-Cut by Whittle Programming, offers a powerful and easy-to-use tool, which allows the engineers to study a number of situations in a short period of time.

Having in mind that the final objective is to maximise the NPV of the project, Opti-Cut provides the engineers with fairly good NPV figures for each run. These figures are certainly not the exact NPV of the project, but they give valuable information for comparison purposes.

The first step is to define some ranges for the variables to analyse, in order to obtain the number of scenarios to run.

- Mine capacity is not a continuous variable. It moves in "steps" by adding or subtracting loading equipment, so some reasonable ranges can easily be defined in order to have fixed values to be analysed later.
- As mentioned, the minimum amount of pre-stripping is easy to define, starting with the tons required to guarantee plant feed, working at marginal COG. From there, some discrete increments can be defined, mainly based in the characteristics of the mining phases involved in the initial years of the project. Certainly pre-stripping and mine capacity are related, and for a small mine capacity more pre-stripping is required.
- Some data helps when defining a stockpiling policy. Obviously the most important information is related to space availability, secondly there is a "reasonable" maximum size related to the size of the operation involved. Very large stockpiles are hard to manage and not reliable from the mining point of view, mainly due to the fact that their grade becomes heterogeneous and therefore hard to predict. Based on this, some maximum stockpile size can be defined for consideration in the planning process.

Mine capacities, pre-stripping tons and defined stockpile sizes can then be combined to define a number of scenarios to be analysed in order to obtain the most adequate, considering the reality of the operation to be planned.

Definitively, there is not a 100% automatic way to define the best mining scenario. From the technical point of view it is easy to define "the most probable" ones, and then use them as a starting point to select the one most adequate to the company's interests. The recommended process is to run Opti-Cut for each one of the scenarios and compare the results.

The selection process is difficult and requires several analyses. Displaying the results in graphical form allows the engineer to easily detect the sensitivity of the project to different variations.

Some Examples

For some massive deposits, interesting results were found when different scenarios were analysed. Some variables that are commonly considered as not relevant to the COG definition, happened to be the most influential, and, vice versa, some considered as key values are not that relevant at all.

Some examples of results obtained from different real ore bodies are shown in the following paragraphs, the real figures have been changed at the request of the interested parties.

Case 1

The expansion of a copper mine is under analysis and the new plant size is defined. The question is how much should the mine capacity grow to feed the expanded plant?

Potential mine capacities are defined by the options of buying one, two or three new items of loading equipment. Investment for each case is clear, corresponding to the loading equipment plus the associated trucks and ancillary equipment.

Opti-Cut runs were done for each capacity and a COG profile obtained. Using those profiles, a rough Opti-Cut mine plan was obtained and evaluated, introducing the investment for NPV calculation purposes.

Results were compared and plotted as shown in Figures 1 to 3.

