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DETERMINATION OF AN OPTIMUM CUTOFF GRADE POLICY CONSIDERING THE STOCK PILE ALTERNATIVE

by

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ABSTRACT

The current mine planning practice is to consider the mining system as three main stages: Mine - Plant - Refinery. Lane's algorithm is used within this context to determine an optimum cutoff grade policy. The determination of the cutoff grade is based on the fact that one of those stages alone limits the capacity of the operation or that pairs of stages together limit the total operation. The output from Lane's algorithm is the cutoff grade policy and production schedule through the life of the operation. An optimum cutoff grade policy commonly indicates a general decline in cutoff grade during the life of the mining operation, usually as a result of its declining present value. One implication of this phenomenon is that grades that are not economic in the early years can be treated economically later.

Three alternatives for handling the stock pile option have been analyzed in the present work. These alternatives are different in the sense that two of them consider the possibility of sending ore from the stock pile to the mill during the life of an increment. The other alternative considers sending ore to the mill after the material in the increment is finished.

Two computational programs have been developed in this

thesis. The first is to determine an optimum cutoff grade policy using the Lane's algorithm. The second is a modification of Lane's algorithm to consider the stock pile alternative. Even though the stock pile alternative has some disadvantages, it is a useful option to consider under certain conditions. The computational programs developed in this work make it possible to analyze the optimum cutoff grade policy in a simpler and faster way.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION TO THE PROBLEM

Most of the literature on the determination of an optimum cutoff grade policy follows conventional marginal analysis in which a cutoff grade is determined to be the break even point at which income exactly equals total operating cost. This is a procedure that yields a static cutoff grade value without regard to the state of the mining operation.

This traditional approach raises some questions about certain costs, such as invested capital and working capital. These categories are not included since the procedure implies that all material subjected to beneficiation must provide a cash surplus over the operating cost that is sufficient to meet capital expenditures and still produce at least a minimum rate of return.

It must also be realized that this single static criterion for cutoff grade calculation bears other fundamental problems since it is independent of time, factor location, grade distribution, etc. Thus, it takes no account of the time value of money, the physical mine, plant and refinery capacities, the sequence in which the material is mined, available investment capital, the

tonnage of ore in the deposit, etc.

Lane (1964) was the first to develop a cutoff grade theory which takes into account the mining system as three main stages with their distinctive costs and limiting capacities. He also used discount cash flow techniques to distinguish between alternative cutoff grade strategies. Lane (1964) considered the mining system as a process with three stages, Mine-Plant-Refinery. The determination of the cutoff grade is based on the fact that one of those stages alone limits the total capacity of the operation or that pairs of stages together limit the total operation. The output for the algorithm is the cutoff grade and the production scheduling through the life of the operation.

Looking at the cutoff grade and the production scheduling generated for Lane's algorithm it is possible to see that a significant amount of material sent to the waste dump in the early years of production, would probably be good enough to be sent to the treatment plant in the later years.

1.2 PREVIOUS WORK

Information regarding the specific analysis of the economic management of the stock pile is very scarce. It has been discussed in a superficial way in some papers where

the main subject is the economic importance of the cutoff grade (Beras, 1979; Callaway, 1958; Halls, 1969). In other papers the stock pile alternative has been discussed as an alternative for smoothing the production pattern (Manula and Kim, 1967; Lee, 1974).

Mason (1984) does a descriptive analysis to demonstrate that any theory that proposes changing cutoff grades with time is bound to promote the creation of stock pile. If cutoff grades are higher in the early years of the mine and decrease with time, the stock pile can often end up at an average grade higher than the general mine cutoff grade at some time during the middle years of the operation. In the Mason description there are not, however, any comments about certain specific points, such as the determination of minimum cutoff grade of material to send to the stock pile and optimum time to send the material from the stock pile to the concentrator.

Taylor (1985) justified the use of the stock pile system through the use of some actual examples from mines. At the Craigmont Copper Mine, a substantial sub-grade stock pile that averaged about 0.6% Cu was accumulated from the initial high grade open pit. The operation then moved underground, where sublevel caving yielded a daily output of about 4500 short tons at 1.8% Cu. For many years the stock

pile provided the remaining 1500 short tons per day that were needed to supply the mill.

Another practical example is in Gibraltar Open Pit Copper Mine. A cutoff grade of 0.3% Cu was used in the early years and more than 100,000,000 short tons, grading down to 0.25% Cu, was stock piled. In 1982-83 this surface ore enjoyed a cost advantage of at least $2.50 Canadian/ton over ore that had yet to be exposed in the pit. At the then low copper price, the 0.27% grade had a higher net value than the new 0.37% Cu ore. Taylor (1985) in his paper did not, however, give any information about the methodology used to determine the optimum cutoff grade for the system. He only describes how it is possible to move the cutoff grade up or down under changeable product price condition.

The most complete approach to using the stock pile alternative has been done, so far, by Lane (1988). He makes a determination of a lower cutoff grade for the stock pile based upon the cost of handling material. It is determined to be the break even cutoff grade. He provides a very good theoretical analysis to determine the optimum amount of material to send from the stock pile to the concentrator. However the determination of the optimum time is purely empirical. Another important point to take into account in this approach is the fact that he considers

an average grade rather than a combination of higher grades in the stock pile.

1.3 SCOPE OF THE WORK

There are many theories related to the determination of an optimum cutoff grade policy, including Taylor (1972), Henning (1963), Lillico (1973), Lane (1964) and some other studies that are not as important. These theories generate a procedure an yielding optimum cutoff grade policy. Hennings (1963) derived formulas to determine cutoff grade based upon break even analysis. He showed the sunk cost to be without direct relevance, and for the first time, showed that true maximization of present value demanded a declining cutoff grade. Lillico (1973) considers a cutoff grade strategy which maximizes the net present value. His work considers a dynamic cutoff grade policy rather than a static cutoff grade policy. This implies that cutoff grade has to vary in order to achieve the maximum net present value (rather than considering the cutoff grade to be fixed). Taylor's analysis (1972) is very similar to Lane's approach. Three stages in the process are used and balancing cutoff grades and economical cutoff grades are calculated. Probably the most important difference between the approaches is in the way that the balancing cutoff grades are computed. Taylor (1972) uses some statistical

parameters which describe the grade distribution throughout the ore body.

In this work Lane's algorithm has been chosen as the basis for developing an optimum cutoff grade policy considering the stock pile. This choice was made since (1) it is one of the first theories and (2) it is the most complete work including the principal parameters which affect the calculation of an optimum cutoff grade policy. Moreover, if we consider the deficiencies present in Lane's theory we will find exactly the same deficiencies in the other theories.

This thesis will examine the operating strategy in which the alternative of the stock pile is included. This approach will be done through a modification of Lane's algorithm. This modification consists of, first of all, running the Lane's algorithm and picking up the lowest cutoff grade for the entire life of the project and considering that grade as the lowest limit grade for the ore which will be sent to the stock pile. After that, mineral that in the original program was sent to the waste dump is now sent to the stock pile. All mineral above the lowest limit and below the cutoff grade for that year is sent to the stock pile.

If there is ore in the stock pile above the cutoff

grade available to be sent to the mill, the program consider the comparison between the ore in the stock pile and the ore coming from the mine through the profit for both alternatives and chooses the higher profit. This process involves a dynamic creation of the stock pile because the stock pile is changing year by year.

As it was explained, it is fundamental to understand the Lane's algorithm to understand the modification. Lane's algorithm is explained in detail in Chapter 3. Also explained in Chapter 3 is the computational program generated in this work to determine the optimum cutoff grade. In Chapter 4, the modifications of the Lane's algorithm are done. Also shown in Chapter 4 are the steps followed in the resolution of the system considering the alternative of the stock pile and the computational program created to solve this system. A demonstrative example is run and a sensitivity analysis is performed to examine the variation of the total undiscounted profit with respect to variations in the costs associated with the stock pile. A modification of the algorithm considering two other stock pile alternatives is done in Chapter 5. The conclusions and the recommendations for this study are presented in Chapter 6.

CHAPTER 2

OPERATIONAL CONSIDERATIONS IN HANDLING STOCK PILES

In the routine operation of the haulage system in open pit, the truck goes to the shovel to load ore or waste, and after that, it goes to the concentrator plant or to the waste dump. Adding a new possibility of a dumping point, in this case the stock pile for the truck, could be thought of as a potential problem. In fact, the difference between the classic system and the new approach analyzed in this thesis is minimum.

In this chapter, a description of the haulage system used in Chuquicamata is done, (Espinoza, 1980). Even though this system is actually being replaced it is useful to see how an open pit mining system could work by including the stock pile alternative and to realize that, for a system like this, it really does not matter if a new dumping point like the stock pile is added.

2.1 TRUCKS ASSIGNMENT TO SHOVELS BY MEANS OF COMPUTER IN CHUQUICAMATA.

At the end of 1979 a computerized system for the dynamic assignment of trucks to shovels was developed to improve the performance of load and haul equipment and to check in real time the operation of that equipment.

The system was based on a 64 Kb microcomputer

that controlled a network of four terminals of Called-Assignment stations, located in strategic points of the mine and connected by telephone cables, as is shown in Figure 1.

The system works as follows: one operator located in the station of Called-Assignment enters the number of the empty truck returning from the dumping points, crusher or waste dump. The signal is sent by telephone cable to the computer, which determines the most adequate shovel which the truck must be loaded, taking into account the production program for each shovel, the travel time for the trucks, the queue at the shovel, and the operational priorities of some of the shovels. The number of the chosen shovel is sent to an indicator screen, which indicates to the truck driver where he must go to load. The input data for the computer program are the number of trucks and shovels working at that moment, the tonnages and grades schedules for each shovel, and the dumping point for the production of each shovel.

As we can see in Figure 1, the dumping points are the concentrator plant, the three waste dump (71, 57, and 67) and the sulfide stock pile. The addition of new dumps, does not introduce big changes in the operation. As a conclusion we can say that adding a new dumping point like

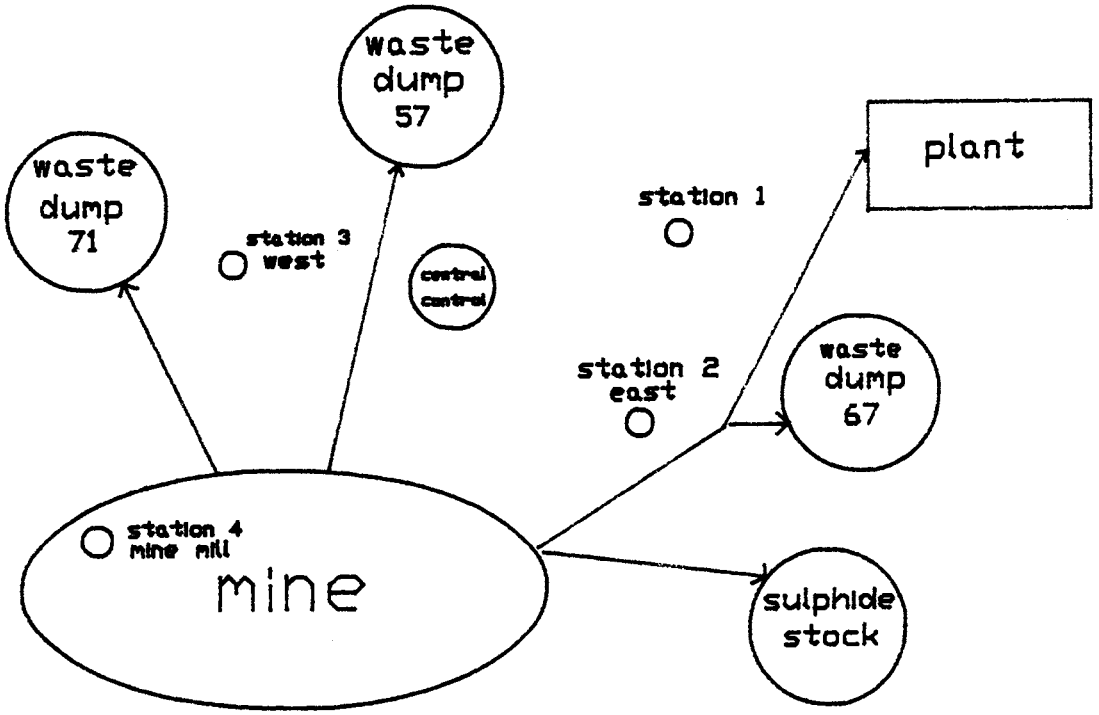

Figure 1.Scheme of the Load, Haul and Dump system

the stock pile should not create problems to the loading-haulage operation.

2.2 OTHER OPERATIONAL PROBLEMS RELATED TO STOCK PILES

To consider the stock pile alternative we must assume that we have enough space to dump the material. The proposed system in segregated stock piles requires several different dumping points to be available at any moment.

From the cost point of view, it is important to emphasize that a more detailed sampling system could be necessary. The differences in grades between the mineral to be sent to each dumping point is small. For this reason we need better control over the grade inventory than in the former system.

On the other hand, when we prepare the bench for blasting, the blast holes are usually sampled. This means that we can obtain very accurate information about the grade distribution over the area which will be blasted.

Another important consideration to take into account is that the material may deteriorate during long exposure to the environment. Some leaching may occur, with consequent loss of mineral; oxidation may create difficulties in the treatment plant and cause poor recoveries which will be another possible source of additional cost. Such effects are not always easy to anticipate because the behavior

of the material in the particular environment may not be fully understood without some years of experience.

CHAPTER 3

DESCRIPTION OF THE LANE'S ALGORITHM

3.1 CHOOSING THE OPTIMUM CUTOFF GRADE

3.1.1 INTRODUCTION

Lane's theory of cutoff grades (Lane, 1964) is based on a mining system which consists of three stages: mining, concentrating, and refining. The mine is the area where ore is extracted from the ground, the concentrator is a facility where the crude ore is upgraded by various processes to a concentrate, and the refinery is where a finishing process, such as smelting or electrowinning is conducted to produce a final product.

In order to find the best choice of cutoff grade, the criterion used for comparing the merit of any choice is the Maximum Present Value. Therefore, attention is focused on choosing a cutoff grade to maximize the present value of the cash flow from the operation.

First, the cutoff grade formulae are derived by assuming that each of the three stages alone limits the total capacity of the operation. These grades are called the limiting cutoff grades.

Next, three balancing cutoff grades are defined. These are grades which just balance the capacities of each pair of stages. They are independent of economics altogether

being directly determined by the grade distribution. Also they are dynamic in that, in an irregular ore body, they can vary rapidly as mining progresses. One of the most important deficiencies in this algorithm is that Lane assumes that prices and costs are constant through the life of the project. Another important assumption in this theory is that it considers equal availability of material per push back in a given moment.

Finally, it is shown that the choice of the cutoff grade is always one of the six grades, either a limiting economic or a balancing cutoff grade.

3.1.2 DETERMINATION OF MINERALIZED RESERVES

No mine plans can be drawn up without some prior assumption
about cutoff grades. Mine planning is a process of working and reworking data and it is possible to start with any sensible starting values, usually a break even cutoff grade, and then to refine them repeatedly until the plans are acceptable. This means repeating them until there is no apparent way to achieve any further improvements. Cutoff grade is just one element in this process which is concerned with the whole problem of the optimum progression through the mineralized body.

The process usually begins by determining a break even

cutoff grade. Then a final pit limit is determined. After that, the pit is divide into nested increments, which are defined by its grades categories and tonnages.

The mineralized reserves that are required for a cutoff grade analysis using the Lane's algorithm are estimated from tonnages and grades that will be achieved as a consequence of working at different operational cutoff values (Lane, 1988). From an operational point of view two considerations are important. The first is selectivity. Different mining methods achieve a different selectivity between ore and waste. For example, small shovels and trucks can discriminate between ore and waste on a finer basis than large ones. Similarly, underground, small-scale open stopes give rise to less dilution than large-scale block caving methods. The grade distribution data must, therefore, be related to the actual degree of selectivity that is practicable with the equipment that is in use. Geostatistics provides a basis for modifying distributions to allow for different sizes of mining unit.

The second is the accuracy of grade measurements for grade control. Because sampling and assaying involves statistical errors, some material will be misclassified; ore will be rejected as waste and vice versa. Where

reasonably possible, it should also be integrated into the grade distribution data. In other words the grade distribution should consist of estimates of tonnages and grades that will be achieved by operating at the different cutoff grades regardless of the actual occurrence of the different grades in the mineralized body.

It is convenient to present reserve data in the form of a table giving grade categories along one side and mining increment along the other. The increments correspond to successive phases of the mine plan and can be of whatever size needed to conform to normal mine planning practice. For example, if mine plans are projected in some detail for four quarters, then more approximately by year for several years and finally, very roughly over five year periods, these same phases should be adopted for mining increments in the table. However it is important that mining increments are defined in terms of tonnage, not time. Although the increments may correspond approximately to quarters or years, they are not linked to these periods. Different cutoff strategies will cause them to be mined at different rates.

3.1.3 THE MODEL

Lane (1964) considered a mining operation as a combination of three main stages: mining, concentrating, and

refining. The mine is the actual area where ore is extracted from the ground; the concentrator is a plant, such a mill and flotation circuits or a mill and leach circuits, from which an intermediate concentrate is obtained; the refinery is a finishing process, such as smelting or electrowinning, which produce the eventual product. Not all mining operations involve all three stages, of course, and some involve more. However, three provide a good general model. Each stage is assumed to have its own associated unit cost and a limiting capacity. The following is the notation used by Lane to describe costs and capacities.

M: Maximum material throughput per period.

C: Maximum ore throughput per period.

R: Maximum output of final product per period.

m: Cost per unit of material.

c: Cost per unit of ore.

r: Cost per unit of product.

f: Fixed cost per period.

s: Selling price per unit of product.

y: Recovery as a proportion.

3.1.4 LIMITING ECONOMIC CUTOFF GRADES

In order to explore the influence of cutoff grade on the economic at the operation, a basic profit expression

is formulated. From this a present value expression is constructed and, conclusions about optimum limiting economic cutoff grades can be derived.

The expression for the profit is:

$$P = (s-r)*Qr - c*Qc - m*Qm - f*T \qquad (3.1)$$

Where:

P: Profit

Qm: Quantity of material to be mined

Qc: Quantity of material considered as ore

Qr: Quantity of material in refining process

T: Period of time

This is the basic profit expression. From it, the profit obtained by mining the next Qm of material can be calculated.

However, the ultimate objective is to maximize the present value of future profits rather than just the total of these profits. It is necessary to construct an expression for the increase in the present value resulting from mining the next Qm of material.

Let us assume that the maximum possible present value of the future profit from the operation is V. Assume also that the maximum possible present value of the future profit after the next Qm of material has been mined is W.

Now the problem can be regarded as one in which the

next Qm of material has to be mined and resulting ore and product treated, and, at the end of the time necessary to do this, a lump sum payment of W is received. The cutoff grade applicable to Qm must be chosen so that the present value of the profit from mining the Qm of material plus the present value of the W received in the future is as large as possible.

From the definition of the present value:

$$V = P + W/(1 + d)^{T} \qquad (3.2)$$

where d is the discount rate.

Since attention is being confined to the immediate future, T is short and a mathematical approximation can conveniently be introduced:

$$V - W = P - d*V*T \qquad (3.3)$$

V-W is the increase in the present value achieved by mining the Qm of material. Calling it V and writing the expression in full:

$$v = (s-r)*Qr - c*Qc - m*Qm - (f+d*V)*T \qquad (3.4)$$

This is the basic present value expression. It differs from the profit expression by the added fixed cost term d*V.

Before any cutoff grade formulae can be derived from the present value expression, the dependence of the time T on the quantities Qm, Qc, and Qr must be known. By first assuming that the mine, concentrator, and refinery in turn limit the capacity of the total operation, three limiting

economic cutoff grade are found.

a.-MINE LIMIT

$$T = Qm/M \tag{3.5}$$

$$Vm = (s-r)*Qr - c*Qc - [m + (f+d*V)/M]*Qm \tag{3.6}$$

Given Qm, the cutoff grade affects only Qr and Qc. Therefore the cutoff grade must be chosen to make:

$$(s-r)*Qr - c*Qc \tag{3.7}$$

as large as possible. This implies that every unit of material for which (s-r)* mineral content exceeds the concentrating cost, c should be classified as ore. Therefore, the optimum cutoff grade or breakeven grade is given by:

$$(s - r)*y*gm = c \tag{3.8}$$

$$gm = c/[(s-r)*y] \tag{3.9}$$

b.-CONCENTRATOR LIMIT

$$T = Qc/C \tag{3.10}$$

$$Vc = (s-r)*QR - [c+(f+d*V)/C]*Qc - m*Qm \tag{3.11}$$

$$gc = [s -r - (f+d*V)/C]/[(s-r)*y] \tag{3.12}$$

c.-REFINERY LIMIT

$$T = Qr/R \tag{3.13}$$

$$Vr = [s-r-(f+d*V)/R]*Qr - c*Qc - m*Qm \tag{3.14}$$

$$gr = c/[s -r - (f+d*V)/R]*y \tag{3.15}$$

3.1.5 BALANCING CUTOFF GRADES

Sometimes the capacity of the operation is limited simultaneously by two and, exceptionally, by all three. The balancing cutoff grades can usefully be introduced. These are the cutoff grades which cause each pair of stages to be just in balance at their maximum capacities.

The balancing cutoff grades are then defined as follow:

gmc, ore: material = C:M

gmr, product: material = R:M

grc, product: ore = R:C

3.1.6 OPTIMUM CUTOFF GRADES

The overall cutoff grade is one of the six cutoff grades consisting of the three limiting cutoff grades and the three balancing cutoff grades. To see why this is so and to determine the actual optimum in particular circumstances, it is best to consider each pair of stages in turn.

First, take the mine and the concentrator. In the section on the limiting economic cutoff grades, expressions were derived for the increase in present value at different throughputs assuming the mine and the concentrator alone limited capacity (see equations [3.6] and [3.11]).

As the cutoff grades varies, Qr and Qc vary and hence so do Vm and Vc. At low cutoff grades Vm is larger than Vc

and at high cutoff grades Vm is smaller than Vc. This is shown graphically in Figure 2.

The curves intersect at one point only and this corresponds to the balancing cutoff grade gmc.

When the mine and the concentrator limit capacity simultaneously, the increase in present value that can be achieved at any cutoff grade is actually the lower of Vm and Vc. It is marked heavily in the diagram in Figure 2. As can be seen, in this case the maximum is at the vertex gmc.