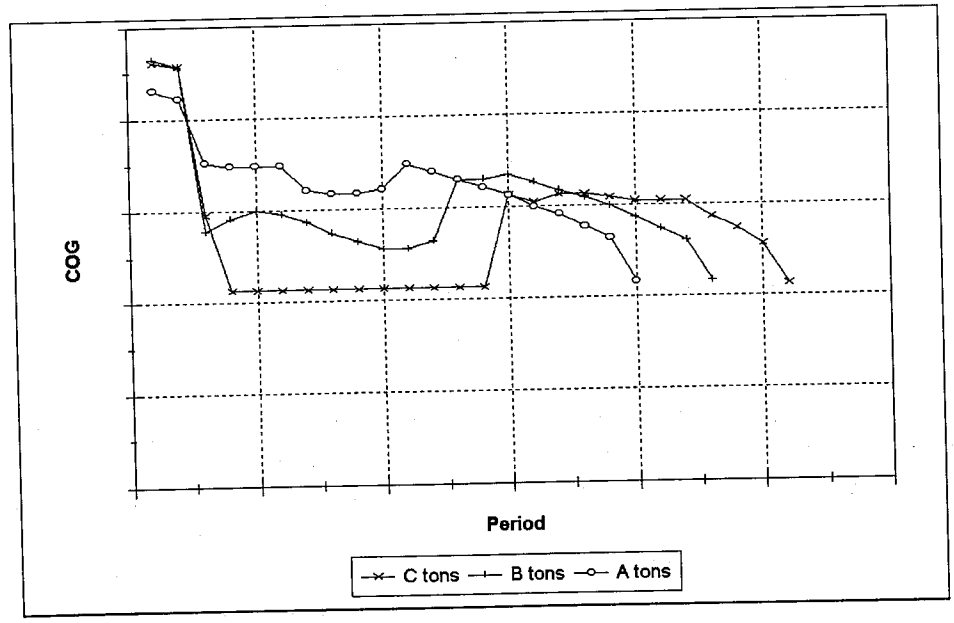

Figure 1: Cut-Off Grade vs Period Different Mine Capacity

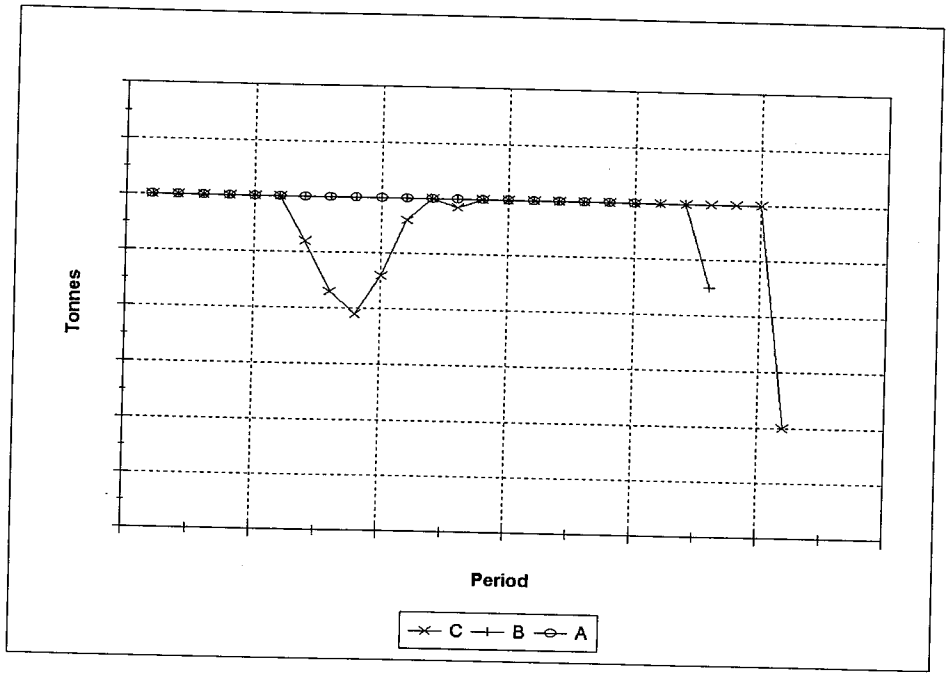

Figure 2: Ore to Plant

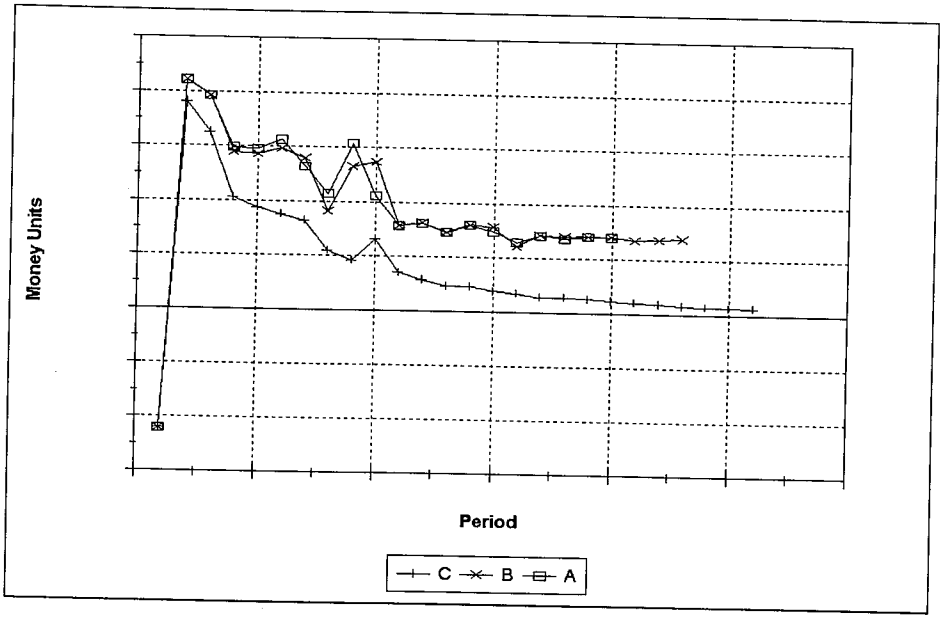

Figure 3: Yearly Cash Flow

From the above-mentioned figures, Option B was selected as the more convenient. It is clear that capacity C is too small and cannot feed the required ore to the plant in years 7 to 11, even working with the marginal value. Also, cash flow difference between options A and B is minimum and doesn't pay for the risk increase and major investment. For this option, new Opti-Cut runs were made, this time changing other parameters, in order to perform a sensitivity analysis. Three metal prices, say a, b, c, with 15% difference between them were used, and Opti-Cut runs made for each one. Results were plotted as shown in Figure 4.

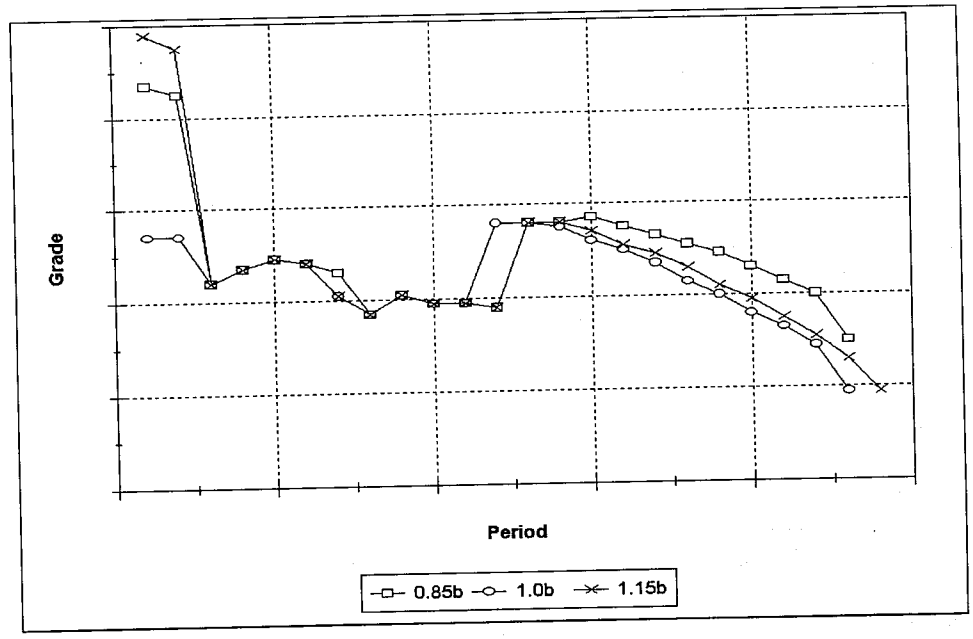

Figure 4: COG vs Price

For the same option, three discount rates were used, a, b and c.

Results from these runs are plotted in Figure 5.