However two others cases must be examined. these are best illustrated graphically in Figures 3 and 4. As Figures 3 and 4 show, the balancing cutoff grade gmc is less than gm. The mine is really the bottleneck in the operation and gm is the optimum cutoff grade. On the other hand, when gmc is greater than gc, the concentrator is the bottleneck and gc is the optimum cutoff grade.

Thus the following rule may be formulated for an operation limited by the mine and the concentrator. Calling the optimum cutoff grade Gmc: Mine and Concentrator

Gmc = gm if gmc <= gm

= gc if gmc >= gc

= gmc otherwise.

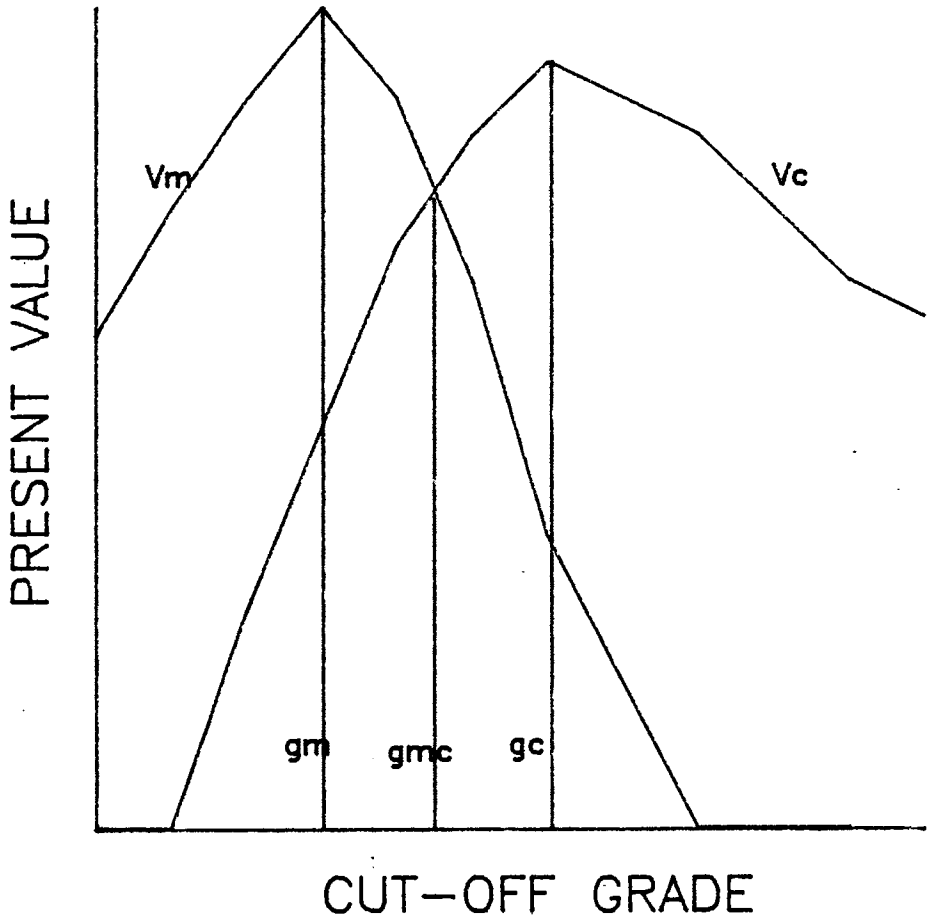

Figure 2. Relation Between COG and Present Value: Case 1

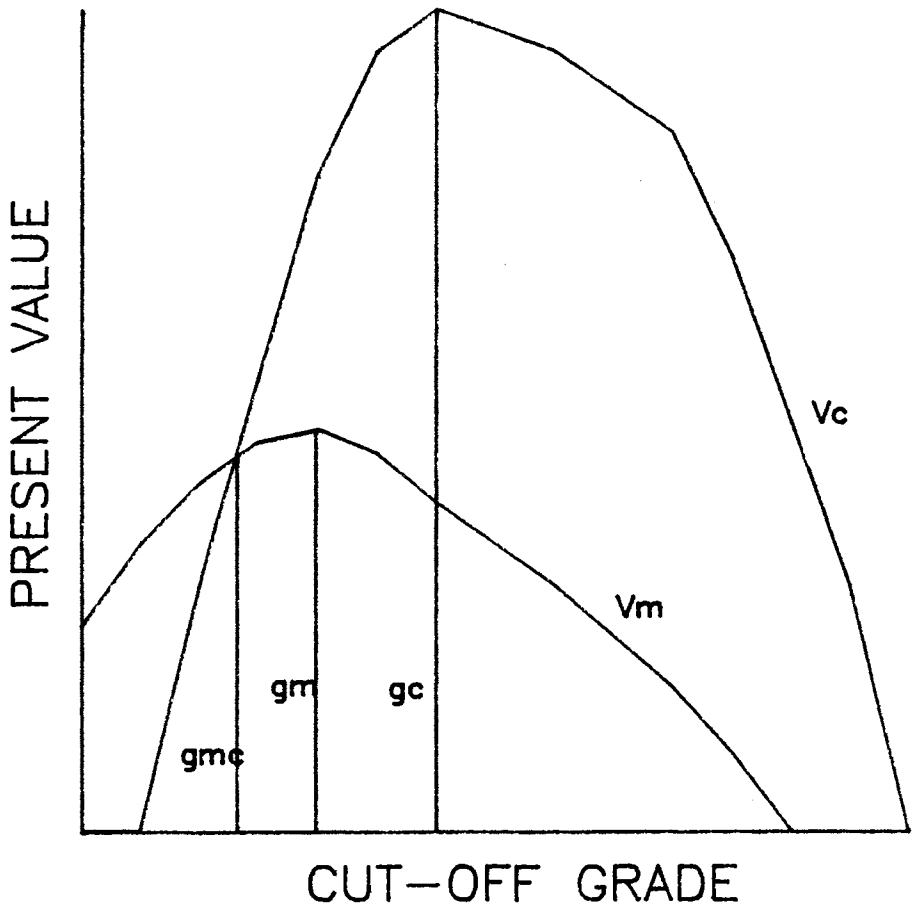

Figure 3. Relation Between COG and Present Value: Case 2

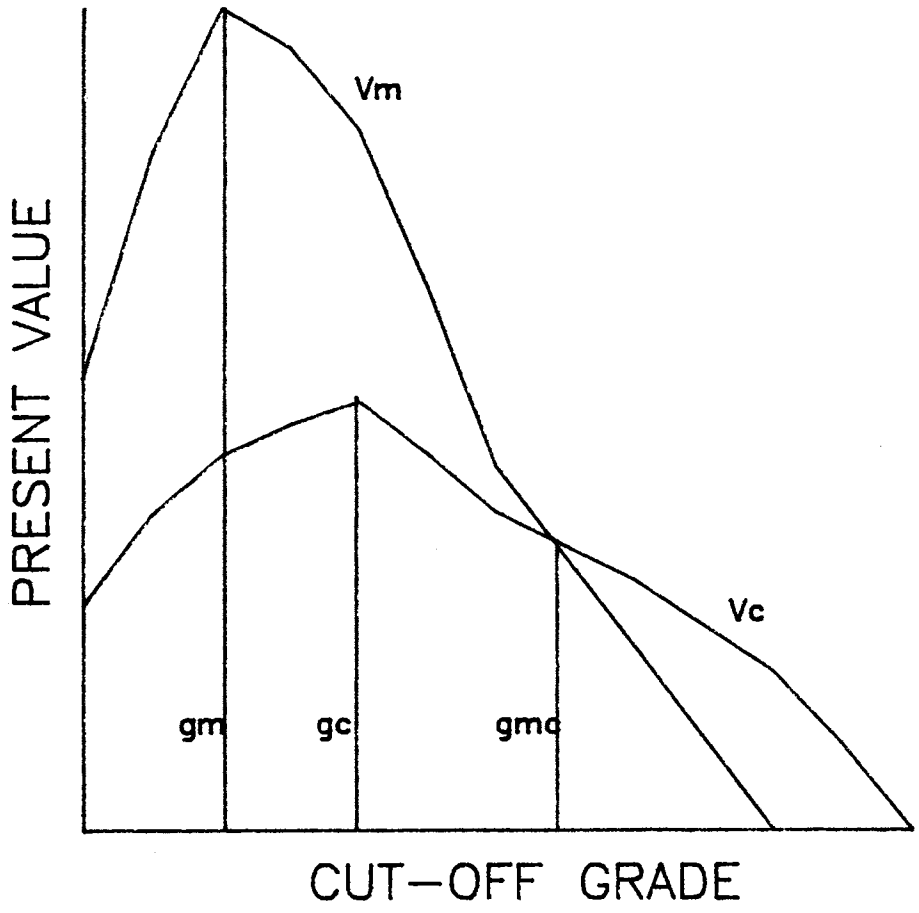

Figure 4. Relation Between COG and Present Value: Case 3

In a similar way, by considering the other pairs of stages:

Mine and Refinery

Gmr = gm if gmr <= gm

= gr if gmr >= gr

= gmc otherwise

Concentrator and Refinery

Gcr = gr if grc <= gr

= gc if grc >= gc

= grc otherwise

The overall optimum cutoff grade is now one of the three, Gmc, Gmr, and Grc. The position is illustrated graphically in Figure 5.

The largest increase in present value that can be achieve at any cutoff grade, allowing for the capacity restrictions, is actually the least of Vm, Vr, and Vc. This is the curve marked heavily in the diagram in Figure 5. The optimum cutoff grade obviously corresponds to the highest point in this triangle and it can be shown that this always occurs at the middle value of Gmc, Gmr, and Grc.

Overall Optimum Cutoff Grade G

= Middle Value (Gmc, Gmr, Grc) (3.16)

In the case illustrated it is Gmr. Further, the associated increase in present value, v, is always the least

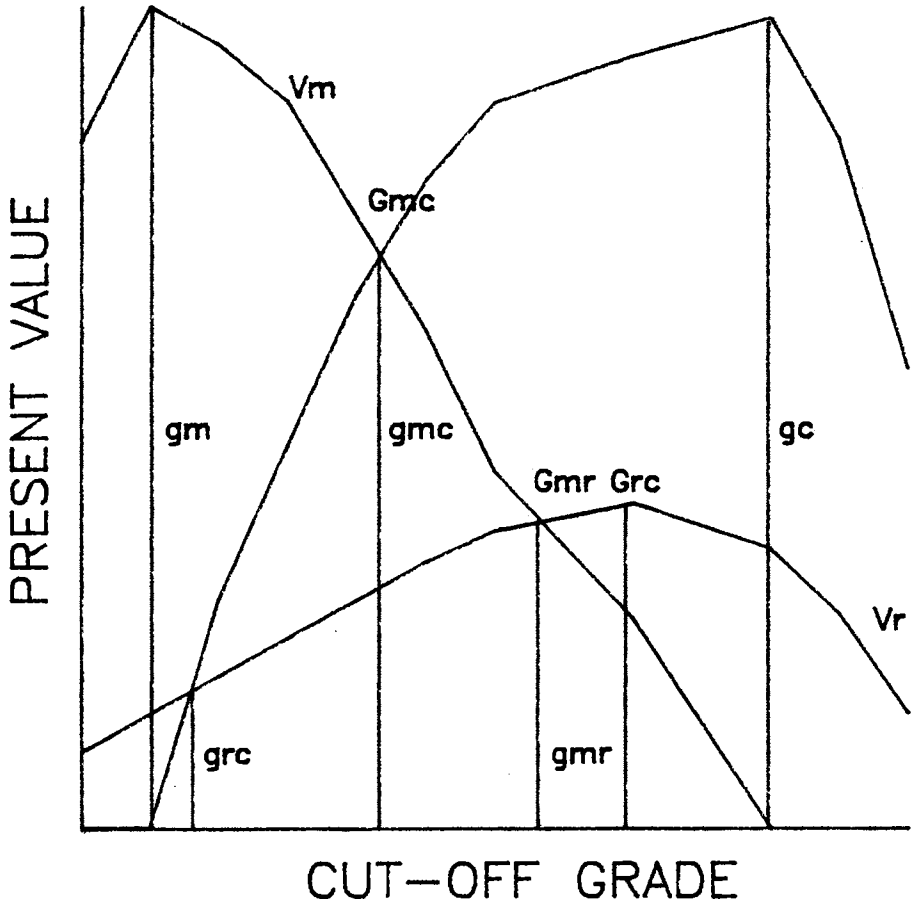

Figure 5. Overall Optimum Cutoff Grade: Case 1

of the three increases which are possible considering the stages in pairs.

The highest point in the triangle need not be at one of the vertices as in the diagram in Figure 5. It can be at one of the maximum points at gm, gr or gc. Under these circumstances, total capacity is limited by the one stage only and the two associated values of Gmc, Gmr and Gcr coincide. The diagram in Figure 6 illustrates the position. There Gmc and Grc coincide at gc. Thus this is the optimum and the concentrator alone limits capacity.

3.2 STEPS OF THE ALGORITHM

The following are the necessary steps to determine the optimum cutoff grade based on the Lane's algorithm.

STEP 1. Describe the input information as a matrix with N rows and M columns. The first and second columns are grade
categories and column three to column M correspond to tonnages per grades.

STEP 2. Compute the total tonnage, the concentrator tonnage, and refining tonnage as a function of the cutoff grade (cog).

STEP 3. With the information obtained in step 2, compute the present value (i=1,N) for mine, mill, and refinery.

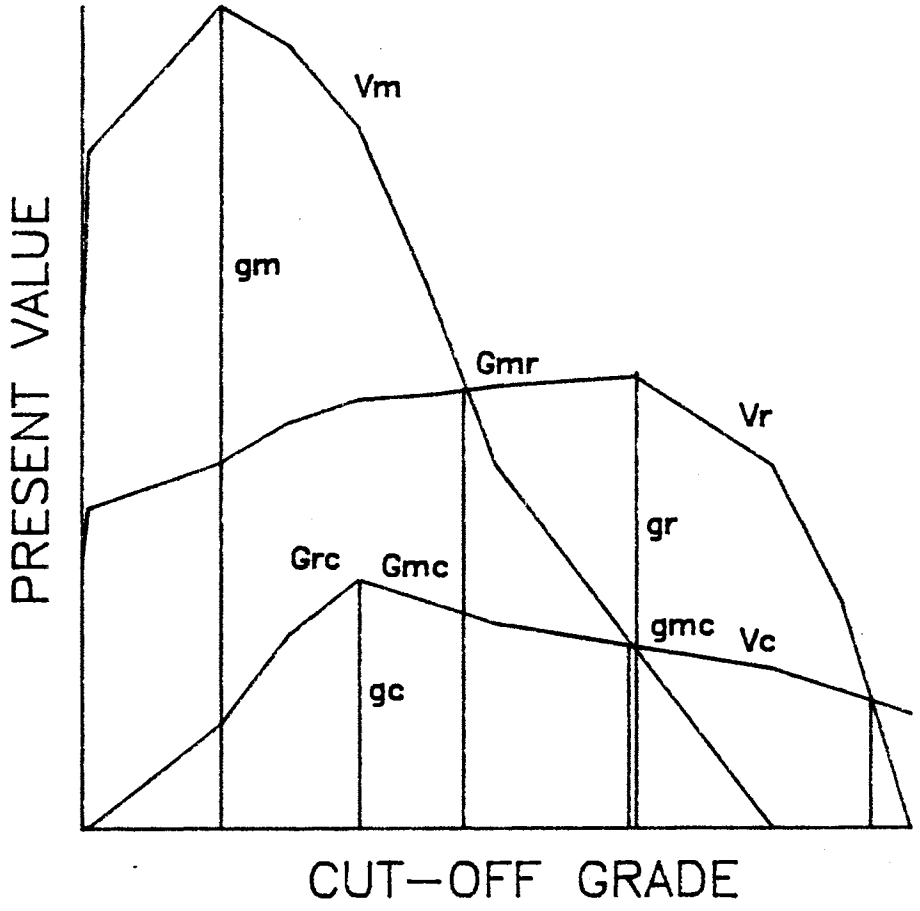

Figure 6 Overall Optimum Cutoff Grade: Case 2

STEP 4. Draw the graphs of cog vs. mine present value and cog vs. mill present value. The intersection of these two curves corresponds to the balancing cog for the mine and mill (gmc). Following the same procedure, get the balancing cog for the mine and refinery (gmr) and the mill and refinery (gcr).

STEP 5. Set the net present value to zero, NPV =0

STEP 6. Set V=NPV

STEP 7. Find the economical cog for each stage

Mine gm

Mill gc

Refinery gr

STEP 8. Find the optimum cog for each pair of stages using the following criteria:

```
Gmc = gm    if gmc <= gm
    = gc    if gmc >= gc
    = gmc   otherwise.
Gmr = gm   if gmr <= gm
    = gr   if gmr >= gr
    = gmc  otherwise
Gcr = gr   if grc <= gr
    = gc   if grc >= gc
    = grc  otherwise.
```

STEP 9. Find the overall optimum cog (OCG) taking the

middle value of Gmc, Gmr, and Grc.

STEP 10. Find the interval in the grade categories in which the OCG is included. If the OCG does not correspond exactly to an extreme value create a new interval where the OCG corresponds to an extreme value. Label that interval as L.

STEP 11. For the OCG, find the total tonnage QM, the total tonnage sent to mill STC, and the total tonnage sent to the refinery STR.

STEP 12. Divide QM by mine capacity = TP1

Divide STC by mill capacity = TP2

Divide STR by refinery capacity = TP3

Pick the highest value of TP1, TP2, TP3 and set it equal to TP

STEP 13. Divide QM, STC, and STR by TP. These amounts correspond to the annual tonnages for the mine, mill and concentrator (QM1,QC1,QR1).

STEP 14. Compute the present value for QM1, QC1, QR1

STEP 15. Compute the net present value NPV for the time TP and add it to the contribution due to the other increments, assuming that the other increments will be mined with the same OCG.

STEP 16. Compare NPV with V. If they are not equal go to step 6, if they are equal go to the following step.

STEP 17. Subtract the tonnage QC1 from the intervals L to N as a proportion of the total tonnage.

Tonnage to subtract from the intervals =

(tonnage in the interval/ STC)*QC1

for intervals L to N

STEP 18. Subtract the tonnage QM1-QC1 from the intervals 1 to L-1. The tonnage to subtract from the interval =

[tonnage in the interval/(QM-STC)]*(QM1-QC1)

STEP 19. Is there ore in the increment?

Yes, go to step 5

No, go to the following step

STEP 20. Is this the last increment?

No, change to the next increment and go to step 2

Yes, go to following step

STEP 21. Taking the profits for the entire project, compute the net present value year by year.

STEP 22. Compare the net present values found in step 21 with the net present values obtained in the last iteration.

If they are not equal go to step 2 and repeat the entire process again. To obtain the economic cutoff grade use the NPV corresponding to that year.

If they are equal cutoff grades are optimum.

STEP 23. END.

3.3 MANUAL SOLUTION OF AN EXAMPLE

An example taken from Lane's publication (Lane, 1964) is developed in a manual way to show how Lane's algorithm works.

DATA

Mine capacity	100
Concentrator capacity	50
Refinery capacity	40
Mine cost	1
Conc. cost	2
Ref. cost	5
Sales price	25
Fixed cost	300
Yield	100%

Ore reserves: Table 1 shows the inventory of reserves for this example:

Table 1. Ore Reserve Inventory

Grade Interval	Quantity
0.0 - 0.1	100
0.1 - 0.2	100
0.2 - 0.3	100
:	:
:	:
0.9 - 1.0	100
Total	1000

The first cutoff grades to be calculated are the three balancing cutoff grade, taking into account that they will remain constant through the life of the push back.

3.3.1.- CALCULATION OF THE BALANCING CUTOFF GRADES:

To determine the balancing cutoff grades, find the net present value for the mine, plant and refinery as a function of the cutoff grade. First, the tonnages corresponding to the Mine, Plant and Refinery as a function of the cutoff grade must be calculated.

In the inventory of ore reserves, we are going to get different tonnages for the Mine, Plant and Refinery for different cutoff grades. For example, if the cutoff grade is 0, we have 1000 Tons for the Mine, 1000 Tons for the Concentrator and 500 Tons for the Refinery. In Table 2 the variation of the tonnages as a function of the cutoff grade, is shown.

Using equations (3.6), (3.11), and (3.14) and replacing the corresponding costs in the formulas and considering V=0 (the values of the balancing cutoff grades are the same for any value of V) we obtain:

$$Vm = 20*Qr - 2*Qc - 4*Qm \quad (3.17)$$

$$Vc = 20*Qr - 8*Qc - 1*Qm \quad (3.18)$$

$$Vr = 12.5*Qr - 2*Qc - 1*Qm \quad (3.19)$$

Taking the values listed in Table 2 and using

equations (3.17), (3.18), and (3.19) we can get the net present value as a function of the cutoff grade. Those values are shown in Table 3.

Now we draw a graph considering cutoff grade versus Mine net present value and cutoff grade versus concentrator net present value.

Table 2. Tonnages as a Function of the Cutoff Grade

C.O.G.	Qm	Qc	Qr
.0	1000	1000	500
.1	1000	900	495
.2	1000	800	480
.3	1000	700	455
.4	1000	600	420
.5	1000	500	375
.6	1000	400	320
.7	1000	300	255
.8	1000	200	180
.9	1000	100	95

Table 3. Net Present Values as a Function of the Cutoff Grade

C.O.G	Vm	Vc	Vr
.0	4000	1000	3250
.1	4100	1700	3388
.2	4000	2200	3400
.3	3700	2500	3288
.4	3200	2600	3050
.5	2500	2500	2688
.6	1600	2200	2200
.7	0.50	1700	1588
.8	-800	1000	850
.9	-2300	100	-12.5

The intersection of both curves will give us the balancing cutoff grade for the Mine and Concentrator. As is shown in Figure 7, the balancing cutoff grade for Mine and Concentrator is gmc = 0.5.

Doing the same thing for the other two pairs: Mine and Refinery; and Concentrator and Refinery, we get the corresponding balancing cutoff grades. As we can see in Figures 8 and 9 the balancing cutoff grades for these cases are:

Mine - Refinery = 0.45

Conc. - Refinery = 0.60

These three cutoff grades remain constant through the life of the push back.

3.3.2 ECONOMIC CUTOFF GRADES

The economic cutoff grades are calculated using equations (3.9), (3.12), and (3.15), described in Section 3.1.4.