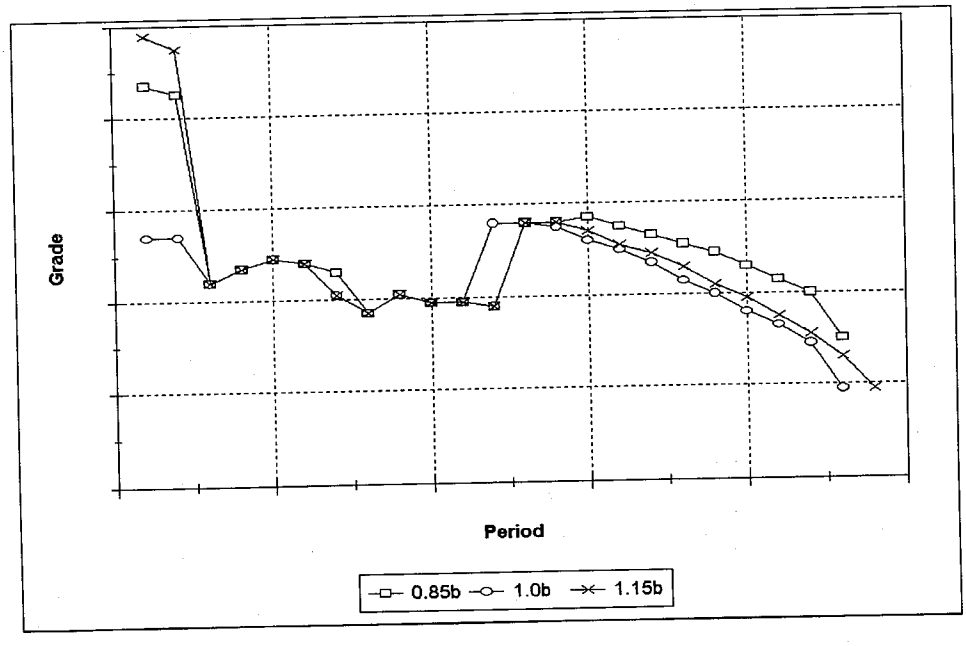

Figure 5: COG vs Time Different Discount Rate

Comments:

From the above figures it can be clearly noted that the most relevant variable in COG definition, from the ones analysed, is the mine capacity. COG, for this particular deposit and mine is very insensitive to price and discount rate variations.

Case 2

A mine size and its pre-stripping level must be decided for a deposit to be mined. Final pit, mining phases and ore production are defined, as well as mining and processing costs. Three mine capacities are to be analysed, A, B and C, corresponding to one starting capacity and increments of one and two additional shovels. Also, three figures for pre-stripping, P1, P2 and P3, were studied.

This combination produces 9 scenarios to analyze.

Opti-Cut runs were made for each scenario and results plotted, as shown in Figures 6 to 11.