As we can see gc and gr are both dependent on the present value. So from this point, the process is iterative. We are going to start with V = 0. For V = 0 we have

gm = 0.10

gc = 0.40

gr = 0.16

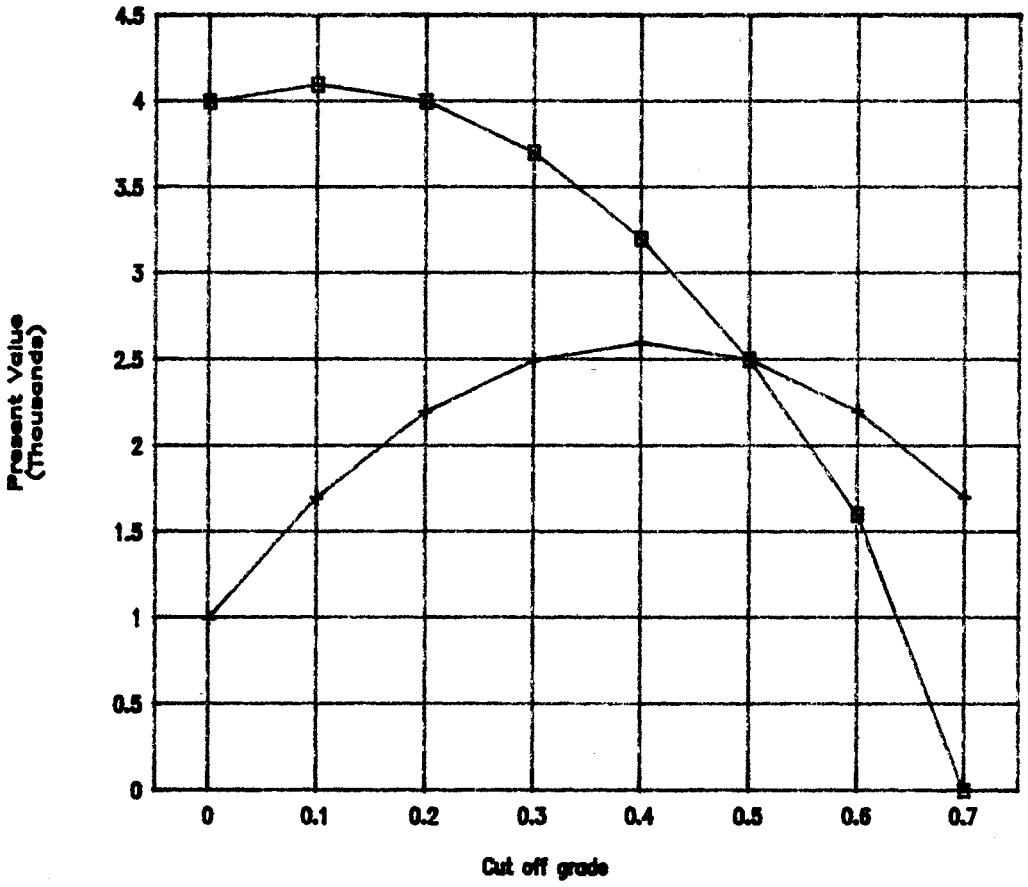

Figure 7. Balancing Cutoff Grade: Mine - Concentrator

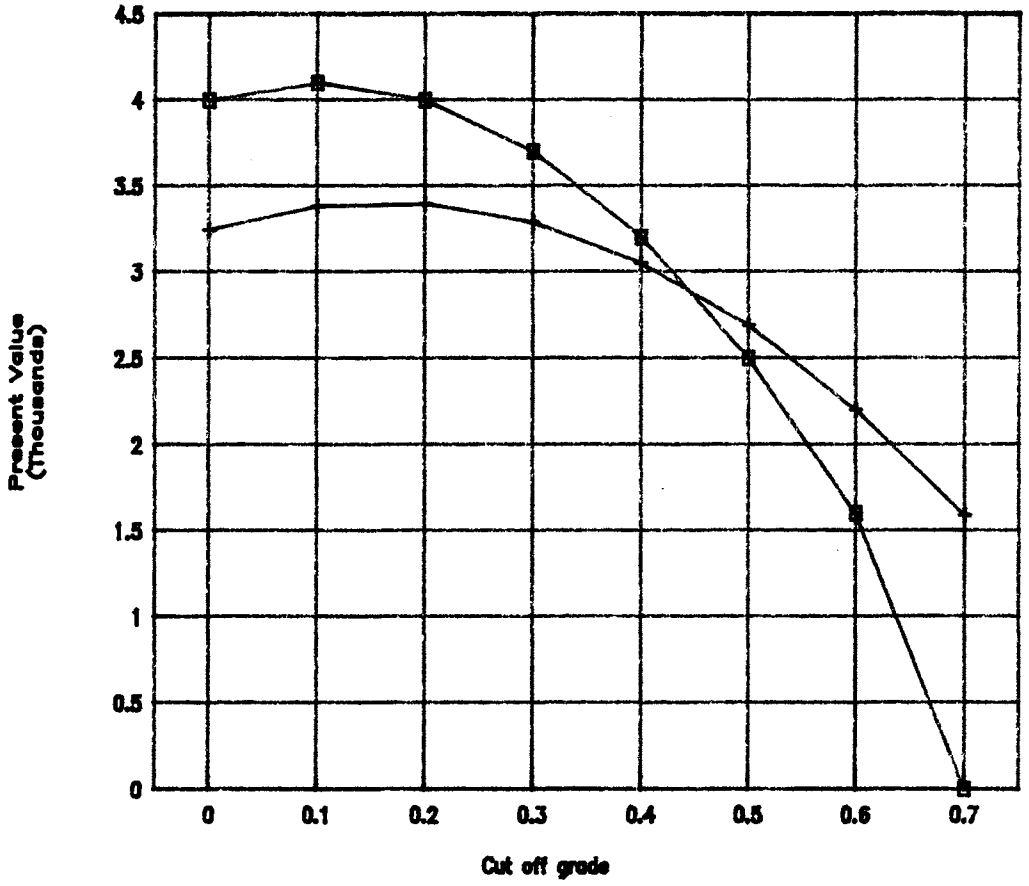

Figure 8. Balancing Cutoff Grade: Mine - Refinery

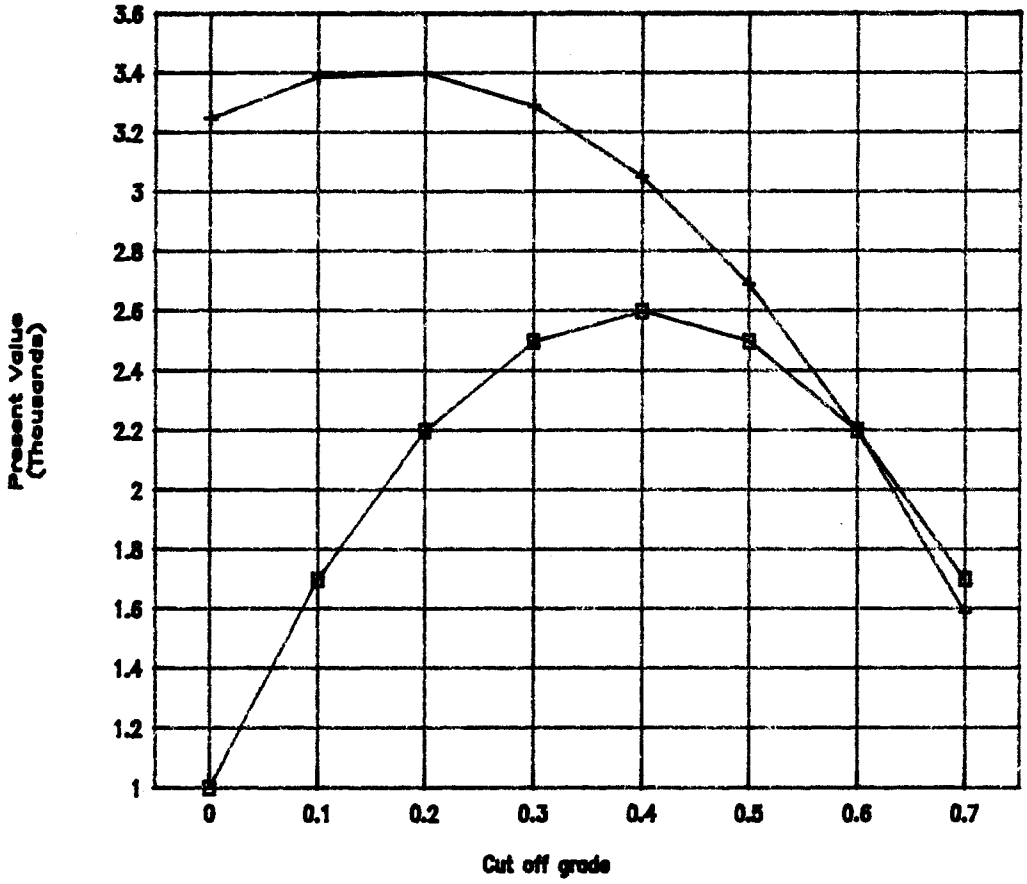

Figure 9. Balancing Cutoff Grade: Concentrator - Refinery

3.3.3 OPTIMUM CUTOFF GRADES

Considering the rules set up in Section 3.1.6 (optimum cutoff grades), we have:

For Mine and Concentrator:

Gmc = 0.4

For Mine and refinery:

Gmr = 0.16

For Refinery and Concentrator:

Grc = 0.40

Taking the middle value we have the optimum cutoff grade, which in this case is equal to:

G = 0.40

For an optimum cutoff grade of 0.40 we have:

Total tonnage to be mined: 1000

Total tonnage to send to Concentrator: 600

Total tonnage to refinning: 420

Now we have to assume that we are going to mine the total push back with a cutoff grade of 0.40. The time required will be:

For Mine capacity:

1000/100 = 10 years

For Concentrator capacity:

600/50 = 12 years

For Refinery capacity:

420/40 = 10.5 years

We can see that the bottleneck in this case is the Concentrator, and the duration of the push back will be 12 years. The following are the annual tonnages:

Mine

1000/12 = 83.33 Tons/yr

Concentrator

600/12 = 50 Tons/yr

Refinery

420/12 = 35 Tons/yr

Assuming that we are mining the total push back with a cutoff grade of 0.40 we can get the results shown in Table 4.

Strictly, this solution applies in the first year only because the present values decline from year to year, and gc and gr have to be recalculated. However, initially, the present value has been taken as zero and the optimum of 0.40 therefore applies throughout.

Now the annual profit of 216.7 for 12 years can be discounted back at 15 percent to give 1174 as an estimate of the present value V. Using this value the limiting economic cutoff grade can be recalculated.

gm = 0.10

gc = 0.58

Table 4. Initial Results for V = 0

YEAR	COG	QM	QC	QR	PROFIT
1	0.40	83.3	50	35	216.7
2	0.40	83.3	50	35	216.7
3	0.40	83.3	50	35	216.7
:	:	:	:	:	:
:	:	:	:	:	:
:	:	:	:	:	:
:	:	:	:	:	:
:	:	:	:	:	:
12	0.40	83.3	50	35	216.7

gr = 0.25

From this a new overall optimum can be calculated:

Gmc = 0.50

Gmr = 0.25

Grc = 0.58

The new overall optimum is:

G = 0.50

Now we can compute a new annual profit.

For G = 0.50 we have:

Total Mine tonnage: 1000 Tons

Total Conc. Tonnage: 500 Tons

Total Ref. tonnage: 375 Tons

The maximum duration will be:

Mine 1000/100 = 10 years

Conc. 500/50 = 10 years

Ref. 375/40 = 9.37

Thus the time is 10 years and the annual tonnages are:

Mine 1000/10 = 100 Tons/yr.

Conc. 500/10 = 50 Tons/yr.

Ref. 375/10 = 37.5 Tons/yr.

With these values and assuming again that we mine the total push back with a cutoff grade of 0.50, we can determine the annual profits for 10 years and obtain a new net present value.

Annual profit = 250

Again, discounting back this profit for 10 years at 15 percent we determine a new net present value, which is 1255 in this case.

If we compare this NPV with the previous NPV, we observe some difference. Thus we have to make another iteration considering V = 1255.

The economic cutoff grades are:

gm = 0.10

gc = 0.59

gr = 0.26

The optimum cutoff grades are:

Gmc = 0.50

Gmr = 0.26

Grc = 0.59

The overall optimum is:

G = 0.50

Mine 1000/100 = 10 years

Conc. 500/50 = 10 years

Ref. 375/40 = 9.37 years

Thus the time is 10 years and the annual tonnages are:

Mine 1000/10 = 100 Tons/yr.

Conc. 500/10 = 50 Tons/yr.

Ref. 375/10 = 37.5 Tons/yr.

With these values, we can calculate the annual profit. This is 250/year. Over ten years the net present value is equal to 1255, which is exactly equal to the NPV calculated at the previous iteration. That means that we have found the optimum cutoff grade.

This result is applicable only in the first year thus we subtract the annual tonnages mined and sent to the concentrator to determine the remaining amount of material.

We already have mined 100 Tons and sent to Concentrator 50 Tons in the first year. Furthermore, we have to subtract those amounts from the ore reserve inventory.

First subtract the amount corresponding to the concentrator, which is 50 Tons. Subtract this amount from the intervals 0.5 - 0.6 and upward, as a proportion of the amount of material corresponding to that interval.

For example, for the interval 0.5 - 0.6 we have 100 Tons and the total amount of material above the cut off grade 0.5 is 500 Tons. Therefore, the amount of material that we have to subtract is:

(100/1000)*50 = 10 Tons.

Since all the intervals have the same amount of material, the amount of material to subtract from each interval above the cutoff grade will be the same. That is, 10 Tons from each interval.

Now, if we mined a total of 100 Tons and sent 50 Tons to the Concentrator, we have to subtract the other 50 Tons from the intervals which are below the cutoff grade, that is, the tonnage is subtracted from the interval .0 - .1 to .4 - .5.

The remaining total amount of material is:

1000 - (Amount of material above the COG equal 500) = 500

Now the amount of material to subtract from each interval below the cutoff grade is:

(50/500)*50 = 10

The inventory of reserves after mining the first year is shown in Table 5.

Now we have to compute the optimum cutoff grade for the second year following the same procedure as in the first year. That is, starting with V = 0 and doing successive

iterations. Doing this we can get the cutoff grade policy and the production schedule shown in Table 6.

Table 5. New Inventory of Reserves

Grade Interval	Quantity
0.0 - 0.1	90
0.1 - 0.2	90
0.2 - 0.3	90
:	:
:	:
:	:
0.9 - 1.0	90
Total	900

Table 6. Schedule for the Manual Example

YEAR	COG	QM	QC	QR	PROF	NPV
1.	.50	100.0	50.0	37.5	250.0	1254.7
2.	.50	100.0	50.0	37.5	250.0	1192.9
3.	.50	100.0	50.0	37.5	250.0	1121.8
4.	.50	100.0	50.0	37.5	250.0	1040.1
5.	.50	100.0	50.0	37.5	250.0	946.1
6.	.50	100.0	50.0	37.5	250.0	838.0
7.	.50	100.0	50.0	37.5	250.0	713.7
8.	.49	97.2	50.0	37.1	245.6	573.7
9.	.46	93.0	50.0	36.6	238.2	417.1
10.	.44	88.7	50.0	35.9	229.5	243.0
11.	.41	21.0	12.5	8.8	54.7	52.7

Now in Table 6, we have to discount back each one of the values in the column corresponding to the profit.

For the first year the net present value is:

250*4.16+245.6*0.3269+238.2*0.2843+229.5*0.2472+54.7*0.2387

NPV = 1257.8

Following the preceding process for all years we can get the values shown in Table 7. With the net present values from Table 7 we have to find a new economic cutoff grade. Thus for the first year we have:

gm = 0.10

gc = [2+(300+1157.8*0.15)/50]/20 = 0.57

gr = 2/[20-(300+1157.8*0.15)/40] = 0.25

Table 7. Final Schedule for the Manual Example

YEAR	COG	QM	QC	QR	PROF	NPV
1.	.50	100.0	50.0	37.5	250.0	1257.8
2.	.50	100.0	50.0	37.5	250.0	1196.5
3.	.50	100.0	50.0	37.5	250.0	1126.0
4.	.50	100.0	50.0	37.5	250.0	1044.9
5.	.50	100.0	50.0	37.5	250.0	951.7
6.	.50	100.0	50.0	37.5	250.0	844.5
7.	.50	100.0	50.0	37.5	250.0	721.1
8.	.49	97.2	50.0	37.1	245.6	579.3
9.	.46	93.0	50.0	36.6	238.2	420.6
10.	.44	88.7	50.0	35.9	229.5	245.5
11.	.41	21.0	12.5	8.8	54.7	52.8

As we can see, the economic cutoff grades are almost the same and we get a NPV of 1154.7. Furthermore the cutoff grade policy shown in Table 7 is the optimum. The total output for this example, found through the use of a computational program is given in Appendix E.

The preceding situation is particular for this example. It is more common to find a greater variation in determine the cutoff grade policy for the entire project. In that case, it is necessary to make a new iteration, but now substituting the new net present value in the economic cutoff grade formulas.

3.4 COMPUTATIONAL PROGRAM

Due to the great amount of calculation involved in calculating the optimum cutoff grade using Lane's algorithm, a computer program has been developed (COG.FOR). This program was written in Fortran 77 for an IBM AT computer. The execution time is less than one minute for the example, and requires 35 Kb of main memory. An example, with data taken from Lane's paper (Lane, 1964), was run. The computer code for this program is listed in Appendix A

3.4.1 INPUTS

For the demonstrative example, the input data are shown in Table 8. In Appendix F, the total description of the input data for the COG.FOR program is shown.

Table 8.Input Data for the Demonstration Example

Grade Categories %	Pit Increments in Mining Sequence 1	2	3	4	5	6
0.00 - 0.15	14.4	15.9	17.9	20.3	23.4	27.7
0.15 - 0.20	4.6	5.1	5.5	6.3	7.2	8.3
0.20 - 0.25	4.4	4.9	5.4	6.0	6.7	7.7
0.25 - 0.30	4.3	4.7	5.3	5.6	6.4	7.3
0.30 - 0.35	4.2	4.5	4.9	5.5	6.2	6.7
0.35 - 0.40	4.1	4.4	4.7	5.3	5.6	6.3
0.40 - 0.45	3.9	4.3	4.6	4.9	5.4	5.7
0.45 - 0.50	3.8	4.1	4.5	4.8	5.1	5.3
0.50 - 0.55	3.7	3.9	4.2	4.5	4.6	4.7
0.55 - 0.60	3.6	3.8	3.9	4.2	4.4	4.3
0.60 - 0.65	3.4	3.6	3.8	3.9	4.0	3.7
0.65 - 0.70	3.3	3.5	3.7	3.7	3.6	3.3
+.70	42.3	37.5	31.6	25.0	17.4	9.0
Average % Mineral	1.13	1.07	1.00	0.93	0.87	0.80

Capacities:

Mine	20 million tons material/year
Mill	10 million tons ore/year
Refinery	90.000 tons product/year

Costs:

Mining	0.50 $/ton of material from pit
Mill	0.60 $/ton of ore to mill
Refining	50.0 $/ton of product
Fixed charges	4 million $/year
Selling price	550 $/ton of product
Recovery	90 %

3.4.2 OUTPUTS

The output for this program is a statement of the optimum cutoff grade throughout the life of the operation together with the corresponding tonnages, profit and present values. Part of the output for this example is shown in Table 9 and the total output is given in Appendix B

Table 9. Output From the Program COG

YEAR	INC	COG	QM	QC	QR	PROF	U.PRF	NPV
1.	1.00	.50	17.9	10.0	90.0	26.1	484.2	150.33
2.	1.00	.50	17.9	10.0	90.0	26.1	458.1	146.80
3.	1.00	.50	17.9	10.0	90.0	26.1	432.0	142.75
4.	1.00	.50	17.9	10.0	90.0	26.1	405.9	138.08
5.	1.00	.50	17.9	10.0	90.0	26.1	379.8	132.72
6.	1.00	.50	10.7	6.0	54.2	15.7	353.7	126.55
6.	2.00	.53	8.0	4.0	34.2	9.1	338.0	126.55
7.	2.00	.5	20.0	10.0	85.9	23.0	328.9	120.69
8.	2.00	.53	20.0	10.0	85.9	23.0	305.9	115.83
9.	2.00	.53	20.0	10.0	85.9	23.0	282.9	110.23
10.	2.00	.53	20.0	10.0	85.9	23.0	259.9	103.80
11.	2.00	.53	12.2	6.1	52.6	14.1	236.9	96.40
11.	3.00	.47	7.8	3.9	29.5	7.0	222.8	96.40
12.	3.00	.47	20.0	10.0	76.1	18.0	215.8	89.80
13.	3.00	.47	20.0	10.0	76.1	18.0	197.8	85.22
14.	3.00	.47	20.0	10.0	76.1	18.0	178.8	79.95
15.	3.00	.47	20.0	10.0	76.1	18.0	161.8	73.90
16.	3.00	.45	12.3	6.4	47.7	11.3	143.8	66.94
16.	4.00	.41	7.2	3.6	24.0	4.8	132.5	66.94
17.	4.00	.41	20.0	10.0	66.5	13.2	127.7	60.87
18.	4.00	.41	20.0	10.0	66.5	13.2	114.5	56.77
19.	4.00	.40	19.4	10.0	65.6	13.1	101.3	52.06
20.	4.00	.38	18.8	10.0	64.5	12.9	88.2	46.78
21.	4.00	.36	14.6	8.1	51.2	10.2	75.3	40.91
21.	5.00	.35	3.8	1.9	11.0	1.7	65.3	40.91
22.	5.00	.34	19.5	10.0	56.5	8.5	63.5	35.18
23.	5.00	.33	19.0	10.0	55.8	8.4	55.0	31.92
24.	5.00	.32	18.4	10.0	55.1	8.3	46.5	28.27
25.	5.00	.30	17.9	10.0	54.3	8.2	38.1	24.17
26.	5.00	.29	17.3	10.0	53.3	8.0	29.9	19.60
27.	5.00	.27	4.2	2.5	13.1	2.0	21.8	14.50
27.	6.00	.27	14.1	7.5	34.7	2.8	20.3	14.50
28.	6.00	.26	18.3	10.0	45.7	3.7	17.3	11.91
29.	6.00	.26	18.0	10.0	45.4	3.7	13.6	10.00
30.	6.00	.25	17.7	10.0	44.9	3.6	9.9	7.83
31.	6.00	.24	17.3	10.0	44.4	3.6	6.3	5.39
32.	6.00	.23	14.6	8.7	37.9	3.0	2.7	2.63

CHAPTER 4

OPTIMUM CUTOFF GRADE CONSIDERING STOCK PILE

4.1 DESCRIPTION OF THE SYSTEM

The classical Lane approach (Lane, 1964) to determine the optimum cutoff grade does not consider the stock pile alternative. This means that, all material below the cutoff grade is sent to the waste dump whereas the material above this cutoff grade is sent to the Mill.