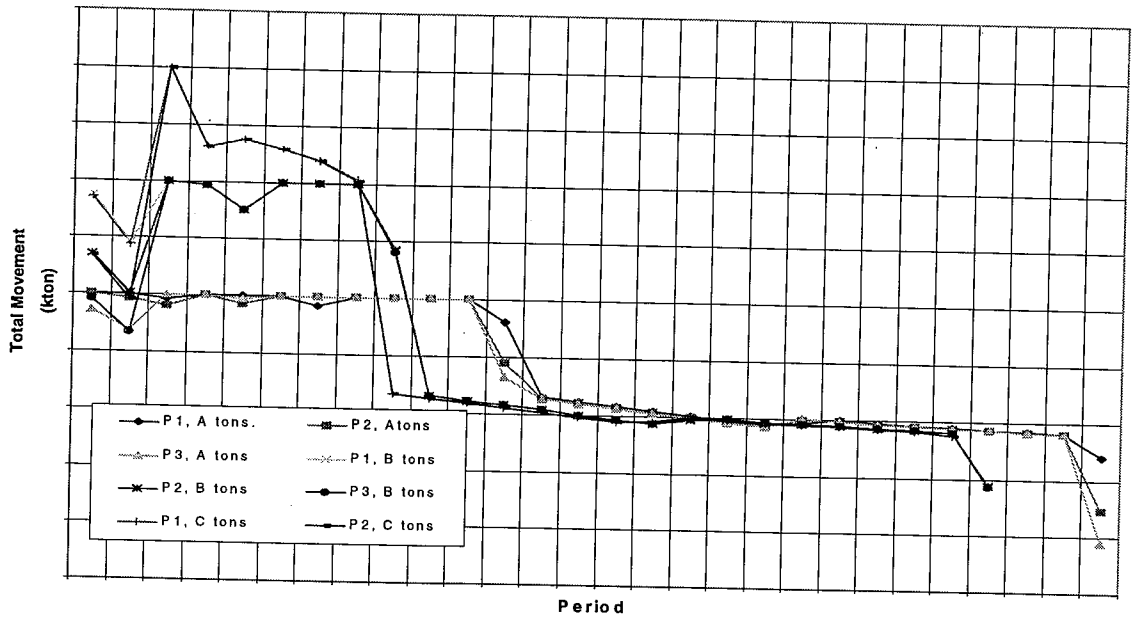

Figure 6: Total Material Movement

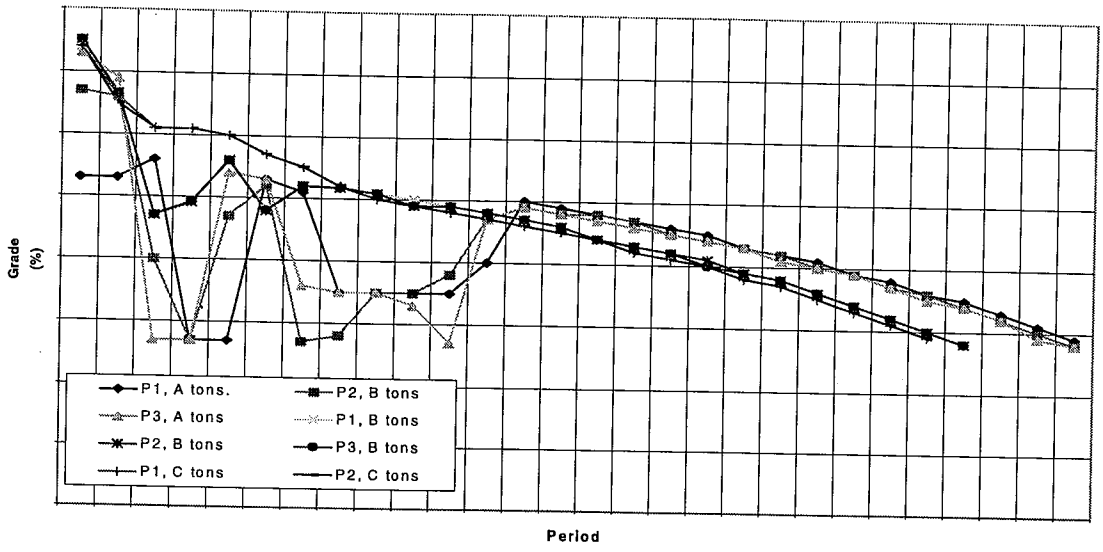

Figure 7: COG vs Period

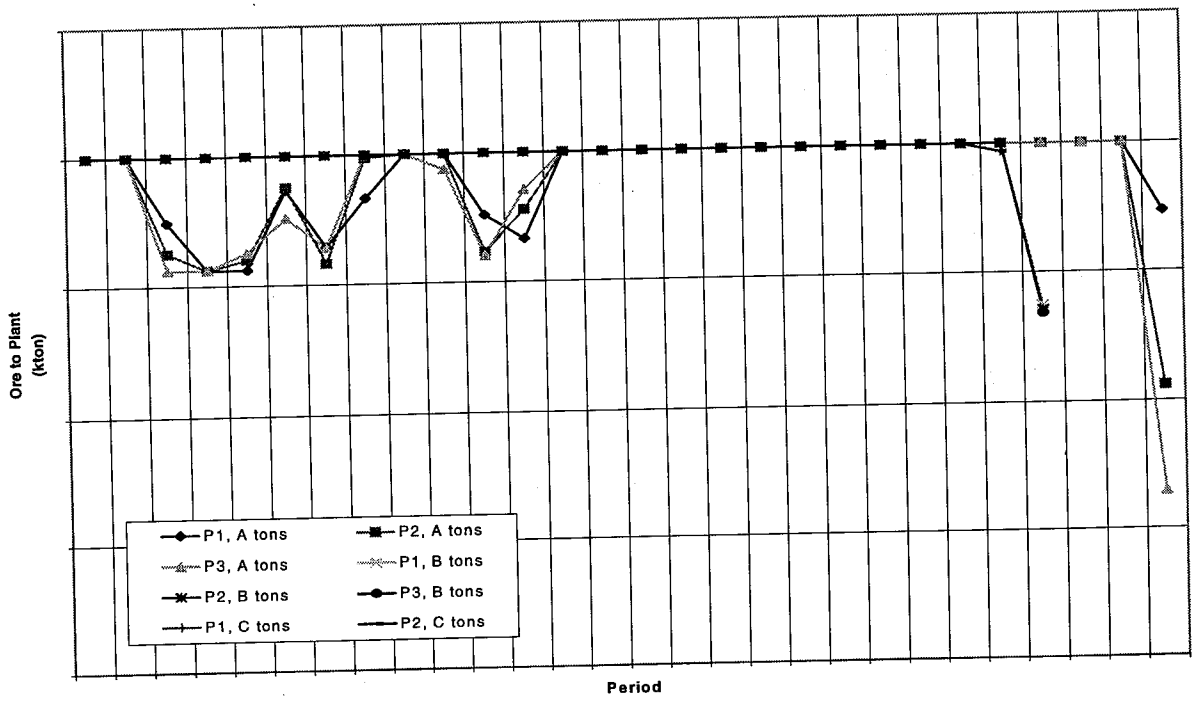

Figure 8: Ore to Plant

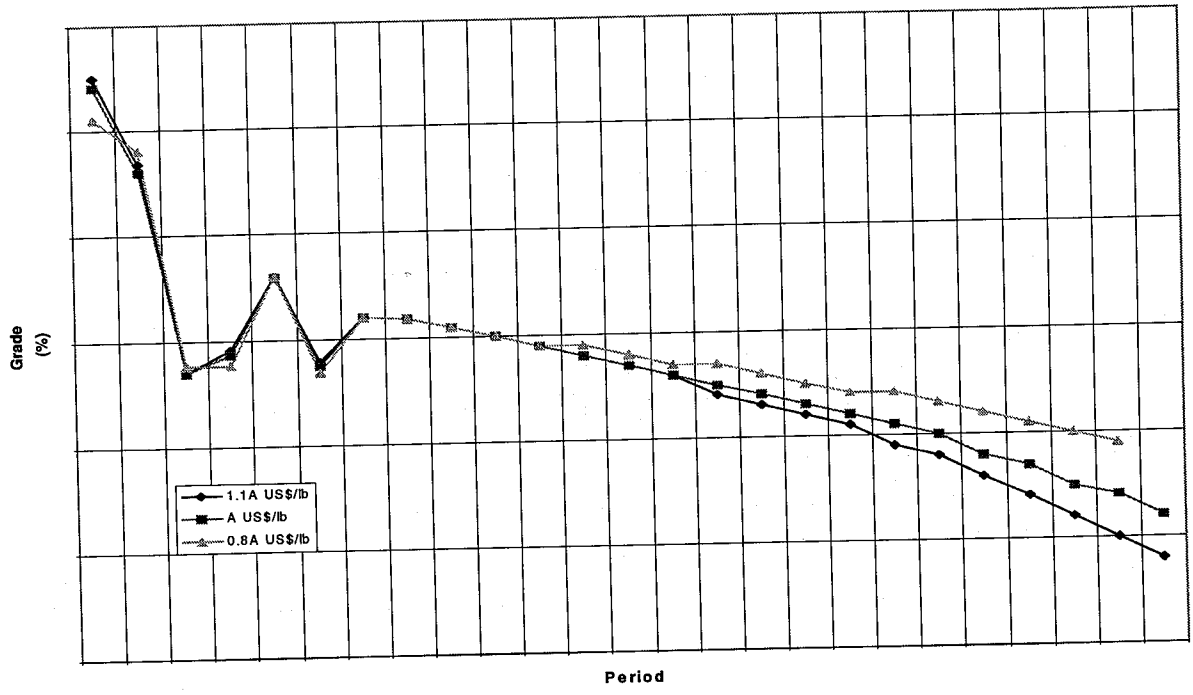

Figure 9: COG vs Price - Case 3

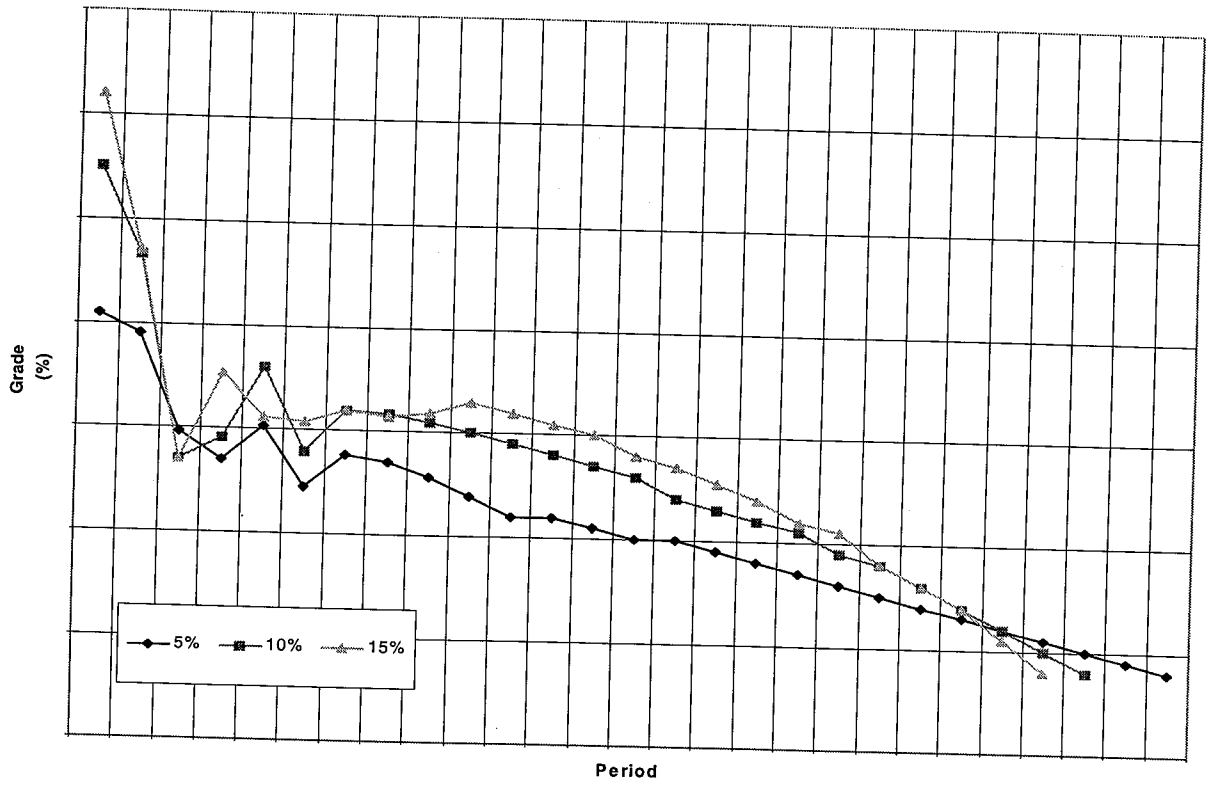

Figure 10: COG vs Period, Different Discount Rates

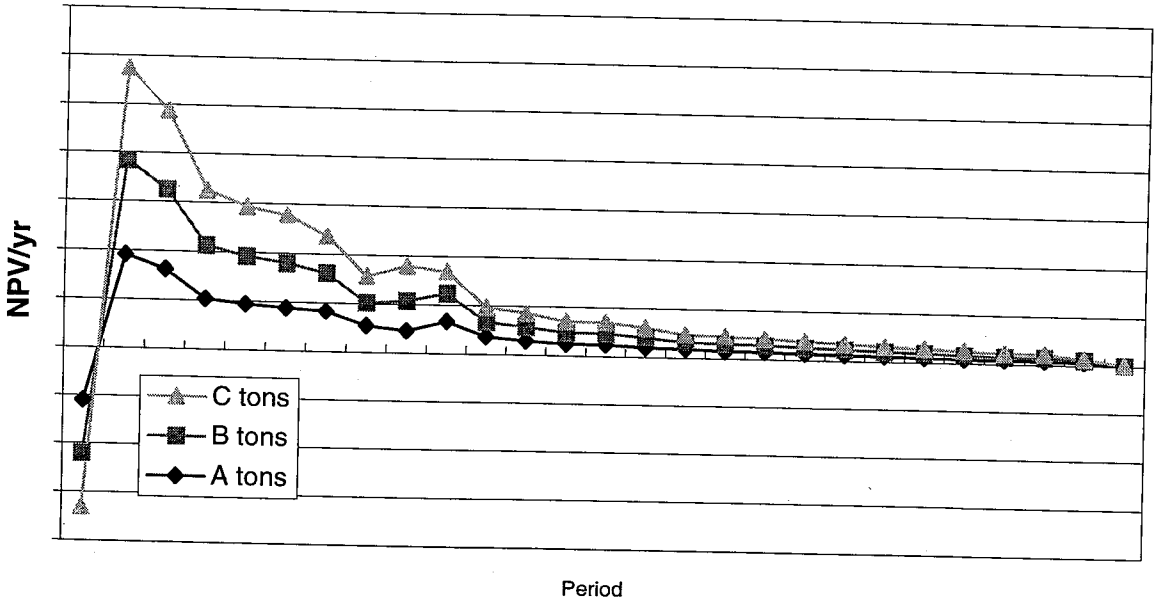

Figure 11: NPV/Year, DIF Capacities

Comments:

The following comments can be made from the figures:

- The lower mine capacity analyzed is not enough to cope with the required plant feed, even working at the marginal COG.