In the proposed system, the stock pile is generated with material which is below the cutoff grade for each period but is above the lowest cutoff grade for the whole project. The cost of handling the material at the stock pile is to be 45% of the total mining cost. This is composed of 40% corresponding to material handling and 5% corresponding to supervision, which is greater than that of the conventional system. Considering only increment 1 in the preceding example (Table 9), all material below 0.5% and above 0.23% will be sent to the stock pile. For the second increment (year 6), material below 0.53% and above 0.23% will be sent to the stock pile.

Let's consider some particular year, for example year 18 (Table 9). The optimum cutoff grade for that year is 0.41% and at the stock pile we have material between 0.23% and 0.53%. In such a case, it is necessary to consider the

possibility of sending material from the stock pile to the mill instead of material from the push back.

The analysis is done by comparing the potential profits generated by both alternatives. The comparison is established between the same grade categories for both alternatives. For example, if we have mineral at the mine between the grades 0.4% and 0.7% and at the stock pile we have mineral between 0.4% and 0.55%, we are going to compare the mineral in grades between 0.4% and 0.55% in the mine with the stock pile. That means, if the profitability of the ore at the stock pile is greater than that of the ore in the mine, we are going to send ore from the stock pile and from the mine to feed the mill. We are sending ore between 0.4% and 0.55% from the stock pile and ore between 0.55% and 0.7% from the mine. If that were the case, then material between 0.23% and 0.55% would be sent to the stock pile.

This stock pile system is dynamic, in the sense that, for some determined year, the stock pile is receiving ore from the mine, and sending ore to the mill. When the mining of the push back has finished, then the process continues, considering the stock pile as a new push back. That is, we calculate an optimum cutoff grade per each year and calculate the amount of material and profit per each year, in the same way that the Lane's algorithm works.

4.2 STEPS IN THE PROCESS

STEP 1. Run the COG.FOR program to get the lowest optimum cutoff grade (SCOG)

STEP 2. Consider the SCOG put a new interval (LD) in the previous data set and include a mining cost for the stock pile.

STEP 3. Compute the total tonnage, the concentrator tonnage and refining tonnage as a function of the cutoff grade (cog).

STEP 4. With the information obtained in step 2, calculate the present value (i=1,N) for mine, mill and refinery.

STEP 5. Draw the graphs of cog vs. mine present value and cog vs. mill present value. The intersection of these two curves corresponds to the balancing cog for the mine and mill (gmc). Repeat this procedure to get the balancing cog for mine and refinery (gmr) and mill and refinery (gcr).

STEP 6. Set the net present value to zero, NPV =0

STEP 7. Set V=NPV

STEP 8. Find the economic cog for each stage

mine, gm

mill, gc

refinery, gr

STEP 9. Find the optimum cog for each pair of stages

with the following criteria:

Gmc = gm if gmc <= gm
= gc if gmc >= gc
= gmc otherwise.

Gmr = gm if gmr <= gm
= gr if gmr >= gr
= gmc otherwise

Gcr = gr if grc <= gr
= gc if grc >= gc
= grc otherwise.

STEP 10. Find the overall optimum cog (OCG) taking the middle value of the: Gmc, Gmr, Grc

STEP 11. Find the interval in the grade categories in which the OCG is included.If the OCG does not correspond exactly to an extreme value create a new interval where the OCG corresponds to an extreme value. Label that interval as L.

STEP 12. For the OCG find the total tonnage mined (QM), the total tonnage sent to mill (STC), and the total tonnage sent to refinery (STR).

STEP 13. Divide QM by mine capacity = TP1

Divide STC by mill capacity = TP2

Divide STR by refinery capacity = TP3

Determine the maximum of TP1, TP2, TP3 and set equal to TP

STEP 14. Divide QM, STC, and STR by TP. These amounts correspond to the annual tonnages for the mine, mill and concentrator (QM1,QC1,QR1).

STEP 15. Compute the present value for QM1, QC1, QR1

STEP 16. Compute the net present value NPV for the time TP and add it the contribution due to the other increments, assuming that the other increments will be mined with the same OCG.

STEP 17. Compare NPV with V. If they are not equal go to step 6, if they are equal go to the following step.

STEP 18. In the push back determine the tonnages, for the mine (QM11), concentrator (QC11) and refinery (QR11), and the profit P1, which correspond exactly to that of the same grade categories in the stock pile.

STEP 19. In the push back determine the tonnages, total QM12, concentrator QC12 and refinery QR12, and the profit P2, which correspond to the upper grade categories in the push back.

STEP 20. For the stock pile determine the total tonnage QMS, the concentrator tonnage QCS, and the refinery tonnage QRS which correspond to intervals LD to L2 (L2 upper interval)

STEP 21. Compute the profit PS in the stock pile.

STEP 22. If PS is greater than P1 send the

corresponding ore QMS from the stock pile to the mill. Also send to the mill the tonnage corresponding to P2 (QC12).

Otherwise: the total feed of the mill is from the push back. Go to step 26.

STEP 23. Subtract the tonnage from the stock pile corresponding to QCS from each interval above the cut off grade, as a proportion of the total tonnage.

STEP 24. Subtract the tonnage QC12 from the intervals L2 to N in the push back. As a proportion of the total tonnage.

The tonnage to subtract from the intervals =

(tonnage in the interval/ STC2)*QC12

for intervals L2 to N

STEP 25. Subtract the tonnage QM12-QC12 from intervals 1 to LD-1 and LD to L-1

The tonnage to subtract from the interval =

[tonnage in the interval/(QM2-STC2)]*(QM12-QC12)

The tonnage subtracted from the intervals 1 to LD-1 is sent to the waste dump and the tonnage subtracted from intervals LD to L2-1 is send to the stock pile.

STEP 26. Subtract the tonnage QC1 from the intervals L to N as a proportion of the total tonnage.

The tonnage to subtract from the intervals =

(tonnage in the interval/ STC)*QC1

for intervals L to N

STEP 27. Subtract the tonnage QM1-QC1 from the intervals 1 to LD-1, and from LD to L-1

The tonnage to subtract from the interval =

[tonnage in the interval/(QM-STC)]*(QM1-QC1)

The tonnage subtracted from the intervals 1 to LD-1 is sent to the waste dump and the tonnage subtracted from intervals LD to L-1 is send to the stock pile.

STEP 28. Is there ore in the increment?

Yes, go to step 6

No, go to the following step

STEP 29. Is this the last increment?

No, proceed to the following increment and go to step 3.

Yes, go to following step

STEP 30. Taking the present values for all years determine the net present value year by year.

STEP 31. Are the net present values computed in step 21 equal to the actual NPV.

No, go to step 3 and do all process again starting from increment 1. However to obtain the economical cog use the NPV which corresponds to that year.

Yes, all the cut off grades are optimum.

STEP 32. Considering the stock pile as a new increment

apply Lane's algorithm to this data, starting from the last year in step 30. Compute the net present value considering all profits through the life of the project.

STEP 33. End.

4.3 MANUAL EXAMPLE FOR THE PROPOSED ALTERNATIVE

To show how this alternative method of stock pile handling works a manual example is developed in this section. The input data is the same as in the example in Section 3.3 except that the cost for the stock pile has been added.

First of all, we run Lane's algorithm to determine the lowest cutoff grade for the project. In this case the value is 0.41, so we have to add a new interval to the ore reserves inventory. Table 10 shows the data used in this example.

The first step in the process is the determination of the balancing cutoff grades. These are calculated exactly in the same way as in Lane's algorithm.

We compute the economic cutoff grade and the optimum cutoff grade in the same way as was shown in Section 3.3; that is, starting with V=0 we make successive iterations to find the optimum cutoff grade. For the first year the optimum cutoff grade is 0.5. We do not have ore in the stock pile at this grade, furthermore, we have no alternative to

Table 10. Data for the Manual Example

Mine Capacity	100
Concentrator capacity	50
Refinery capacity	40
Mine cost	1
Stock pile cost	.6
Con. cost	2
Ref. cost	5
Sales price	25
Fixed cost	300
Yield	100%

Grade Interval	quantity
0.0 - 0.1	100
0.1 - 0.2	100
0.2 - 0.3	100
0.3 - 0.4	100
0.4 - 0.41	10
0.41 - 0.5	90
0.5 - 0.6	100
:	:
:	:
0.9 - 1.0	100
Total	1000

choose other than to send ore to concentrator from the mine. In this case we send 50 tons, and mine a total tonnage of 100 tons.

Now, we have to subtract the annual tonnages, the total tonnage mined and, the tonnage sent to concentrator. As in Lane's algorithm (Section 3.3), we first subtract the amount corresponding to the concentrator which is 50 tons. This amount we have to subtract from the intervals 0.5-0.6 and up, as a proportion of the amount of material corresponding to that intervals. For example, for the interval 0.5-0.6 we have 100 tons and the total amount of material above the cutoff grade is 500 tons. The amount of material that we have to subtract is:

(100/500)*50 = 10 tons.

Since all of the intervals contain the same amount of material, the amount of material to subtract from each interval above the cutoff grade will be the same, that is, 10 tons from each interval.

If we mine a total of 100 tons, and we send 50 tons to the concentrator, we have to subtract another 50 tons from the intervals which are below the cutoff grade. At this stage, we create the stock pile. We have to subtract 50 tons from the intervals which are below the cutoff grade. The 50 tons that are removed, are subtracted from intervals .0-0.1

to 0.4-0.5.

We then send to the stock pile the material that we subtracted from the interval 0.41-0.50 and send to the waste dump the material which was subtracted from the intervals 0.-0.1 to 0.4-0.41. This means that we are sending to the stock pile 10 tons of material subtracted from the interval 0.41-0.5 corresponding to the first year. The stock pile will have the following grade distribution for the first year.

GRADE	TONNAGE
0.41 - 0.50	10

This process means that material that was sent to the waste dump in the previous system is now stock piled.

Following the same procedure as in the first year, we can continue from year 2 to year 7. As we can see in Table 7, we have the same cutoff grade from year 1 to year 7. This means that we cannot take material from the stock pile because all the material in the stock pile is below 0.5. The stock pile at the end of year seven will have the following grade distribution and tonnage:

GRADE	TONNAGE
0.41 - 0.50	70

Now for the year 8 we have a cutoff grade of 0.49. In this case, we have to compute the profit for the ore in the

stock pile corresponding to grade categories 0.49-0.50 and to compare this with the profit for those categories of ore in the push back.

As previously determined the profit for the ore in the mine is 245. This profit was calculated considering the grades between the interval 0.49-0.50 and the interval 0.9-1.0. We are going to divide the profit into two parts, one corresponding to the contribution of the material in the interval 0.49-0.50 and the other corresponding to the contribution of the material in the intervals 0.5-0.6 to 0.9-1.0.

We have a total amount of ore above the cutoff grade equal to 154.5 tons (Appendix E), and, in the interval 0.41-0.50, we have an amount of 27 tons. In the interval 0.49-50 we have three tons. Now we have to compute the amount of material sent to the concentrator corresponding to this interval. This is:

$$(3/154.5)*50 = 0.97$$

The amount of refined material corresponding to this interval is equal to:

Total amount refining = 3.09*37.1 = 114.6 (Appendix E)

The refining material in the interval is

$[(0.49+0.50)/2]*3 = 1.48$ tons

$(1.48/114.6)*37.1 = 0.48$ tons.

The tonnage to send to the waste dump corresponding to this interval is:

(1.48/114.6)*97.2 = 1.25 tons.

The percentage of the fixed cost corresponding to this interval is:

(1.48/114.6)*100 = 1.29%

Now the contribution in the profit corresponding to this interval is:

P = (25-5)*0.48 - 2*0.97 - 1*1.25 - 0.0129*300

P = 2.54

Now we have to determine the profit for the material in the stock pile considering that we are sending to the concentrator an amount of 0.97 tons. The total amount to refine is:

[(0.49 + 0.50)/2]*0.97 = 0.48

The total amount to be mined is 0.97, so the profit is:

PS = (25-5)*0.48 - 2*0.97 - 0.6*0.97 - 0.0129*300

PS = 3.2

Therefore the profit generated for the ore in the stock pile is greater than the profit for the ore in the mine. We are going to send to the concentrator 0.97 tons from the stock pile and 49.03 tons from the push back in year 8. The total profit for year 8 is:

245 - 2.54 + 3.208 = 245.7

The next step is to subtract the ore sent to the concentrator from the stock pile and to subtract from the push back the total material mined and the material sent to the concentrator. When we subtract the tonnage from the push back, the material corresponding to the intervals 0.41-0.49 and 0.49-0.50 is sent to the stock pile. For example, we subtract the material sent to the concentrator from intervals 0.50-0.60 to 0.9-1.0 and subtract material to sent to the waste dump from the interval 0.-0.1 to 0.49-0.50. Therefore, the material corresponding to the intervals 0.41-0.49 and 0.49-0.50 is sent to the stock pile.

We subtract from the push back:

50 - 0.97 = 49.03 tons Conc.

97.2 - 49.03 = 47.2 tons total material.

Now the amount subtracted from the interval 0.41-0.49 in the push back is:

(24/150)*47.2 = 7.6 tons.

And from the interval 0.49-0.50:

(3/150)*47.2 = 0.94 tons.

Thus, we send to the stock pile 7.6 tons from the interval 0.41-0.49 and 0.94 tons from the interval 0.49-0.50.

The situation at the end of year 8 in the stock pile

is:

GRADE	TONNAGE
0.41-0.49	69.82
0.49-0.50	7.75

Following the same procedure we can get the next year, as shown in Table 11. At the end of the push back, we will consider the material remaining in the stock pile as a new push back. That means we have to determine the balancing cutoff grades and the economical cutoff grades in the same way as was explained in Section 3.3.

4.4 COMPUTER PROGRAM FOR THE PROPOSED ALTERNATIVE

In order to apply the developed algorithm, a computer program (SP.FOR) was written using Fortran 77 for an IBM AT computer. The computer code of this program is in Appendix C. This program requires 37 Kb of main memory. The execution time is about two minutes.

In order to establish a comparison with the other alternatives, the program was run for the same example.

INPUT DATA: The input data for the SP.FOR program is shown in Table 12. The data is basically the same data set used by the COG.FOR program. The difference is that we have added a new cost corresponding to that of handling the stock pile, and we have added two more intervals in the grade distribution which in this case, correspond to the

Table 11. Output for the Manual Example

YEAR	COG	QM	QC	QR	PROF	NPV
1.	.50	100.0	50.0	37.5	250.0	1258.8
2.	.50	100.0	50.0	37.5	250.0	1196.4
3.	.50	100.0	50.0	37.5	250.0	1126.1
4.	.50	100.0	50.0	37.5	250.0	1044.9
5.	.50	100.0	50.0	37.5	250.0	952.0
6.	.50	100.0	50.0	37.5	250.0	842.6
7.	.50	100.0	50.0	37.5	250.0	721.4
8.	.49	96.0	49.0	36.6	242.5	597.5
8.*	.49	1.0	1.0	.5	3.2	597.5
9.	.46	89.2	46.2	34.6	228.2	420.9
9.*	.46	3.8	3.8	1.9	12.3	420.9
10.	.44	83.2	44.2	33.2	215.5	243.6
10.*	.44	5.8	5.8	2.7	16.8	243.6
11.	.41	21.0	13.0	8.8	55.0	52.7

*: Material from the stock pile.

Table 12. Input Data for the SP.FOR Program

Grade Categories %	Pit Increments in Mining Sequence 1	2	3	4	5	6
0.00 - 0.15	14.4	15.9	17.9	20.3	23.4	27.7
0.15 - 0.20	4.6	5.1	5.5	6.3	7.2	8.3
0.20 - 0.23	1.76	1.96	2.16	2.4	2.68	3.08
0.23 - 0.25	2.64	2.94	3.24	3.6	4.02	4.62
0.25 - 0.30	4.3	4.7	5.3	5.6	6.4	7.3
0.30 - 0.35	4.2	4.5	4.9	5.5	6.2	6.7
0.35 - 0.40	4.1	4.4	4.7	5.3	5.6	6.3
0.40 - 0.45	3.9	4.3	4.6	4.9	5.4	5.7
0.45 - 0.50	3.8	4.1	4.5	4.8	5.1	5.3
0.50 - 0.55	3.7	3.9	4.2	4.5	4.6	4.7
0.55 - 0.60	3.6	3.8	3.9	4.2	4.4	4.3
0.60 - 0.65	3.4	3.6	3.8	3.9	4.0	3.7
0.65 - 0.70	3.3	3.5	3.7	3.7	3.6	3.3
+.70	42.3	37.5	31.6	25.0	17.4	9.0
Average % Mineral	1.13	1.07	1.00	0.93	0.87	0.80

Capacities:

Mine	20 million tons material/year
Mill	10 million tons ore/year
Refinery	90.000 tons product/year

Costs:

Mining	0.50 $/ton of material from pit
Stock Pile	0.225 $/ton.
Mill	0.60 $/ton of ore to mill
Refining	50.0 $/ton of product
Fixed charges	4 million $/year
Selling price	550 $/ton of product
Recovery	90 %

intervals 0.20-0.23 and 0.23-0.25.

OUTPUT: Table 13 shows part of the output of this program. The total list of the output is shown in Appendix D. The list in Appendix D shows the situation of the stock pile year by year and shows the grade distribution and tonnages. Table 13 also shows the final schedule with a statement of the optimum cutoff grade for each year and the production scheduling through the life of the project.

4.5 SENSITIVITY ANALYSIS REGARDING STOCK PILE COST

To examine the sensitivity of the stock pile option to cost variations, a sensitivity analysis was performed. The program was run for the following stock piling costs:

a.- 0.25 $/ton

b.- 0.30 $/ton

c.- 0.35 $/ton

d.- 0.40 $/ton

The results of the program for these costs are given in Tables 14, 15, 16 and 17.

Considering the cost for the stock pile and the undiscounted profit for the four alternatives studied, we constructed Table 18. The percentage of variation with respect to the original cost is shown in relative terms.

Table 13. Final Schedule Considering the Stock Pile

YEAR	INC	COG	QM	QC	QR	PROF	U.PRF	NPV
1.	1.00	.50	17.8	10.0	89.8	26.0	528.4	150.56
2.	1.00	.50	17.8	10.0	89.8	26.0	502.4	147.13
3.	1.00	.50	17.8	10.0	89.8	26.0	476.4	143.19
4.	1.00	.50	17.8	10.0	89.8	26.0	450.4	138.66
5.	1.00	.50	17.8	10.0	89.8	26.0	424.4	133.45
6.	1.00	.50	11.2	6.3	56.6	16.4	398.4	127.46
6.	2.00	.53	7.4	3.7	31.8	8.5	382.0	127.46
7.	2.00	.53	20.0	10.0	85.9	23.0	373.5	121.69
8.	2.00	.53	20.0	10.0	85.9	23.0	350.5	116.97
9.	2.00	.53	20.0	10.0	85.9	23.0	327.5	111.55
10.	2.00	.53	20.0	10.0	85.9	23.0	304.5	105.31
11.	2.00	.53	12.8	6.4	55.0	14.7	281.5	98.14
11.	3.00	.47	7.2	3.6	27.4	6.5	266.8	98.14
12.	3.00	.47	20.0	10.0	76.1	18.0	260.3	91.66
13.	3.00	.47	20.0	10.0	76.1	18.0	242.3	87.36
14.	3.00	.47	20.0	10.0	76.1	18.0	224.3	82.42
15.	****	.47	1.0	10.0	4.6	1.2	206.3	76.73
15.	3.00	.47	18.7	9.0	71.5	17.2	205.1	76.73
16.	3.00	.47	13.1	6.4	48.8	11.4	187.9	69.82
16.	4.00	.41	6.9	3.5	23.1	4.6	176.5	69.82
17.	4.00	.41	20.0	10.0	66.5	13.2	171.9	64.28
18.	4.00	.41	20.0	10.0	66.5	13.2	158.7	60.70
19.	4.00	.41	20.0	10.0	66.5	13.2	145.5	56.57
20.	****	.41	2.2	2.2	9.2	2.2	132.3	51.83
20.	4.00	.41	17.3	7.8	57.0	11.7	130.1	51.83
21.	4.00	.41	13.6	6.6	43.8	8.4	118.4	45.64
21.	5.00	.35	6.4	3.2	18.3	2.8	110.0	45.64
22.	5.00	.35	20.0	10.0	57.2	8.6	107.2	41.35
23.	5.00	.35	20.0	10.0	57.2	8.6	98.6	38.94
24.	5.00	.35	20.0	10.0	57.2	8.6	90.0	36.17
25.	****	.35	3.7	3.7	15.4	3.7	81.4	32.98
25.	5.00	.35	15.6	6.3	42.5	6.6	77.7	32.98
26.	5.00	.35	14.7	7.2	40.5	5.6	71.1	27.60
26.	6.00	.29	5.3	2.6	12.6	1.0	65.5	27.60
27.	6.00	.29	20.0	10.0	47.6	3.8	64.5	25.08
28.	6.00	.29	20.0	10.0	47.6	3.8	60.7	25.03
29.	6.00	.29	20.0	10.0	47.6	3.8	56.9	24.98
30.	****	.29	5.5	5.5	18.8	3.6	53.1	24.91
30.	6.00	.29	13.6	4.5	27.6	1.6	49.5	24.91
31.	6.00	.29	16.0	7.8	36.7	2.5	47.9	23.50
31.	****	.31	2.2	2.2	6.8	.8	45.6	23.50
32.	****	.31	10.0	10.0	36.5	6.0	44.6	23.79
33.	****	.30	10.0	10.0	36.5	6.0	38.6	21.36
34.	****	.29	10.0	10.0	35.1	5.3	32.6	18.57

Table 13 Cont..

35.	****	.28	10.0	10.0	34.5	5.0	27.3	16.05
36.	****	.27	10.0	10.0	33.7	4.6	22.3	13.47
37.	****	.27	10.0	10.0	32.9	4.2	17.7	10.90
38.	****	.26	10.0	10.0	30.8	3.1	13.5	8.35
39.	****	.25	10.0	10.0	29.0	2.3	10.4	6.45
40.	****	.24	10.0	10.0	27.2	1.4	8.1	5.17
41.	****	.23	10.0	10.0	27.2	1.4	6.7	4.58
42.	****	.23	10.0	10.0	27.2	1.4	5.3	3.91
43.	****	.23	10.0	10.0	28.2	1.9	3.9	3.13
44.	****	.23	8.2	8.2	24.2	2.0	2.0	1.74

****:MINERAL FROM STOCK PILE

Table 14. Schedule With Stock Pile Cost: 0.25 $/ton

YEAR	INC	COG	QM	QC	QR	PROF	U.PRF	NPV
1.	1.00	.50	17.8	10.0	89.8	26.0	524.4	150.52
2.	1.00	.50	17.8	10.0	89.8	26.0	498.4	147.09
3.	1.00	.50	17.8	10.0	89.8	26.0	472.4	143.15
4.	1.00	.50	17.8	10.0	89.8	26.0	446.4	138.61
5.	1.00	.50	17.8	10.0	89.8	26.0	420.4	133.39
6.	1.00	.50	11.2	6.3	56.6	16.4	394.4	127.39
6.	2.00	.53	7.4	3.7	31.8	8.5	378.0	127.39
7.	2.00	.53	20.0	10.0	85.9	23.0	369.5	121.61
8.	2.00	.53	20.0	10.0	85.9	23.0	346.5	116.88
9.	2.00	.53	20.0	10.0	85.9	23.0	323.5	111.45
10.	2.00	.53	20.0	10.0	85.9	23.0	300.5	105.19
11.	2.00	.53	12.8	6.4	55.0	14.7	277.5	98.00
11.	3.00	.47	7.2	3.6	27.4	6.5	262.8	98.00
12.	3.00	.47	20.0	10.0	76.1	18.0	256.3	91.51
13.	3.00	.47	20.0	10.0	76.1	18.0	238.3	87.18
14.	3.00	.47	20.0	10.0	76.1	18.0	220.3	82.21
15.	****	.47	1.0	1.0	4.6	1.2	202.3	76.49
15.	3.00	.47	18.7	9.0	71.5	17.2	201.1	76.49
16.	3.00	.47	13.1	6.4	48.8	11.4	183.9	69.57
16.	4.00	.41	6.9	3.5	23.1	4.6	172.5	69.57
17.	4.00	.41	20.0	10.0	66.5	13.2	167.9	63.99
18.	4.00	.41	20.0	10.0	66.5	13.2	154.7	60.36
19.	4.00	.41	20.0	10.0	66.5	13.2	141.5	56.19
20.	****	.41	2.2	2.2	9.2	2.2	128.3	51.39
20.	4.00	.41	17.3	7.8	57.0	11.7	126.1	51.39
21.	4.00	.41	13.6	6.6	43.8	8.4	114.4	45.19
21.	5.00	.35	6.4	3.2	18.3	2.8	106.0	45.19
22.	5.00	.35	20.0	10.0	57.2	8.6	103.2	40.83
23.	5.00	.35	20.0	10.0	57.2	8.6	94.6	38.34
24.	5.00	.35	20.0	10.0	57.2	8.6	86.0	35.49
25.	****	.35	3.7	3.7	15.4	3.6	77.4	32.20
25.	5.00	.35	15.6	6.3	42.5	6.6	73.8	32.20
26.	5.00	.35	14.7	7.2	40.5	5.6	67.2	26.79
26.	6.00	.29	5.3	2.6	12.6	1.0	61.6	26.79
27.	6.00	.29	20.0	10.0	47.6	3.8	60.6	24.15
28.	6.00	.29	20.0	10.0	47.6	3.8	56.8	23.96
29.	6.00	.29	20.0	10.0	47.6	3.8	53.0	23.74
30.	****	.29	5.5	5.5	18.8	3.4	49.2	23.49
30.	6.00	.29	13.6	4.5	27.6	1.6	45.8	23.49
31.	6.00	.29	16.0	7.8	36.7	2.5	44.2	22.01
31.	****	.31	2.2	2.2	6.8	.7	41.7	22.01
32.	****	.31	10.0	10.0	36.5	5.7	41.0	22.13
33.	****	.30	10.0	10.0	36.0	5.5	35.3	19.70
34.	****	.29	10.0	10.0	34.8	4.9	29.8	17.15
35.	****	.28	10.0	10.0	34.8	4.9	24.9	14.84

Table 14 Cont..

36.	****	.27	10.0	10.0	33.4	4.2	20.0	12.19
37.	****	.26	10.0	10.0	32.6	3.8	15.8	9.84
38.	****	.25	10.0	10.0	31.0	3.0	12.0	7.49
39.	****	.24	10.0	10.0	27.7	1.3	9.0	5.60
40.	****	.24	10.0	10.0	27.7	1.3	7.7	5.09
41.	****	.23	10.0	10.0	27.7	1.3	6.4	4.51
42.	****	.23	10.0	10.0	27.7	1.3	5.1	3.84
43.	****	.23	10.0	10.0	28.7	1.8	3.8	3.07
44.	****	.22	8.2	8.2	24.5	2.0	2.0	1.70

****:MINERAL FROM STOCK PILE

Table 15. Schedule With Stock Pile Cost: 0.30 $/ton

YEAR	INC	COG	QM	QC	QR	PROF	U.PRF	NPV
1.	1.00	.50	17.8	10.0	89.8	26.0	523.7	150.49
2.	1.00	.50	17.8	10.0	89.8	26.0	497.7	147.05
3.	1.00	.50	17.8	10.0	89.8	26.0	471.7	143.09
4.	1.00	.50	17.8	10.0	89.8	26.0	445.7	138.55
5.	1.00	.50	17.8	10.0	89.8	26.0	419.7	133.32
6.	1.00	.50	11.2	6.3	56.6	16.4	393.7	127.31
6.	2.00	.53	7.4	3.7	31.8	8.5	377.3	127.31
7.	2.00	.53	20.0	10.0	85.9	23.0	368.8	121.52
8.	2.00	.53	20.0	10.0	85.9	23.0	345.8	116.78
9.	2.00	.53	20.0	10.0	85.9	23.0	322.8	111.33
10.	2.00	.53	20.0	10.0	85.9	23.0	299.8	105.06
11.	2.00	.53	12.8	6.4	55.0	14.7	276.8	97.84
11.	3.00	.47	7.2	3.6	27.4	6.5	262.1	97.84
12.	3.00	.47	20.0	10.0	76.1	18.0	255.6	91.32
13.	3.00	.47	20.0	10.0	76.1	18.0	237.6	86.97
14.	3.00	.47	20.0	10.0	76.1	18.0	219.6	81.97
15.	****	.47	1.0	1.0	4.6	1.1	201.6	76.22
15.	3.00	.47	18.7	9.0	71.5	17.2	200.5	76.22
16.	3.00	.47	13.1	6.4	48.8	11.4	183.3	69.30
16.	4.00	.41	6.9	3.5	23.1	4.6	171.9	69.30
17.	4.00	.41	20.0	10.0	66.5	13.2	167.3	63.69
18.	4.00	.41	20.0	10.0	66.5	13.2	154.1	60.01
19.	4.00	.41	20.0	10.0	66.5	13.2	140.9	55.78
20.	****	.41	2.2	2.2	9.2	2.1	127.7	50.92
20.	4.00	.41	17.3	7.8	57.0	11.7	125.6	50.92
21.	4.00	.41	13.6	6.6	43.8	8.4	113.9	44.76
21.	5.00	.35	6.4	3.2	18.3	2.8	105.5	44.76
22.	5.00	.35	20.0	10.0	57.2	8.6	102.7	40.34
23.	5.00	.35	20.0	10.0	57.2	8.6	94.1	37.78
24.	5.00	.35	20.0	10.0	57.2	8.6	85.5	34.84
25.	****	.35	3.7	3.7	15.4	3.4	76.9	31.45
25.	5.00	.35	15.6	6.3	42.5	6.6	73.5	31.45
26.	5.00	.35	14.7	7.2	40.5	5.6	66.9	26.12
26.	6.00	.29	5.3	2.6	12.6	1.0	61.3	26.12
27.	6.00	.29	20.0	10.0	47.6	3.8	60.3	23.38
28.	6.00	.29	20.0	10.0	47.6	3.8	56.5	23.08
29.	6.00	.29	20.0	10.0	47.6	3.8	52.7	22.73
30.	****	.29	5.5	5.5	18.8	3.2	48.9	22.32
30.	6.00	.29	13.6	4.5	27.6	1.6	45.7	22.32
31.	6.00	.29	16.0	7.8	36.7	2.5	44.1	20.94
31.	****	.30	2.2	2.2	6.8	.6	41.6	20.94
32.	****	.30	10.0	10.0	36.1	5.0	41.0	21.01
33.	****	.29	10.0	10.0	35.3	4.6	36.0	19.12
34.	****	.28	10.0	10.0	34.1	4.1	31.4	17.36

Table 15 Cont..

35.	****	.28	10.0	10.0	34.4	4.2	27.3	15.89
36.	****	.28	10.0	10.0	34.6	4.3	23.1	14.06
37.	****	.27	10.0	10.0	34.8	4.4	18.8	11.90
38.	****	.27	10.0	10.0	33.7	3.8	14.4	9.26
39.	****	.26	10.0	10.0	32.2	3.1	10.6	6.80
40.	****	.24	10.0	10.0	28.6	1.3	7.5	4.72
41.	****	.24	10.0	10.0	28.6	1.3	6.2	4.14
42.	****	.23	10.0	10.0	28.6	1.3	4.9	3.48
43.	****	.23	10.0	10.0	28.6	1.3	3.6	2.73
44.	****	.23	10.0	10.0	28.6	1.3	2.3	1.85
45.	****	.23	7.7	7.7	21.9	1.0	1.0	.85

****:MINERAL FROM STOCK PILE

Table 16. Schedule With Stock Pile Cost: 0.35 $/ton

YEAR	INC	COG	QM	QC	QR	PROF	U.PRF	NPV
1.	1.00	.50	17.8	10.0	89.8	26.0	512.5	150.39
2.	1.00	.50	17.8	10.0	89.8	26.0	486.5	146.94
3.	1.00	.50	17.8	10.0	89.8	26.0	460.5	142.97
4.	1.00	.50	17.8	10.0	89.8	26.0	434.5	138.40
5.	1.00	.50	17.8	10.0	89.8	26.0	408.5	133.15
6.	1.00	.50	11.2	6.3	56.6	16.4	382.5	127.11
6.	2.00	.53	7.4	3.7	31.8	8.5	366.1	127.11
7.	2.00	.53	20.0	10.0	85.9	23.0	357.6	121.29
8.	2.00	.53	20.0	10.0	85.9	23.0	334.6	116.52
9.	2.00	.53	20.0	10.0	85.9	23.0	311.6	111.03
10.	2.00	.53	20.0	10.0	85.9	23.0	288.6	104.71
11.	2.00	.53	12.8	6.4	55.0	14.7	265.6	97.45
11.	3.00	.47	7.2	3.6	27.4	6.5	250.9	97.45
12.	3.00	.47	20.0	10.0	76.1	18.0	244.4	90.87
13.	3.00	.47	20.0	10.0	76.1	18.0	226.4	86.45
14.	3.00	.47	20.0	10.0	76.1	18.0	208.4	81.37
15.	****	.47	1.0	1.0	4.6	1.1	190.4	75.53
15.	3.00	.47	18.7	9.0	71.5	17.2	189.3	75.53
16.	3.00	.47	13.1	6.4	48.8	11.4	172.1	68.56
16.	4.00	.41	6.9	3.5	23.1	4.6	160.7	68.56
17.	4.00	.41	20.0	10.0	66.5	13.2	156.1	62.84
18.	4.00	.41	20.0	10.0	66.5	13.2	142.9	59.03
19.	4.00	.41	20.0	10.0	66.5	13.2	129.7	54.66
20.	****	.41	2.2	2.2	9.2	1.9	116.5	49.63
20.	4.00	.41	17.3	7.8	57.0	11.7	114.6	49.63
21.	4.00	.41	13.6	6.6	43.8	8.4	102.9	43.39
21.	5.00	.35	6.4	3.2	18.3	2.8	94.5	43.39
22.	5.00	.35	20.0	10.0	57.2	8.6	91.7	38.76
23.	5.00	.35	20.0	10.0	57.2	8.6	83.1	35.96
24.	5.00	.35	20.0	10.0	57.2	8.6	74.5	32.75
25.	****	.35	3.7	3.7	15.4	3.3	65.9	29.05
25.	5.00	.35	15.6	6.3	42.5	6.6	62.6	29.05
26.	5.00	.35	14.7	7.2	40.5	5.6	56.0	23.54
26.	6.00	.29	5.3	2.6	12.6	1.0	50.4	23.54
27.	6.00	.29	20.0	10.0	47.6	3.8	49.4	20.42
28.	6.00	.29	20.0	10.0	47.6	3.8	45.6	19.67
29.	6.00	.29	20.0	10.0	47.6	3.8	41.8	18.81
30.	****	.29	5.5	5.5	18.8	2.9	38.0	17.82
30.	6.00	.29	13.6	4.5	27.6	1.6	35.1	17.82
31.	6.00	.29	16.0	7.8	36.7	2.5	33.5	16.03
31.	****	.29	2.2	2.2	6.8	.5	31.0	16.03
32.	****	.29	10.0	10.0	35.0	4.0	30.5	15.47
33.	****	.28	10.0	10.0	34.7	3.9	26.5	13.78

Table 16 Cont..

34.	****	.27	10.0	10.0	33.6	3.3	22.6	11.98
35.	****	.27	10.0	10.0	33.6	3.3	19.3	10.50
36.	****	.26	10.0	10.0	32.4	2.7	16.0	8.77
37.	****	.26	10.0	10.0	32.5	2.7	13.3	7.36
38.	****	.24	10.0	10.0	29.3	1.1	10.6	5.74
39.	****	.24	10.0	10.0	29.3	1.1	9.5	5.47
40.	****	.23	10.0	10.0	29.3	1.1	8.4	5.16
41.	****	.23	10.0	10.0	29.3	1.2	7.3	4.79
42.	****	.23	10.0	10.0	29.4	1.2	6.1	4.34
43.	****	.23	10.0	10.0	30.2	1.6	4.9	3.81
44.	****	.23	10.0	10.0	31.1	2.0	3.3	2.77
45.	****	.22	2.8	2.8	10.1	1.3	1.3	1.15

****:MINERAL FROM STOCK PILE

Table 17. Schedule With Stock Pile Cost: 0.40 $/ton

YEAR	INC	COG	QM	QC	QR	PROF	U.PRF	NPV
1.	1.00	.50	17.8	10.0	89.8	26.0	511.8	150.34
2.	1.00	.50	17.8	10.0	89.8	26.0	485.8	146.88
3.	1.00	.50	17.8	10.0	89.8	26.0	459.8	142.90
4.	1.00	.50	17.8	10.0	89.8	26.0	433.8	138.32
5.	1.00	.50	17.8	10.0	89.8	26.0	407.8	133.06
6.	1.00	.50	11.2	6.3	56.6	16.4	381.8	127.01
6.	2.00	.53	7.4	3.7	31.8	8.5	365.4	127.01
7.	2.00	.53	20.0	10.0	85.9	23.0	356.9	121.17
8.	2.00	.53	20.0	10.0	85.9	23.0	333.9	116.38
9.	2.00	.53	20.0	10.0	85.9	23.0	310.9	110.87
10.	2.00	.53	20.0	10.0	85.9	23.0	287.9	104.53
11.	2.00	.53	12.8	6.4	55.0	14.7	264.9	97.24
11.	3.00	.47	7.2	3.6	27.4	6.5	250.2	97.24
12.	3.00	.47	20.0	10.0	76.1	18.0	243.7	90.63
13.	3.00	.47	20.0	10.0	76.1	18.0	225.7	86.18
14.	3.00	.47	20.0	10.0	76.1	18.0	207.7	81.05
15.	****	.47	1.0	1.0	4.6	1.0	189.7	75.16
15.	3.00	.47	18.7	9.0	71.4	17.2	188.7	75.16
16.	3.00	.47	13.1	6.4	48.9	11.4	171.5	68.20
16.	4.00	.41	6.9	3.5	23.0	4.6	160.1	68.20
17.	4.00	.41	20.0	10.0	66.5	13.2	155.5	62.41
18.	4.00	.41	20.0	10.0	66.5	13.2	142.3	58.55
19.	4.00	.41	20.0	10.0	66.5	13.2	129.1	54.10
20.	****	.41	2.2	2.2	9.2	1.8	115.9	48.99
20.	4.00	.41	17.3	7.8	57.0	11.7	114.1	48.99
21.	4.00	.41	13.6	6.6	43.9	8.4	102.4	42.76
21.	5.00	.35	6.4	3.2	18.2	2.7	94.0	42.76
22.	5.00	.35	20.0	10.0	57.2	8.6	91.3	38.04
23.	5.00	.35	20.0	10.0	57.2	8.6	82.7	35.13
24.	5.00	.35	20.0	10.0	57.2	8.6	74.1	31.79
25.	****	.35	3.7	3.7	15.4	3.1	65.5	27.95
25.	5.00	.35	15.6	6.3	42.5	6.6	62.4	27.95
26.	5.00	.35	14.7	7.2	40.5	5.7	55.8	22.47
26.	6.00	.29	5.3	2.6	12.6	1.0	50.1	22.47
27.	6.00	.29	20.0	10.0	47.6	3.8	49.1	19.18
28.	6.00	.29	20.0	10.0	47.6	3.8	45.3	18.24
29.	6.00	.29	20.0	10.0	47.6	3.8	41.5	17.17
30.	****	.29	5.5	5.5	18.8	2.6	37.7	15.93
30.	6.00	.29	13.6	4.5	27.6	1.6	35.1	15.93
31.	6.00	.29	16.0	7.8	36.7	2.5	33.5	14.15
31.	****	.27	2.2	2.2	6.6	.4	31.0	14.15
32.	****	.27	10.0	10.0	33.5	2.7	30.6	13.46
33.	****	.26	10.0	10.0	32.7	2.3	27.9	12.74

Table 17 Cont..

34.	****	.26	10.0	10.0	32.7	2.3	25.6	12.33
35.	****	.26	10.0	10.0	33.0	2.5	23.3	11.83
36.	****	.26	10.0	10.0	33.3	2.6	20.8	11.09
37.	****	.26	10.0	10.0	33.4	2.7	18.2	10.10
38.	****	.24	10.0	10.0	30.4	1.2	15.5	8.90
39.	****	.26	10.0	10.0	34.6	3.3	14.3	9.03
40.	****	.24	10.0	10.0	30.8	1.4	11.0	7.10
41.	****	.26	10.0	10.0	35.5	3.8	9.6	6.74
42.	****	.24	10.0	10.0	30.7	1.4	5.8	3.99
43.	****	.23	10.0	10.0	30.7	1.4	4.4	3.22
44.	****	.23	10.0	10.0	30.7	1.4	3.0	2.34
45.	****	.23	10.0	10.0	30.7	1.4	1.6	1.33
46.	****	.22	1.4	1.4	4.2	.2	0.2	.16

****:MINERAL FROM STOCK PILE

Table 18. Output From the Sensitivity Analysis

COST	UNDISCOUNTED PROFIT ($)	PERCENTAGE COST %	VARIATION OUTPUT %
0.225	528.4	.0	.0
0.250	524.4	11.1	0.76
0.300	523.7	33.3	0.89
0.350	512.5	56.	3.0
0.400	511.8	78.	3.1

From Table 18, we can see that the undiscounted profit is not very sensitive to the cost of the stock pile. For example, if we consider the cost to be $0.35 per ton, the cost represents a variation of 56% with respect to the original cost used, $0.225 per ton. The undiscounted profit of $512.5 has a variation of only 3% with respect to the original undiscounted profit for the stock pile. When we used a cost of $0.40 per ton we got a net present value for the stock pile alternative of $150.34 which is almost the same value we get from Lane's algorithm. However, we have to consider that $0.40 per ton, the cost of stock pile, corresponds to 80% of the total mining cost. We consider that the cost of stock pile should not be greater than 50% of the total mining cost.

CHAPTER 5

OTHER ALTERNATIVES FOR HANDLING STOCK PILES

Starting from Lane's algorithm it is possible to create a couple of alternatives in addition to the proposed alternative described in Chapter 4. These additional alternatives are described in detail in this chapter. To facilitate the comparison, the same input data were used. The method used to create the stock pile is exactly the same as that described in Chapter 4. The difference between these alternatives and that described in Chapter 4 is in the way in which the comparison between the ore in the stock pile and the ore in the push back is established as well as when to send ore from the stock pile to the mill.

5.1 ALTERNATIVE B

In this alternative the analysis of whether or not to send material from the stock pile to the mill is repeated taking into account the profit generated by that material in the stock pile and the profit generated by the material in the push back.

If the profit for the ore in the stock pile is greater than the profit of the ore in the push back, the mill is fed with material exclusively coming from the stock pile. This is the difference between this alternative and that detailed

in Chapter 4. The material to feed the mill is sent either from the stock pile or from the push back, but not from both places simultaneously. In order to analyze this alternative, it was neccesary to make some modifications in the program SP.FOR.

As was explained previously the input data used was the same that was used in Chapter 4, that is, the data presented in Table 12. The output from this alternative is shown in Table 19.

5.2 ALTERNATIVE C

In this alternative, material is not sent to the mill from the stock pile during the mining of the push back. Material is stock piled until all the material in the push back is exhausted. Only at that moment does the stock pile start to work as if it was a new push back. Cutoff grades and production schedules are computed.

The input data is the same as in Chapter 4, that is, the data shown in Table 12. Table 20 shows the output for this alternative.