- Pre-stripping level does not influence the COG values very much, which seems to be run mainly by the characteristics of the mining phases.
- Capacity C is required in full in only one year, meaning that it is definitely too much to be set as the mine figure. Capacities A and B are used in full for several years. The total movement requirement drops dramatically once the mine is open and the starting mining phases are mined out.
- Obviously the bigger the mine capacity, the bigger the COG values obtained and the mean grade feed to the plant, which has the effect of increasing the business NPV. On the other hand, this means more investment and a negative effect on NPV. Once again, the only way to obtain the best situation is by evaluating them. This means estimating investment figures and running Opti-Cut using them as part of the NPV calculation process. Figure 11 shows the yearly income for one of the scenarios, using different mine capacities. It can be notice that, even having a major initial investment, option C, which correspond to the highest capacity, produces better figures.

Conclusions

For the two cases shown, it is clear that the most influential variable in COG definition is mine capacity. This is quite clear in the Lane approach, but not often considered when planning a mine, when most of the time mine capacity is defined as the figure large enough to cope with plant requirements. Sometimes, to invest in more loading and hauling equipment and therefore increase the cut-off grade may lead to better NPV and a less risky operational situation globally.

Other parameters, like price and discount rate, that look more directly related when defining marginal values, are not that relevant at the moment of selecting COG using the Opportunity Cost concept.

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