Table 19. Output for Alternative B

YEAR	INC	OCG	QM	QC	QR	PROF	U.PRF	NPV
1.	1.00	.50	17.8	10.0	89.8	26.0	515.5	150.41
2.	1.00	.50	17.8	10.0	89.8	26.0	489.5	146.96
3.	1.00	.50	17.8	10.0	89.8	26.0	463.5	142.99
4.	1.00	.50	17.8	10.0	89.8	26.0	437.5	138.43
5.	1.00	.50	17.8	10.0	89.8	26.0	411.5	133.18
6.	1.00	.50	11.2	6.3	56.6	16.4	385.5	127.15
6.	2.00	.53	7.4	3.7	31.8	8.5	369.1	127.15
7.	2.00	.53	20.0	10.0	85.9	23.0	360.6	121.34
8.	2.00	.53	20.0	10.0	85.9	23.0	337.6	116.57
9.	2.00	.53	20.0	10.0	85.9	23.0	314.6	111.09
10.	2.00	.53	20.0	10.0	85.9	23.0	291.6	104.78
11.	2.00	.53	12.8	6.4	55.0	14.7	268.6	97.53
11.	3.00	.47	7.2	3.6	27.4	6.5	253.9	97.53
12.	3.00	.47	20.0	10.0	76.1	18.0	247.4	90.96
13.	3.00	.47	20.0	10.0	76.1	18.0	229.4	86.56
14.	3.00	.47	20.0	10.0	76.1	18.0	211.4	81.49
15.	3.00	.47	20.0	10.0	76.1	18.0	193.0	75.67
16.	3.00	.45	12.8	6.6	49.6	11.8	175.4	68.97
16.	4.00	.45	6.	3.4	22.5	4.5	163.6	68.97
17.	4.00	.41	20.0	10.0	66.5	13.2	159.1	63.06
18.	4.00	.41	20.0	10.0	66.5	13.2	145.9	59.29
19.	4.00	.41	19.6	10.0	65.9	13.1	132.7	54.95
20.	4.00	.39	19.2	10.0	65.2	13.0	119.6	50.07
21.	4.00	.37	14.5	7.8	50.1	10.0	106.6	44.57
21.	5.00	.35	4.4	2.2	12.5	1.9	96.6	44.57
22.	5.00	.35	20.0	10.0	57.2	8.6	94.7	39.37
23.	5.00	.34	19.7	10.0	56.8	8.6	86.1	36.66
24.	5.00	.33	19.2	10.0	56.2	8.5	77.5	33.59
25.	5.00	.32	18.7	10.0	55.5	8.4	69.0	30.14
26.	5.00	.31	17.8	10.0	54.1	8.2	60.6	26.27
27.	5.00	.30	.3	.2	1.0	.2	52.4	22.04
27.	6.00	.29	19.6	9.8	46.7	3.7	52.2	22.04
28.	****	.26	10.0	10.0	32.4	4.0	48.5	21.46
29.	****	.26	10.0	10.0	32.4	4.0	44.5	20.72
30.	****	.26	10.0	10.0	32.4	4.0	40.5	19.87
31.	****	.26	10.0	10.0	32.4	4.0	36.5	18.90
32.	****	.26	10.0	10.0	32.4	4.0	32.5	17.78
33.	****	.26	10.0	10.0	32.4	4.0	28.5	16.50
34.	****	.26	10.0	10.0	32.4	4.0	24.5	15.02
35.	****	.26	10.0	10.0	32.4	4.0	20.5	13.31
36.	6.00	.26	18.2	10.0	45.6	3.7	16.5	11.36
37.	6.00	.25	17.8	10.0	45.6	3.6	12.8	9.37
38.	6.00	.25	17.5	10.0	44.7	3.6	9.2	7.14
39.	6.00	.24	16.4	10.0	43.3	3.4	5.6	4.62
40.	6.00	.23	10.5	6.4	27.7	2.2	2.2	1.89

****: MINERAL FROM STOCK PILE

Table 20. Output for Alternative C

YEAR	INC	COG	QM	QC	QR	PROF	U.PRF	NPV
1.	1.00	.50	17.8	10.0	89.8	26.0	529.6	150.46
2.	1.00	.50	17.8	10.0	89.8	26.0	503.6	147.01
3.	1.00	.50	17.8	10.0	89.8	26.0	477.6	143.06
4.	1.00	.50	17.8	10.0	89.8	26.0	451.6	138.50
5.	1.00	.50	17.8	10.0	89.8	26.0	425.6	133.27
6.	1.00	.50	11.2	6.3	56.6	16.4	399.6	127.25
6.	2.00	.53	7.4	3.7	31.8	8.5	383.2	127.25
7.	2.00	.53	20.0	10.0	85.9	23.0	374.7	121.45
8.	2.00	.53	20.0	10.0	85.9	23.0	351.7	116.70
9.	2.00	.53	20.0	10.0	85.9	23.0	328.7	111.24
10.	2.00	.53	20.0	10.0	85.9	23.0	305.7	104.95
11.	2.00	.53	12.8	6.4	55.0	14.7	282.7	97.73
11.	3.00	.47	7.2	3.6	27.4	6.5	268.0	97.73
12.	3.00	.47	20.0	10.0	76.1	18.0	261.5	91.19
13.	3.00	.47	20.0	10.0	76.1	18.0	243.5	86.82
14.	3.00	.47	20.0	10.0	76.1	18.0	225.5	81.79
15.	3.00	.47	20.0	10.0	76.1	18.0	207.5	76.01
16.	3.00	.45	12.8	6.7	49.8	11.8	189.5	69.36
16.	4.00	.41	6.7	3.3	22.2	4.4	177.7	69.36
17.	4.00	.41	20.0	10.0	66.5	13.2	173.2	63.52
18.	4.00	.41	20.0	10.0	66.5	13.2	160.1	59.82
19.	4.00	.40	19.5	10.0	65.6	13.1	146.9	55.57
20.	4.00	.38	18.8	10.0	64.6	12.9	133.8	50.82
21.	4.00	.36	15.1	8.5	53.4	10.7	120.9	45.55
21.	5.00	.35	3.0	1.5	8.6	1.3	110.2	45.55
22.	5.00	.34	19.5	10.0	56.5	8.5	108.9	40.43
23.	5.00	.33	19.0	10.0	55.9	8.4	100.4	37.95
24.	5.00	.32	18.5	10.0	55.1	8.3	92.0	35.20
25.	5.00	.30	17.8	10.0	54.1	8.2	83.7	32.14
26.	5.00	.29	17.3	10.0	53.4	8.0	75.5	28.79
27.	5.00	.27	5.0	3.0	15.8	2.4	67.5	25.07
27.	6.00	.27	13.1	7.0	32.4	2.6	65.1	25.07
28.	6.00	.26	18.3	10.0	45.8	3.7	62.5	23.85
29.	6.00	.26	17.8	10.0	45.0	3.6	58.8	23.72
30.	6.00	.25	17.7	10.0	44.9	3.6	55.2	23.65
31.	6.00	.24	17.1	10.0	44.2	3.5	51.6	23.57
32.	6.00	.23	15.9	9.7	42.0	3.3	48.1	23.57
32.	****	.30	.3	.3	.9	.1	44.8	23.57
33.	****	.30	10.0	10.0	36.2	5.8	44.7	23.69
34.	****	.30	10.0	10.0	35.4	5.4	38.9	21.41
35.	****	.29	10.0	10.0	34.9	5.2	33.5	19.18
36.	****	.28	10.0	10.0	33.9	4.7	28.3	16.87
37.	****	.27	10.0	10.0	34.4	4.9	23.6	14.70
38.	****	.27	10.0	10.0	33.3	4.4	18.7	11.97
39.	****	.26	10.0	10.0	31.7	3.6	14.3	9.35

Table 20 Cont..

40.	****	.25	10.0	10.0	29.8	2.6	10.7	7.14
41.	****	.24	10.0	10.0	27.6	1.6	8.1	5.58
42.	****	.23	10.0	10.0	27.9	1.7	6.5	4.86
43.	****	.23	10.0	10.0	28.5	2.0	4.8	3.87
44.	****	.23	9.7	9.7	29.3	2.8	2.8	2.42

****:MINERAL FROM STOCK PILE

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

To analyze the stock pile alternative, it was necessary to create a couple of computational programs. One program was designed to run the Lane algorithm and the other was designed to analyze the stock pile alternative. These programs are not very expensive in terms of computer memory storage, and they are fast in their execution time. This facilitates for the analysis of a large number of alternatives.

The stock pile should always be considered as an option in open pit mine planning. The contribution in the NPV due to the stock pile, depends upon each particular case. It depends especially upon the spread between the highest and the lowest grades in the project cutoff grade strategy. If that spread is significant, the stock pile will be a potential component to be considered for the project.

The alternative of adding a stock pile to the open pit mining system has been shown to generate a higher net present value than the method proposed by Lane. The difference in the values of the undiscounted summation of profits was significant for the two methods studied.

As we can see in Table 19, the NPV and the

undiscounted
profit for the alternative B (Chapter 5) is better than the system proposed by Lane (Chapter 3), but not as good as the alternative in Chapter 4. This is because the stock pile starts to send ore to the mill only in year 28. In the previous alternative, the first time that the stock pile sends ore to the mill is in year 15. Moreover, using material from the stock pile in years 28 through 35 means that almost all of the material in the stock pile is used. At the end of year 40, mining the remaining material in the stock pile is not economically profitable even though we have material in the stock pile between the grades of 0.23% and 0.26%.

Alternative C (Chapter 5) has a better net present value and a better undiscounted profit than the original Lane's algorithm. This alternative also has a slightly higher net present value than alternative B, but smaller than the alternative in Chapter 4.

From an operational point of view, this alternative has an advantage over the alternative in Chapter 4. It is not neccesary to blend material as in the production schedule generated by the alternative in Chapter 4 (Table 13), or to stop the production in mine for 8 years and start to produce again, as in alternative B.

Of the three methods studied for handling stock pile, the most convenient method from an operational point of view is alternative C. As was explained in Section 5.2.1, this alternative has the advantage that is not necessary to do a blending of material or to stop the production in some determined period of time.

Adding the stock pile to the system should not necessarily mean that problems will develop during loading, hauling and dumping operations, as was shown in Chapter 2. Since most major open pit mines have advanced systems to make the truck shovel assignments, the system should work in the same way as the previous system even if we add a new dumping point like the stock pile.

In addition to the economic reasons for using a stock pile, there are other reasons that are difficult to evaluate in an exact economic way. For example, if we are storing a given amount of reserves, we could think about reducing the safety factor to evaluate the slope stability. We could consider a bigger slope angle by taking into account that if anything occurs in the mine, we have mineral in stock to feed the mill. Also, we can reduce the number of main access roads, taking into account the prior considerations.

6.2 RECOMMENDATIONS

In this work we are assuming, that if a stock pile is

used we will employ a segregated stock pile. This means that we will create a series of dumps with different grades. It would be interesting to study the alternative of using only one dump. This could mean, determining a new lowest cutoff grade to identify which material will be sent to the stock pile, and then working with the average grade of the material in the stock pile. This makes the system more simple but it also means a reduction in the amount of material sent to the stock pile.

Another interesting point for future research related with the stock pile alternative is to study the variation of the cost and the selling price of the product through the life of the project instead of considering both parameters as fixed quantities, as was done in this work.

REFERENCES CITED

Beras, V.M., 1979, "General Theory of Cut Off Grade as Applied to Porphyry Copper Type Deposit". Ph.D. Dissertation, Colorado School of Mines, Golden Co.

Callaway, H.M., 1958, "Economic Relation of Mining Rate to Grade of Ore", Mining Engineering, April, 1958 pp. 470-472.

Espinoza, R., 1980, "Aplicaciones de Computacion a la Explotacion de Minas en Codelco Chile". Mineria de los Cobres Porfidicos Vol. I. pp. 363-398. Santiago de Chile, November, 1980.

Halls, J.L., Bellum, D.P., and Lewis, C.K., 1969, "Determination of Optimum Ore Reserves and Plant Size by Incremental Finantial Analysis", Transactions of the institute of mining and metallurgy, Section A: Mining Industry, Volume 78, 1969, p. A25.

Lane, K.F. 1964, "Choosing the optimum cut off grade", Colorado School of Mines Quarterly, Volume 59, 1964, pp. 811-829.

Lane, K.F., 1988, "The economic definition of ore, cut off grades in theory and practice", Mining Journal books limited, London, 1988

Lee, T.A.,1972, "The Mammoth Quarry, Stockpiles and Simulation", Application of the computers methods in the mineral industry: Proccedings of the tenth International Simposium, Johannesburg, 1972.

Manula, C.B., Kim, Y.C., 1967, "Optimum Production Planning", Society of Mining Egineers, Preprint No, 67AR34, February 1967.

Mason, P.M., 1984, "Capital and operational planning for open pit in a modern economy", 18th International Simposium application of computers and mathematics in the ineral industry, I.M.M, London, 1984.

Taylor, H.K., 1972, "General background theory of cutoff grades", Trans. Inst. Min. Metall. Section A Min. Industry, Volume 18, 1972, pp. A160-A179.

APPENDIX A

COMPUTER CODE COG.FOR PROGRAM

```
C     ************************************************
c     ************************************************
C     ** PROGRAM TO DETERMINE OPTIMUM CUT OFF GRADE    **
C     **          USING THE  LANE'S ALGORITHM          **
C     **                                               **
C     ** MADE BY:    MANUEL SCHELLMAN M.               **
C     **                                               **
C     **     COLORADO SCHOOL OF MINES                  **
C     **     OCTOBER 1989.                             **
C     **                                               **
c     ************************************************
C     ************************************************
      DIMENSION CUT(100),QC(100),C(30,30),YEAR(100),B(30,30)
      DIMENSION D1(30,30),PRF(100),TPE(100),PPV1(50)
      DIMENSION OPTM(100),QM2(100),QC2(100),QR2(100),TC(20)
      COMMON A(30,30),L1(100),T(100),DIF,OCG,A7,STOT
      COMMON POR,I,J,L,M,N,PRO,REF,REC,K2,E2(20,20),MAR2
      COMMON TP,TP1,TP2,TP3,P,PV,T1,D,CM,CP,CR,FC,COSM
      COMMON COSP,COSR,TNPV,CAM,CAP,CAR,TPA,PB,TB(20)
      COMMON TNPB,TNPC,TNPF
      COMMON/FRED/ STC,QC1,QM,QM1
      COMMON/BONG/ QMT,STC4,QM4,QC4,TP4,QR4,DTP,J1
      REAL L1,LP(100),MAY,NPV,NPV1(100),INC(100)
      REAL MED,NPF(100)
      DIMENSION QR(1000),VM(1000),VC(1000),VR(1000)
      OPEN(UNIT=10,FILE='DAT.DAT',STATUS='OLD')
      OPEN(UNIT=200,FILE='RES.RES',STATUS='NEW')
      READ(10,*)N,M
      DO 15 I=1,N
           READ(10,*)(A(I,J),J=1,M)
   15 CONTINUE
C     READ TON AND GRADES ABOVE THE INTERVALS
   16 DO 20 I=1,M
         READ(10,*)T(I),L1(I)
   20 CONTINUE
C     READ CAPACITIES, REF. INDEX, UPPER VALUE.
      READ(10,*)CM,CP,CR,IR,UPV
C  READ COST MINE PLANT REF FIXED COST SELL
C  PRICE REC DISC RATE
      READ(10,*)COSM,COSP,COSR,FC,PV,REC,D
      CALL INI1(M,T,TC,NC,N,MAR4,MAR3)
    4 CALL INI2(I4,I1,MAR2,A7,K1,MAR,N1,N)
      CALL ASIG(N,M,C,A,D1)
C  START MAIN LOOP
      CALL ASI2(CM,CP,CR,CAM,CAP,CAR)
      DO 800 J=3,M
        J1=1
        CALL BACUT(N1,A,CUT,QM,J,A7,T,QC,UPV)
```

```
C   FIGURE THE AVERAGE GRADE BY INTERVALS
        CALL AVRG(N1,A,J,QR,T,L1,A4,V)
C   FIGURE PRESENT VALUE MINE PLANT REF.
        CA=1.0E+08
        DO 75 I=1,N1
        VM(I)=((PV-COSR)*QR(I)*REC-COSP*QC(I)-(COSM+
     +  (FC+D*V)/CAM)*QM)/CA
        VC(I)=((PV-COSR)*QR(I)*REC-(COSP+(FC+D*V)/CAP)
     +  *QC(I)-COSM*QM)/CA
        VR(I)=((PV-COSR-(FC+D*V)/CAR)*QR(I)*REC-COSP*QC(I)
     +  -COSM*QM)/CA
   75   CONTINUE
C  FIND THE INTERSECCTION
        CALL MIPLA(N1,VM,VC,CUT,GMC1)
        CALL MIREF(N1,VM,VR,CUT,GMR1)
  111   CALL PLAREF(N1,VC,VR,CUT,GCR1)
C   FIGURE ECONOMIC CUT OFF GRADES
        IF(T(J).NE.0)THEN
          N1=N1-1
        ENDIF
        N=N1
  127   IF(MAR.EQ.0)THEN
          NPV=0
        ENDIF
        IF(MAR3.EQ.1) THEN
            NPV=NPV1(I4)*A7
        ENDIF
  128   V=NPV
        CALL SUMAT(N,A,J,A7,T,QM)
        GEM=(COSP/((PV-COSR)*REC))*100
        GEP=((COSP+(FC+D*V)/CAP)/((PV-COSR)*REC))*100
        GER=(COSP/((PV-COSR-(FC+D*V)/CAR)*REC))*100
        CALL ENOC(GMC1,GMR1,GCR1,GEM,GEP,GER,OCG,MED,CHU,IR)
        IF(MAR4.EQ.1) GOTO 171
        IF(MAR.EQ.0) THEN
            IF(CHU.LE.0.004) GOTO 1009
        ENDIF
  171   OCG=MED
        L=0
        MAR4=0
C  FIND THE INTERVAL FOR  COG
        DO 180 I=1,N
           IF(OCG.GE.A(I,1).AND.OCG.LT.A(I,2)) THEN
             L=I
             GOTO 184
           ELSE
             GOTO 180
           ENDIF
```

```
  180   CONTINUE
        IF(L.EQ.0) THEN
           DO 183 I=1,N
              IF(OCG.GT.A(I,1))  THEN
                  GOTO 183
              ELSE
                L=I
                GOTO 190
              ENDIF
  183       CONTINUE
        ENDIF
  184   DIF=ABS(A(L,1)-OCG)
  185   IF(DIF.LE.0.0001) GOTO 190
        A1=A(L,2)-A(L,1)
        A2=A(L,2)-OCG
           A3=A2/A1
           POR=1-A3
           GOTO 300
  190   CALL TONCON(L,N,A,J,A7,T,STC,REC,STREF,L1)
        GOTO 400
C   FIGURE NEW INTERVAL
  300   CALL CALINT(N,L,J,M,B,A,OCG,POR)
        LA=L+1
        CALL TONCON(LA,N,A,J,A7,T,STC,REC,STREF,L1)
C  FIGURE ANNUAL TONNAGES
  400   CALL TONA(QM,CM,STC,CP,STREF,CR,TP,QM1,QC1,QR1,IR)
        IF(TP.LT.1) THEN
           CALL ASI3(QM,STC,STREF,TP,QM1,QC1,QR1,T1)
        ELSE
           T1=1
        ENDIF
        IF(MAR.EQ.1)THEN
           TP=TA
           T1=TA
        ENDIF
C  DETERMINE PROFIT AND NPV
  492   P=(PV-COSR)*QR1-COSP*QC1-COSM*QM1-T1*FC
        IF(TP.LT.1) THEN
           NPV=P
        ELSE
           NPV=0
           CALL ASI3(QM,STC,QC1,QM1,QMT,STC4,QC4,QM4)
           TP4=TP
           PB=P
           MAR2=0
           CALL BONGO
           NPV=NPV+TNPB
        ENDIF
```

```
        IF(MAR.EQ.1)THEN
          CALL FREDE
          NPV=NPV+TNPF
          TP=TPA
        ENDIF
        CALL CALCTON
        NPV=NPV+TNPC
        IF(MAR.EQ.1)THEN
           TP=TA
        ENDIF
C  PRINT PARTIAL OUTPUT
 1009   CALL PRI1(MED,K1,J,GMC1,GMR1,GCR1,GEM,GEP,GER,OCG,
     +  QM1,A7,QC1,QR1,TP,P,NPV)
        REST=ABS(NPV-V)
        IF(REST.LE.0.009) THEN
           GOTO 500
        ENDIF
        IF(MAR.EQ.1) THEN
           GOTO 500
        ELSE
           CALL CAMB(M,N,A,D1)
        ENDIF
        IF(MAR3.EQ.1) GOTO 500
  495   IF(CHU.GT.0.005) THEN
           CALL CAMB(M,N,A,D1)
           IF(DIF.LE.0.0001) THEN
              GOTO 128
           ELSE
              N=N-1
              GOTO 128
           ENDIF
         ENDIF
C  STORAGE OPTIMUM RESULTS
  50  0  YEAR(I1)=K1
        TPE(I1)=K1
        INC(I1)=J-2
        OPTM(I1)=OCG
        QM2(I1)=QM1
        QC2(I1)=QC1
        QR2(I1)=QR1
        PRF(I1)=P
        NPV1(I1)=NPV
        I1=I1+1
        K1=K1+1
        IF(MAR.EQ.0)THEN
           IF(TP.LE.1) THEN
               GOTO 600
           ENDIF
```

```
        ELSE
           GOTO 551
        ENDIF
C  SUBTRACT THE TONNAGES BY INTERVALS
        CALL RESTA(OCG,A,L,J,N,STC,QC1,T,QM,QM1)
  551   CALL ASI2(CAM,CAP,CAR,CM,CP,CR)
        CALL CAMB(M,N,D1,A)
        MAR=0
        I4=I4+1
        MAR4=1
        GOTO 127
  60  0 K1=K1-1
        CALL ASI3(CM-QM1,CP-QC1,CR-QR1,1-TP,CM,CP,CR,TA)
        MAR=1
        CALL ASIG(N1,M,A,C,D1)
        I4=I4+1
        MAR4=1
  800 CONTINUE
      CALL PRI2(I1,QM2,A7,QC2,QR2,PRF,NPV1,YEAR,INC,OPTM,NPF)
      CALL ONPV(I1,TPE,NPV1,PRF,D)
      DO 2100 I=1,I1-1
         DOF=ABS(NPV1(I)-NPF(I))
         IF(DOF.LE.0.001) THEN
            GOTO 2100
         ELSE
            LA=I1-1
            CALL INTER(LA,NPF,NPV1)
            CALL CAMB(M,NC,A,C)
            CALL INTER(M,T,TC)
            CALL ASI2(CAM,CAP,CAR,CM,CP,CR)
            N=NC
            MAR3=1
            GOTO 4
         ENDIF
 2100 CONTINUE
      END
C*************************************************************
C     SUBROUTINE CALCTON
C   Figure out the contribution in the NPV for the increment
C   J+1 to N
C*************************************************************
      SUBROUTINE CALCTON
      COMMON A(30,30),L1(100),T(100),DIF,OCG,A7,STOT
      COMMON POR,I,J,L,M,N,PRO,REF,REC,K2,E2(20,20),MAR2
      COMMON TP,TP1,TP2,TP3,P,PV,T1,D,CM,CP,CR,FC,COSM
      COMMON COSP,COSR,TNPV,CAM,CAP,CAR,TPA,PB,TB(20)
      COMMON/BONG/QMT,STC4,QM4,QC4,TP4,QR4,DTP,J1
      COMMON TNPB,TNPC,TNPF
```

```
      DIMENSION  E1(20,20),TR(20)
      REAL L1,NP,NPA
      MAR2=1
      TE=TP
      MAR1=1
      TNP3=0
      CALL ASI3(1-DTP,CAM-QM4,CAP-QC4,CAR-QR4,TPA,CAM1,
     + CAP1,CAR1)
      CALL CAMB(M,N,E1,A)
      CALL INTER(M,TR,T)
      DO 1500 J1=J+1,M
        TE =TE+TPA
        IF(MAR1.EQ.1)GOTO 1190
1504    CALL RESTA(OCG,E1,L,J1,N,STCA,QC1A,TR,QMA,QM1A)
        TE=TE+0
1190    DIF=ABS(E1(L,1)-OCG)
        IF(DIF.GT.0.0001) GOTO 1330
        CALL TONCON(L,N,E1,J1,A7,TR,STCA,REC,STAREF,L1)
        CALL SUMAT(N,E1,J1,A7,TR,QMA)
        GOTO 1459
1330    LA=L+1
        CALL TONCON(LA,N,E1,J1,A7,TR,STCA,REC,STAREF,L1)
        CALL SUMAT(N,E1,J1,A7,TR,QMA)
1459    CALL TONA(QMA,CAM1,STCA,CAP1,STAREF,CAR1,TPA,QM1A,
       +QC1A,QR1A,IR)
        IF(MAR1.EQ.1) THEN
           T1=1-DTP
        ELSE
           T1=1
        ENDIF
1492    PA=(PV-COSR)*QR1A-COSP*QC1A-COSM*QM1A-T1*FC
        IF(PA.LE.0) THEN
          PA=0
        ENDIF
        IF(MAR1.EQ.1) THEN
           NP=PA
1493       NPA=NP/(1+D)**TE
        ENDIF
        IF(MAR1.EQ.1) THEN
           CALL ASI2(CAM,CAP,CAR,CAM1,CAP1,CAR1)
           MAR1=0
           TNP3=TNP3+NPA
           GOTO 1504
        ELSE
           CALL ASI2(QM1A,STCA,TPA,QM4,STC4,TP4)
           CALL ASI2(QMA,QC1A,PA,QMT,QC4,PB)
           CALL CAMB(M,N,E2,E1)
           CALL INTER(M,TB,TR)
```

```
            CALL BONGO
            ES=TNPB
            ES=ES/(1+D)**TE
            TNP3=TNP3+ES
            CALL ASI2(CAM-QM4,CAP-QC4,CAR-QR4,CAM1,CAP1,CAR1)
            TE=TE+TPA
            TPA=1-DTP
            MAR1=1
          ENDIF
 1500 CONTINUE
      TNPC=TNP3
      RETURN
      END
C  ***************************************************
C     SUBROUTINE FREDE
C  It is used when begin the develop of a new increment
C  ***************************************************
      SUBROUTINE FREDE
      COMMON A(30,30),L1(100),T(100),DIF,OCG,A7,STOT
      COMMON POR,I,J,L,M,N,PRO,REF,REC,K2,E2(20,20),MAR2
      COMMON TP,TP1,TP2,TP3,P,PV,T1,D,CM,CP,CR,FC,COSM
      COMMON COSP,COSR,TNPV,CAM,CAP,CAR,TPA,PB,TB(20)
      COMMON /FRED/ STC,QC1,QM,QM1
      COMMON/BONG/QMT,STC4,QM4,QC4,TP4,QR4,DTP,J1
      COMMON TNPB,TNPC,TNPF
      REAL L1,NP,NPA
      MAR2=0
      CALL RESTA(OCG,A,L,J,N,STC,QC1,T,QM,QM1)
      TE=TP
      TPA=0
      TNP4=0
      J1=J
      TE =TE+TPA
      DIF=ABS(A(L,1)-OCG)
      IF(DIF.GT.0.0001) GOTO 2330
      CALL TONCON(L,N,A,J1,A7,T,STCA,REC,STAREF,L1)
      CALL SUMAT(N,A,J1,A7,T,QMA)
      GOTO 2459
 2330   LA=L+1
        CALL TONCON(LA,N,A,J1,A7,T,STCA,REC,STAREF,L1)
        CALL SUMAT(N,A,J1,A7,T,QMA)
 2459   CALL TONA(QMA,CAM,STCA,CAP,STAREF,CAR,TPA,QM1A,
     +  QC1A,QR1A,IR)
        IF(TPA.LT.1) THEN
           CALL ASI3(QMA,STCA,STAREF,TPA,QM1A,QC1A,QR1A,T1)
        ELSE
           T1=1
           GOTO 2492
```

```
        ENDIF
 2492   PA=(PV-COSR)*QR1A-COSP*QC1A-COSM*QM1A-T1*FC
        IF(TPA.LT.1) THEN
         NP=(PV-COSR)*QR1A-COSP*QC1A-COSM*QM1A-(FC+D*PA)*TPA
        ENDIF
        CALL ASI2(QMA,STCA,QM1A,QMT,STC4,QM4)
        CALL ASI2(QC1A,TPA,PA,QC4,TP4,PB)
        CALL BONGO
        TNP4=TNPB
        TNPF=TNP4+NPA
      RETURN
      END
C*************************************************************
C       SUBROUTINE BONGO
C  figure out prifit and NPV corresponding to the decimal
C   part for each increment
C*************************************************************
      SUBROUTINE BONGO
      COMMON A(30,30),L1(100),T(100),DIF,OCG,A7,STOT
      COMMON POR,I,J,L,M,N,PRO,REF,REC,K2,E2(20,20),MAR2
      COMMON TP,TP1,TP2,TP3,P,PV,T1,D,CM,CP,CR,FC,COSM
      COMMON COSP,COSR,TNPV,CAM,CAP,CAR,TPA,PB,TB(20)
      COMMON/BONG/ QMT,STC4,QM4,QC4,TP4,QR4,DTP,J1
      COMMON TNPB,TNPC,TNPF
      REAL L1,NPV2
      IF(MAR2.EQ.0) THEN
         CALL CAMB(M,N,E2,A)
         CALL INTER(M,TB,T)
      ENDIF
      IF(MAR2.EQ.0) THEN
         J1=J
      ENDIF
      TNP2=0
      NTP=TP4
      DTP=TP4-NTP
      NPV2=PB*(((1+D)**NTP-1)/(D*(D+1)**NTP))
      QM3=QM4*NTP
      QC3=QC4*NTP
      CALL RESTA(OCG,E2,L,J1,N,STC4,QC3,TB,QMT,QM3)
      DIF=ABS(E2(L,1)-OCG)
      IF(DIF.GT.0.0001) GOTO 2330
       CALL TONCON(L,N,E2,J1,A7,TB,STCA,REC,STA,L1)
       CALL SUMAT(N,E2,J1,A7,TB,QMA)
       GOTO 2459
 2330   LA= L+1
        CALL TONCON(LA,N,E2,J1,A7,TB,STCA,REC,STA,L1)
        CALL SUMAT(N,E2,J1,A7,TB,QMA)
 2459   QC4=STCA
```

```
      QM4=QMA
      QR4=STA
      T2=DTP
      P1=(PV-COSR)*QR4-COSP*QC4-COSM*QM4-T2*FC
      TNP2=P1/(1+D)**TP4
       TNP2=TNP2+NPV2
      TNPB=TNP2
      RETURN
      END
C *************************************************************
C     SUBROUTINE ASIG
C  Assign the original matrix A to an auxiliar matrix C & D1
C *************************************************************
      SUBROUTINE ASIG(N,M,C,A,D1)
      DIMENSION A(30,30),C(30,30),D1(30,30)
      DO 9 I=1,N
          DO 8 J=1,M
             C(I,J)=A(I,J)
             D1(I,J)=A(I,J)
    8     CONTINUE
    9 CONTINUE
      RETURN
      END
C *************************************************************
C     SUBROUTINE MIPLA
C   Figure out the balancing cut off grade corresponding
C   to mine and concentrator
C *************************************************************
      SUBROUTINE MIPLA(N1,VM,VC,CUT,GMC1)
      DIMENSION VM(1000),VC(1000),CUT(100)
      REAL M1,M2
      DO 90 I=1,N1
         M1=(VM(I)-VM(I+1))/(CUT(I)-CUT(I+1))
         M2=(VC(I)-VC(I+1))/(CUT(I)-CUT(I+1))
         B1=VM(I)-M1*CUT(I)
         A1=M1
         B2=VC(I)-M2*CUT(I)
           A2=M2
         IF((M2-M1).EQ.0) GOTO 90
         X=(B2-B1)/(A1-A2)
         Y=A1*((B2-B1)/(A1-A2))+B1
         IF(CUT(I).LE.X.AND.CUT(I+1).GE.X) GOTO 95
         GOTO 90
   8  0   IF(VM(I).LE.Y.OR.VM(I+1).GE.Y) GOTO 95
   90 CONTINUE
   95 IF(X.LE.0) THEN
          D3=ABS(VM(N1)-VC(N1))
          D2=ABS(VM(1)-VC(1))
```

```
          IF(D2.GT.D3) THEN
             GMC1=CUT(N1)
          ELSE
             GMC1=0
          ENDIF
       ELSE
          GMC1=X
       ENDIF
       RETURN
       END
C ******************************************************
C      SUBROUTINE MIREF
C  Figure out the balancing cut off grade corresponding
C  to mine and refinery
C ******************************************************
       SUBROUTINE MIREF(N1,VM,VR,CUT,GMR1)
       DIMENSION VM(1000),VR(1000),CUT(100)
       REAL M1,M2
       DO 105 I=1,N1
          M1=(VM(I)-VM(I+1))/(CUT(I)-CUT(I+1))
          M2=(VR(I)-VR(I+1))/(CUT(I)-CUT(I+1))
          B1=VM(I)-M1*CUT(I)
          A1=M1
          B2=VR(I)-M2*CUT(I)
          A2=M2
          IF((M2-M1).EQ.0) GOTO 105
          X=(B2-B1)/(A1-A2)
          Y=A1*((B2-B1)/(A1-A2))+B1
          IF(CUT(I).LE.X.AND.CUT(I+1).GE.X) GOTO 110
          GOTO 105
  10  0   IF(VM(I).LE.Y.OR.VM(I+1).GE.Y) GOTO 110
  105 CONTINUE
  110 IF (X.LE.0) THEN
             D3=ABS(VM(N1)-VR(N1))
             D2=ABS(VM(1)-VR(1))
             IF(D2.GT.D3) THEN
                GMR1=CUT(N1)
             ELSE
                GMR1=0
             ENDIF
       ELSE
             GMR1=X
       ENDIF
       RETURN
       END
```

```
C ************************************************
C     SUBROUTINE PLAREF
C  Figure out the balancing cut off grade corrsponding
C  to concentrator and refinery
C ************************************************
      SUBROUTINE PLAREF(N1,VC,VR,CUT,GCR1)
      DIMENSION VC(1000),VR(1000),CUT(100)
      REAL M1,M2
      DO 120 I=1,N1
          M1=(VC(I)-VC(I+1))/(CUT(I)-CUT(I+1))
          M2=(VR(I)-VR(I+1))/(CUT(I)-CUT(I+1))
          B1=VC(I)-M1*CUT(I)
          A1=M1
          B2=VR(I)-M2*CUT(I)
          A2=M2
          IF((M2-M1).EQ.0) GOTO 120
          X=(B2-B1)/(A1-A2)
          Y=A1*((B2-B1)/(A1-A2)) +B1
          IF(CUT(I).LE.X.AND.CUT(I+1).GE.X) GOTO 125
          GOTO 120
  115     IF(VC(I).LE.Y.AND.VC(I+1).LE.Y) GOTO 125
  120 CONTINUE
  125 IF(X.LE.0.0001) THEN
           D3=ABS(VC(N1)-VR(N1))
           D2=ABS(VC(1)-VR(1))
           IF(D2.GT.D3) THEN
               GCR1=CUT(N1)
           ELSE
                 GCR1=0
           ENDIF
      ELSE
           GCR1=X
      ENDIF
      RETURN
      END
C ************************************************
C     SUBROUTIINE SUMAT
C  Figure out the tonnage by increment
C ************************************************
      SUBROUTINE SUMAT(N,A,J,A7,T,QM)
      DIMENSION A(30,30),T(100)
      QM=0
      DO 129 I=1,N
         QM=QM+A(I,J)*A7
  129 CONTINUE
      QM=QM+T(J)*A7
      RETURN
      END
```

```
C ********************************************************
C     SUBROUTINE ENOC
C    Find the optimum cut off grade OCG
C ********************************************************
      SUBROUTINE ENOC(GMC1,GMR1,GCR1,GEM,GEP,GER,OCG,MED,CHU)
       REAL MED,MAY
       IF(GMC1.LE.GEM)THEN
            GMC=GEM
       ENDIF
       IF(GMC1.GE.GEP)THEN
            GMC=GEP
       ELSE
            GMC=GMC1
       ENDIF
       IF(IR.EQ.0)THEN
           MED=GMC
           GOTO 170
       ENDIF
       IF(GMR1.LE.GEM)THEN
            GMR=GEM
       ENDIF
       IF(GMR1.GE.GER)THEN
            GMR =GER
       ELSE
            GMR=GMR1
       ENDIF
       IF(GCR1.LE.GER)THEN
           GCR=GER
       ENDIF
       IF(GCR1.GE.GEP)THEN
            GCR=GEP
       ELSE
            GCR=GCR1
       ENDIF
       MAY=GMC
       IF(MAY.GE.GMR) GOTO 130
       MAY=GMR
  130  IF(MAY.GE.GCR) GOTO 135
       MAY=GCR
  135  IF(GMC.EQ.MAY) GOTO 140
       IF(GMR.EQ.MAY) GOTO 145
       IF(GMC.LE.GMR) GOTO 150
       MED=GMC
       GOTO 170
  140  IF(GMR.LE.GCR) GOTO 160
       MED=GMR
       GOTO 170
  145  IF(GMC.LE.GCR) GOTO 160
```

```
      MED=GMC
      GOTO 170
  150 MED=GMR
      GOTO 170
  160 MED=GCR
      GOTO 170
  170 CHU=ABS(OCG-MED)
      RETURN
      END
C *******************************************************
C     SUBROUTINE TONCON
C  Figure out the total tonnage to send to  concentrator
C  and total tonnage refining
C *******************************************************
      SUBROUTINE TONCON(LA,N,A,J,A7,T,STC,REC,STREF,L1)
      DIMENSION A(30,30),T(100)
      REAL L1(100)
      STC=0
      DO 200 I=LA,N
          STC=STC+A(I,J)*A7
  200 CONTINUE
      STC=STC+T(J)*A7
      STREF=0
      DO 210 I=LA,N
           PRO=(A(I,1)+A(I,2))/2
           REF=A(I,J)*PRO*10000*REC
           STREF=STREF+REF
  210 CONTINUE
      STREF=STREF+T(J)*L1(J)*10000*REC
      RETURN
      END
C *******************************************************
C     SUBROUTINE TONA
C  Figure out annual tonnage and time
C *******************************************************
     SUBROUTINE TONA(QM,CM,STC,CP,STREF,CR,TP,QM1,QC1,QR1,IR)
C  FIGURE OUT ANNUAL TONNAGES
        TP1=QM/CM
        TP2=STC/CP
        TP3=STREF/CR
        IF(IR.EQ.0)THEN
            IF(TP1.GE.TP2)THEN
               GOTO 460
            ELSE
               GOTO 470
            ENDIF
        ENDIF
        IF(TP1.GE.TP2.AND.TP1.GE.TP3) GOTO 460
```

```
      IF(TP2.GE.TP1.AND.TP2.GE.TP3) GOTO 470
      IF(TP3.GE.TP1.AND.TP3.GE.TP2) GOTO 480
460   QM1=QM/TP1
      QC1=STC/TP1
      QR1=STREF/TP1
      TP=TP1
      GOTO 490
470   QM1=QM/TP2
      QC1=STC/TP2
      QR1=STREF/TP2
      TP=TP2
      GOTO 490
480   QM1=QM/TP3
      QC1=STC/TP3
      QR1=STREF/TP3
        TP=TP3
490   RETURN
      END
C *****************************************************
C       SUBROUTINE CAMB
C  Actualization matrix
C *****************************************************
      SUBROUTINE CAMB(M,N,A,D1)
      DIMENSION A(30,30),D1(30,30)
      DO 494 I3=1,M
         DO 493 I5=1,N
              A(I5,I3)=D1(I5,I3)
493      CONTINUE
494   CONTINUE
      RETURN
      END
C *********************************************************
C       SUBROUTINE RESTA
C  Substrac the total annual tonnage and the concentrator
C  tonnage to the increment.
C *********************************************************
      SUBROUTINE RESTA(OCG,A,L,J,N,STC,QC1,T,QM,QM1)
      DIMENSION A(30,30),T(100)
      DIFE=ABS(OCG-A(L,1))
      IF(DIFE.LE.0.00001) GOTO 520
      DO 505 I=L+1,N
         A(I,J)=A(I,J)-(A(I,J)/STC)*QC1
505   CONTINUE
      T(J)=T(J)-(T(J)/STC)*QC1
      DO 510 I=1,L
         A(I,J)=A(I,J)-(A(I,J)/(QM-STC))*(QM1-QC1)
510   CONTINUE
      GOTO 550
```

```
  520    DO 525 I=L+1,N
            A(I,J)=A(I,J)-(A(I,J)/STC)*QC1
  525    CONTINUE
         T(J)=T(J)-(T(J)/STC)*QC1
         DO 530 I=1,L
            A(I,J)=A(I,J)-(A(I,J)/(QM-STC))*(QM1-QC1)
  530    CONTINUE
  550    RETURN
         END
C ******************************************************
C        SUBROUTINE INTER
C Actualization vector
C ******************************************************
         SUBROUTINE INTER(M,TB,TR)
         DIMENSION TB(100),TR(100)
         DO 2130 J1=1,M
             TB(J1)=TR(J1)
 2130    CONTINUE
         RETURN
         END
C ******************************************************
C    SUBROUTINE BACUT
C  Find the total and concentrator tonnage as a function
C  of the cut off grade
C ******************************************************
       SUBROUTINE BACUT(N1,A,CUT,QM,J,A7,T,QC,UPV)
       DIMENSION A(30,30),CUT(100),T(100),QC(100)
         DO 30 I=1,N1
           CUT(I)=A(I,1)
   30    CONTINUE
         CUT(N1+1)=UPV
         QM=0
         DO 35 I=1,N1
          QM=QM + A(I,J)*A7
   35    CONTINUE
         M1=1
         IF(T(J).EQ.0) GOTO 37
          QM=QM+T(J)*A7
   3 7    DO 50 I=1,N1
          ST=0
             DO 40 L=M1,N1
            ST=ST+A(L,J)*A7
   40      CONTINUE
          QC(I)=ST+T(J)*A7
          M1=M1+1
   50    CONTINUE
         QC(N1+1)=T(J)*A7
       RETURN
```

```
      END
C ***********************************************************
C     SUBROUTINE AVRG
C  Find the refining tonnage as a function of the
C   cutoff grade
C ***********************************************************
      SUBROUTINE AVRG(N1,A,J,QR,T,L1,A4,V)
      DIMENSION A(30,30),T(100),QR(1000)
      REAL L1(100),LP(100)
        DO 60 I=1,N1
          LP(I)=(A(I,1)+A(I,2))/2
   60   CONTINUE
        M1=1
        DO 65 I=1,N1
          ST=0
          DO 63 L=M1,N1
            FINO=A(L,J)*LP(L)*10000
               ST=ST+FINO
   63     CONTINUE
          QR(I)=ST + T(J)*L1(J)*10000
          M1=M1+1
   65   CONTINUE
        IF(T(J).EQ.0) GOTO 70
        QR(N1+1)=T(J)*L1(J)*10000
        N1=N1+1
   70   A4=0
        V=0.
      RETURN
      END
C ***********************************************************
C    SUBROUTINE INI1
C  Initiation of variables one time in the program
C ***********************************************************
      SUBROUTINE INI1(M,T,TC,NC,N,MAR4,MAR3)
      DIMENSION T(100),TC(20)
      DO 2 J=1,M
         TC(J)=T(J)
    2 CONTINUE
      NC=N
      MAR4=0
      MAR3=0
      RETURN
      END
C ***********************************************************
C   SUBROUTINE INI2
C  Initiayion of variables by each iteration.
C ***********************************************************
      SUBROUTINE INI2(I4,I1,MAR2,A7,K1,MAR,N1,N)
```

```
      I4=1
      I1=1
      MAR2=0
      A7=1000000.
      K1=1
      MAR=0
      N1=N
      RETURN
      END
C ************************************************************
C     SUBROUTINE ASI2
C  Assign variables 3
C ************************************************************
      SUBROUTINE ASI2(CM,CP,CR,CAM,CAP,CAR)
      CAM=CM
      CAP=CP
      CAR=CR
      RETURN
      END
C ************************************************************
C     SUBROUTINE ASI3
C  Assign variables 4
C ************************************************************
      SUBROUTINE ASI3(QM,STC,STREF,TP,QM1,QC1,QR1,T1)
      QM1=QM
      QC1=STC
      QR1=STREF
      T1=TP
      RETURN
      END
C ************************************************************
C     SUBROUTINE CALINT
C  Find and create the interval for the op. cut. grade
C ************************************************************
      SUBROUTINE CALINT(N,L,J,M,B,A,OCG,POR)
      DIMENSION A(30,30),B(30,30)
      K2=0
        DO 320 I=1,N
           K2=K2+1
           IF(I.EQ.L) GOTO 310
           B(K2,1)=A(I,1)
           B(K2,2)=A(I,2)
           DO 301 J1=J,M
              B(K2,J1)=A(I,J1)
 301       CONTINUE
           GOTO 320
 310       B(L,1)=A(I,1)
           B(L,2)=OCG
```

```
            DO 311 J1=J,M
               B(L,J1)=A(I,J1)*POR
  311       CONTINUE
            B(L+1,1)=OCG
            B(L+1,2)=A(I,2)
            DO 312 J1=J,M
               B(L+1,J1)=A(I,J1)-A(I,J1)*POR
  312       CONTINUE
            K2=K2+1
  320    CONTINUE
         N=N+1
         DO 321 I=1,N
            A(I,1)=B(I,1)
            A(I,2)=B(I,2)
            DO 313 J1=J,M
               A(I,J1)=B(I,J1)
  313       CONTINUE
  321    CONTINUE
       RETURN
       END
C ******************************************************
C      SUBROUTINE PRI1
C  Print partial results.
C ******************************************************
       SUBROUTINE PRI1(MED,K1,J,GMC1,GMR1,GCR1,GEM,GEP,GER
      +,OCG,QM1,A7,QC1,QR1,TP,P,NPV)
       REAL MED,NPV
         MED=OCG
         WRITE(200,*)
          WRITE(200,1010)K1
         WRITE(200,1011)J-2
         WRITE(200,1015)GMC1
         WRITE(200,1020)GMR1
         WRITE(200,1030)GCR1
         WRITE(200,1040)GEM,GEP,GER
         WRITE(200,1050)OCG
         WRITE(200,1060)QM1/A7,QC1/A7,QR1/1000
         WRITE(200,1070)TP,P/A7,NPV/A7
 1010    FORMAT(10X,'YEAR='I2)
 1011    FORMAT(10X,'INC='I2)
 1015    FORMAT('GMC=',F6.4)
 1020    FORMAT('GMR=',F6.4)
 1030    FORMAT('GCR=',F6.4)
 1040    FORMAT('GEM=',F6.4,10X,'GEP=',F6.4,10X,'GER=',F6.4)
 1050    FORMAT('OP.CUT.GRADE=',F6.4)
 1060    FORMAT('QM=',F8.4,2X,'QC='F8.4,2X,'QR=',F8.4)
 1070    FORMAT('TIME=',F5.2,2X,'PROFIT=',F5.1,2X,
      + 'NPV=',F7.1)
```

```
      RETURN
      END
C ******************************************************
C     SUBROUTINE PRI2
C       Print the final optimum output
C ******************************************************
      SUBROUTINE PRI2(I1,QM2,A7,QC2,QR2,PRF,NPV1,YEAR,INC
     +,OPTM,NPF)
      DIMENSION QM2(100),QC2(100),QR2(100),PRF(100)
      DIMENSION OPTM(100),YEAR(100)
      REAL NPV1(100),INC(100),NPF(100)
      WRITE(200,*)
      WRITE(200,*)
      WRITE(200,1080)
      DO 810 I=1,I1-1
      QM2(I)=QM2(I)/A7
      QC2(I)=QC2(I)/A7
      QR2(I)=QR2(I)/1000
      PRF(I)=PRF(I)/A7
      NPV1(I)=NPV1(I)/A7
      WRITE(200,1090)YEAR(I),INC(I),OPTM(I),QM2(I),QC2(I),
     +QR2(I),PRF(I),NPF(I)
  810 CONTINUE
 1080 FORMAT('YEAR',3X,'INC',3X,'COG',6X,'QM',7X,'QC',7X,
     +,'QR',5X,'PROF',8X,'NPV')
 1090 FORMAT(F3.0,3X,F4.2,F6.2,3X,F6.1,3X,F6.1,4X,F5.1,3X,
     +,F5.1,7X,F6.0)
      RETURN
      END
C*******************************************************
C     SUBROUTINE ONPV
C  This subroutine figure out the optimum NPV considering
C  all  profits
C ******************************************************
      SUBROUTINE ONPV(I1,TPE,NPV1,PRF,D)
      DIMENSION TPE(100),PRF(100)
      REAL NPV1(100)
      DO 1200 K3=1,I1-1
         SP=0
         IF(TPE(K3).EQ.0) THEN
              NPV1(K3)=NPV1(K3-1)
         ELSE
            DO 1999 I=K3,I1-1
               SP=SP+PRF(I)/(1+D)**TPE(I)
 1999       CONTINUE
            NPV1(K3)=SP
            IF(TPE(K3).GE.1) THEN
               DO 2001 I=1,I1-1
```

```
                  TPE(I)=TPE(I)-1
 2001           CONTINUE
              ENDIF
           ENDIF
 1200 CONTINUE
      RETURN
      END
```

APPENDIX B

OUTPUT FROM THE PROGRAM COG.FOR

```
          YEAR= 1
          INC= 1
GMC= .5861
GMR= .6506
GCR= .5039
GEM= .1333          GEP= .7233          GER= .3252
OP.CUT.GRADE= .5039
QM= 17.8507  QC=  9.9988  QR= 90.0000
TIME= 5.60  PROFIT= 26.1  NPV=  147.8


          YEAR= 2
          INC= 1
GMC= .5861
GMR= .6506
GCR= .5039
GEM= .1333          GEP= .7116          GER= .3161
OP.CUT.GRADE= .5039
QM= 17.8507  QC=  9.9988  QR= 90.0000
TIME= 4.60  PROFIT= 26.1  NPV=  144.1


          YEAR= 3
          INC= 1
GMC= .5861
GMR= .6506
GCR= .5039
GEM= .1333          GEP= .6980          GER= .3063
OP.CUT.GRADE= .5039
QM= 17.8507  QC=  9.9988  QR= 90.0000
TIME= 3.60  PROFIT= 26.1  NPV=  139.6


          YEAR= 4
          INC= 1
GMC= .5861
GMR= .6506
GCR= .5039
GEM= .1333          GEP= .6825          GER= .2957
OP.CUT.GRADE= .5039
QM= 17.8507  QC=  9.9988  QR= 90.0000
TIME= 2.60  PROFIT= 26.1  NPV=  134.4


          YEAR= 5
          INC= 1
GMC= .5861
GMR= .6506
```

```
GCR= .5039
GEM= .1333          GEP= .6646          GER= .2845
OP.CUT.GRADE= .5039
QM= 17.8507  QC=  9.9988  QR= 90.0000
TIME= 1.60  PROFIT= 26.1  NPV=  128.5


          YEAR= 6
          INC= 1
GMC= .5861
GMR= .6506
GCR= .5039
GEM= .1333          GEP= .6441          GER= .2725
OP.CUT.GRADE= .5039
QM= 10.7466  QC=  6.0196  QR= 54.1824
TIME=  .60  PROFIT= 15.7  NPV=  122.9


          YEAR= 6
          INC= 2
GMC= .5282
GMR= .4710
GCR= .5957
GEM= .1333          GEP= .6441          GER= .2725
OP.CUT.GRADE= .5282
QM=  7.9609  QC=  3.9804  QR= 34.2072
TIME=  .40  PROFIT=  9.1  NPV=  121.2


          YEAR= 7
          INC= 2
GMC= .5282
GMR= .4710
GCR= .5957
GEM= .1333          GEP= .6245          GER= .2621
OP.CUT.GRADE= .5282
QM= 20.0000  QC= 10.0000  QR= 85.9383
TIME= 4.61  PROFIT= 23.0  NPV=  112.1


          YEAR= 8
          INC= 2
GMC= .5282
GMR= .4710
GCR= .5957
GEM= .1333          GEP= .6083          GER= .2540
OP.CUT.GRADE= .5282
QM= 20.0000  QC= 10.0000  QR= 85.9383
```

```
TIME= 3.61  PROFIT= 23.0  NPV=  105.9


          YEAR= 9
          INC= 2
GMC= .5282
GMR= .4710
GCR= .5957
GEM= .1333          GEP= .5897          GER= .2452
OP.CUT.GRADE= .5282
QM= 20.0000  QC= 10.0000  QR= 85.9383
TIME= 2.61  PROFIT= 23.0  NPV=   98.9


          YEAR=10
          INC= 2
GMC= .5282
GMR= .4710
GCR= .5957
GEM= .1333          GEP= .5682          GER= .2359
OP.CUT.GRADE= .5282
QM= 20.0000  QC= 10.0000  QR= 85.9383
TIME= 1.61  PROFIT= 23.0  NPV=   90.7


          YEAR=11
          INC= 2
GMC= .5282
GMR= .4710
GCR= .5957
GEM= .1333          GEP= .5436          GER= .2261
OP.CUT.GRADE= .5282
QM= 12.2391  QC=  6.1196  QR= 52.5904
TIME=  .61  PROFIT= 14.1  NPV=   82.5


          YEAR=11
          INC= 3
GMC= .4689
GMR= .2428
GCR= .7000
GEM= .1333          GEP= .5436          GER= .2261
OP.CUT.GRADE= .4689
QM=  7.7609  QC=  3.8804  QR= 29.5292
TIME=  .39  PROFIT=  7.0  NPV=   89.7


          YEAR=12
```

```
          INC= 3
GMC= .4689
GMR= .2428
GCR= .7000
GEM= .1333           GEP= .5216           GER= .2179
OP.CUT.GRADE= .4689
QM= 20.0000  QC= 10.0000  QR= 76.0976
TIME= 4.61  PROFIT= 18.0  NPV=   82.7


          YEAR=13
          INC= 3
GMC= .4689
GMR= .2428
GCR= .7000
GEM= .1333           GEP= .5063           GER= .2126
OP.CUT.GRADE= .4689
QM= 20.0000  QC= 10.0000  QR= 76.0976
TIME= 3.61  PROFIT= 18.0  NPV=   77.1


          YEAR=14
          INC= 3
GMC= .4689
GMR= .2428
GCR= .7000
GEM= .1333           GEP= .4887           GER= .2068
OP.CUT.GRADE= .4689
QM= 20.0000  QC= 10.0000  QR= 76.0976
TIME= 2.61  PROFIT= 18.0  NPV=   70.6


          YEAR=15
          INC= 3
GMC= .4689
GMR= .2428
GCR= .7000
GEM= .1333           GEP= .4685           GER= .2006
OP.CUT.GRADE= .4685
QM= 19.9877  QC= 10.0000  QR= 76.0768
TIME= 1.61  PROFIT= 18.0  NPV=   63.2


          YEAR=16
          INC= 3
GMC= .4689
GMR= .2428
GCR= .7000
```

```
GEM= .1333          GEP= .4453          GER= .1938
OP.CUT.GRADE= .4453
QM= 12.2514  QC=  6.3864  QR= 47.6875
TIME=  .64  PROFIT= 11.3  NPV=   58.8


          YEAR=16
          INC= 4
GMC= .4102
GMR= .0000
GCR= .7000
GEM= .1333          GEP= .4453          GER= .1938
OP.CUT.GRADE= .4102
QM=  7.2272  QC=  3.6136  QR= 24.0145
TIME=  .36  PROFIT=  4.8  NPV=   60.3


          YEAR=17
          INC= 4
GMC= .4102
GMR= .0000
GCR= .7000
GEM= .1333          GEP= .4251          GER= .1883
OP.CUT.GRADE= .4102
QM= 20.0000  QC= 10.0000  QR= 66.4558
TIME= 4.64  PROFIT= 13.2  NPV=   55.5


          YEAR=18
          INC= 4
GMC= .4102
GMR= .0000
GCR= .7000
GEM= .1333          GEP= .4115          GER= .1847
OP.CUT.GRADE= .4102
QM= 20.0000  QC= 10.0000  QR= 66.4558
TIME= 3.64  PROFIT= 13.2  NPV=   50.7


          YEAR=19
          INC= 4
GMC= .4102
GMR= .0000
GCR= .7000
GEM= .1333          GEP= .3957          GER= .1808
OP.CUT.GRADE= .3957
QM= 19.4359  QC= 10.0000  QR= 65.6040
TIME= 2.72  PROFIT= 13.1  NPV=   46.6
```

```
          YEAR=20
          INC= 4
GMC= .4102
GMR= .0000
GCR= .7000
GEM= .1333          GEP= .3782          GER= .1766
OP.CUT.GRADE= .3782
QM= 18.7564  QC= 10.0000  QR= 64.5279
TIME= 1.78  PROFIT= 12.9  NPV=   42.4


          YEAR=21
          INC= 4
GMC= .4102
GMR= .0000
GCR= .7000
GEM= .1333          GEP= .3586          GER= .1721
OP.CUT.GRADE= .3586
QM= 14.5805  QC=  8.0760  QR= 51.1642
TIME=  .81  PROFIT= 10.2  NPV=   39.1


          YEAR=21
          INC= 5
GMC= .3509
GMR= .0000
GCR= .7000
GEM= .1333          GEP= .3586          GER= .1721
OP.CUT.GRADE= .3509
QM=  3.8480  QC=  1.9240  QR= 11.0114
TIME=  .19  PROFIT=  1.7  NPV=   34.1


          YEAR=22
          INC= 5
GMC= .3509
GMR= .0000
GCR= .7000
GEM= .1333          GEP= .3395          GER= .1680
OP.CUT.GRADE= .3395
QM= 19.4532  QC= 10.0000  QR= 56.5164
TIME= 4.94  PROFIT=  8.5  NPV=   33.1


          YEAR=23
          INC= 5
GMC= .3509
```

```
GMR= .0000
GCR= .7000
GEM= .1333          GEP= .3286          GER= .1657
OP.CUT.GRADE= .3286
QM= 18.9571  QC= 10.0000  QR= 55.8417
TIME= 4.05  PROFIT=  8.4  NPV=   30.1


          YEAR=24
          INC= 5
GMC= .3509
GMR= .0000
GCR= .7000
GEM= .1333          GEP= .3164          GER= .1632
OP.CUT.GRADE= .3164
QM= 18.4294  QC= 10.0000  QR= 55.0953
TIME= 3.13  PROFIT=  8.3  NPV=   27.0


          YEAR=25
          INC= 5
GMC= .3509
GMR= .0000
GCR= .7000
GEM= .1333          GEP= .3028          GER= .1605
OP.CUT.GRADE= .3028
QM= 17.8721  QC= 10.0000  QR= 54.2720
TIME= 2.20  PROFIT=  8.2  NPV=   23.5


          YEAR=26
          INC= 5
GMC= .3509
GMR= .0000
GCR= .7000
GEM= .1333          GEP= .2876          GER= .1576
OP.CUT.GRADE= .2876
QM= 17.2731  QC= 10.0000  QR= 53.3433
TIME= 1.24  PROFIT=  8.0  NPV=   19.5


          YEAR=27
          INC= 5
GMC= .3509
GMR= .0000
GCR= .7000
GEM= .1333          GEP= .2706          GER= .1545
OP.CUT.GRADE= .2706
```

QM= 4.1671 QC= 2.5031 QR= 13.0965
TIME= .25 PROFIT= 2.0 NPV= 14.7

YEAR=27
INC= 6
GMC= .2932
GMR= .0000
GCR= .7000
GEM= .1333 GEP= .2706 GER= .1545
OP.CUT.GRADE= .2706
QM= 14.0663 QC= 7.4969 QR= 34.6696
TIME= .75 PROFIT= 2.8 NPV= 14.6

YEAR=28
INC= 6
GMC= .2932
GMR= .0000
GCR= .7000
GEM= .1333 GEP= .2619 GER= .1530
OP.CUT.GRADE= .2619
QM= 18.3291 QC= 10.0000 QR= 45.7301
TIME= 4.69 PROFIT= 3.7 NPV= 11.9

YEAR=29
INC= 6
GMC= .2932
GMR= .0000
GCR= .7000
GEM= .1333 GEP= .2556 GER= .1519
OP.CUT.GRADE= .2556
QM= 18.0215 QC= 10.0000 QR= 45.3534
TIME= 3.75 PROFIT= 3.7 NPV= 10.0

YEAR=30
INC= 6
GMC= .2932
GMR= .0000
GCR= .7000
GEM= .1333 GEP= .2483 GER= .1507
OP.CUT.GRADE= .2483
QM= 17.6813 QC= 10.0000 QR= 44.9253
TIME= 2.80 PROFIT= 3.6 NPV= 7.9

```
          YEAR=31
          INC= 6
GMC= .2932
GMR= .0000
GCR= .7000
GEM= .1333          GEP= .2402          GER= .1493
OP.CUT.GRADE= .2402
QM= 17.2971  QC= 10.0000  QR= 44.4268
TIME= 1.84  PROFIT=  3.6  NPV=    5.4


          YEAR=32
          INC= 6
GMC= .2932
GMR= .0000
GCR= .7000
GEM= .1333          GEP= .2310          GER= .1478
OP.CUT.GRADE= .2310
QM= 14.6048  QC=  8.6501  QR= 37.9498
TIME=  .87  PROFIT=  3.0  NPV=    3.0
```

YEAR	INC	COG	QM	QC	QR	PROF	NPV
1.	1.00	.50	17.9	10.0	90.0	26.1	150.
2.	1.00	.50	17.9	10.0	90.0	26.1	147.
3.	1.00	.50	17.9	10.0	90.0	26.1	143.
4.	1.00	.50	17.9	10.0	90.0	26.1	138.
5.	1.00	.50	17.9	10.0	90.0	26.1	133.
6.	1.00	.50	10.7	6.0	54.2	15.7	127.
6.	2.00	.53	8.0	4.0	34.2	9.1	127.
7.	2.00	.53	20.0	10.0	85.9	23.0	121.
8.	2.00	.53	20.0	10.0	85.9	23.0	116.
9.	2.00	.53	20.0	10.0	85.9	23.0	110.
10.	2.00	.53	20.0	10.0	85.9	23.0	104.
11.	2.00	.53	12.2	6.1	52.6	14.1	96.
11.	3.00	.47	7.8	3.9	29.5	7.0	96.
12.	3.00	.47	20.0	10.0	76.1	18.0	90.
13.	3.00	.47	20.0	10.0	76.1	18.0	85.
14.	3.00	.47	20.0	10.0	76.1	18.0	80.
15.	3.00	.47	20.0	10.0	76.1	18.0	74.
16.	3.00	.45	12.3	6.4	47.7	11.3	67.
16.	4.00	.41	7.2	3.6	24.0	4.8	67.
17.	4.00	.41	20.0	10.0	66.5	13.2	61.
18.	4.00	.41	20.0	10.0	66.5	13.2	57.
19.	4.00	.40	19.4	10.0	65.6	13.1	52.
20.	4.00	.38	18.8	10.0	64.5	12.9	47.
21.	4.00	.36	14.6	8.1	51.2	10.2	41.
21.	5.00	.35	3.8	1.9	11.0	1.7	41.
22.	5.00	.34	19.5	10.0	56.5	8.5	35.
23.	5.00	.33	19.0	10.0	55.8	8.4	32.
24.	5.00	.32	18.4	10.0	55.1	8.3	28.
25.	5.00	.30	17.9	10.0	54.3	8.2	24.
26.	5.00	.29	17.3	10.0	53.3	8.0	20.
27.	5.00	.27	4.2	2.5	13.1	2.0	15.
27.	6.00	.27	14.1	7.5	34.7	2.8	15.
28.	6.00	.26	18.3	10.0	45.7	3.7	12.
29.	6.00	.26	18.0	10.0	45.4	3.7	10.
30.	6.00	.25	17.7	10.0	44.9	3.6	8.
31.	6.00	.24	17.3	10.0	44.4	3.6	5.
32.	6.00	.23	14.6	8.7	37.9	3.0	3.

APPENDIX C

COMPUTER CODE SP.FOR PROGRAM

```
C    ************************************************
C    ************************************************
C    **                                            **
C    **     MODIFIED LANE'S ALGORITHM TO DETERMINE  **
C    **        OPTIMUM CUT OFF GRADE CONSIDERING    **
C    **            THE STOCK PILE ALTERNATIVE       **
C    **                                             **
C    **          MADE BY: MANUEL SCHELLMAN M.       **
C    **                                             **
C    **          COLORADO SCHOOL OF MINES           **
C    **          SEPTEMBER 1989                     **
C    **                                             **
C    ************************************************
C    ************************************************
      DIMENSION CUT(100),QC(100),C(50,10),YEAR(100)
      DIMENSION B(50,10),D1(50,10),PRF(100),TPE(100)
      DIMENSION OPTM(100),QM2(100),QC2(100),QR2(100)
      DIMENSION TC(20),PPV1(50),AS(50,10),TS(20),DS(50,10)
      DIMENSIONQR(200),VM(200),VC(200),VR(200),AS1(50,10)
      DIMENSION TPE1(100),CS(50,10)
      COMMON A(50,10),L1(100),T(100),DIF,OCG,A7,STOT
      COMMON POR,I,J,L,M,N,PRO,REF,REC,K2,E2(50,10),MAR2
      COMMON TP,TP1,TP2,TP3,P,PV,T1,D,CM,CP,CR,FC,COSM
      COMMON COSP,COSR,TNPV,CAM,CAP,CAR,TPA,PB,TB(20)
      COMMON TNPB,TNPC,TNPF
      COMMON/FRED/ STC,QC1,QM,QM1
      COMMON/BONG/ QMT,STC4,QM4,QC4,TP4,QR4,DTP,J1
      REAL L1,LP(100),MAY,NPV,NPV1(100),INC(100),MED
      REAL NPF(100)
      INTEGER SP
      OPEN(UNIT=10,FILE='DATS.DAT',STATUS='OLD')
      OPEN(UNIT=200,FILE='RESS.RES',STATUS='NEW')
      READ(10,*)N,M
      DO 15 I=1,N
           READ(10,*)(A(I,J),J=1,M)
   15 CONTINUE
C     READ TON AND GRADES ABOVE THE INTERVALS
   16 DO 20 I=1,M
         READ(10,*)T(I),L1(I)
   20 CONTINUE
C     READ CAPACITIES
      READ(10,*)CM,CP,CR
C  READ COST MINE PLANT REF FIXED COST SELL PRICE
C    REC DISC RATE
      READ(10,*)COSM,COSP,COSR,FC,PV,REC,D
      READ(10,*)LD,COSS
      DO 12 I=1,10
         TS(I)=0
```

```
   12 CONTINUE
      SP=1000000000
      SP1=10.0E+30
      MAR5=1
      CALL INI1(M,T,TC,NC,N,MAR4,MAR3)
    4 CALL INI2(I4,I1,MAR2,A7,K1,MAR,N1,N)
      CALL ASIG(N,M,C,A,D1)
      MS=0
      NS=N
      DO 13 I=1,N
         AS(I,1)=A(I,1)
         DS(I,1)=A(I,1)
         AS(I,2)=A(I,2)
         AS(I,3)=0
         DS(I,3)=0
         DS(I,2)=A(I,2)
         CS(I,1)=A(I,1)
         CS(I,2)=A(I,2)
   13 CONTINUE
      L2=0
      CALL ASI2(CM,CP,CR,CAM,CAP,CAR)
      DO 800 J=3,M
C  FIND THE BALANCING CUT OFF GRADES
        J1=1
        CALL BACUT(N1,A,CUT,QM,J,A7,T,QC)
        CALL AVRG(N1,A,J,QR,T,L1,A4,V)
        CA=1.0E+08
        DO 75 I=1,N1
        VM(I)=((PV-COSR)*QR(I)*REC-COSP*QC(I)-(COSM+(FC+D*V)
     +  /CAM)*QM)/CA
        VC(I)=((PV-COSR)*QR(I)*REC-(COSP+(FC+D*V)/CAP)*QC(I)
     +  -COSM*QM)/CA
        VR(I)=((PV-COSR-(FC+D*V)/CAR)*QR(I)*REC-COSP*QC(I)
     +  -COSM*QM)/CA
    75  CONTINUE
C  FIND THE INTERSECCTION
        CALL MIPLA(N1,VM,VC,CUT,GMC1)
        CALL MIREF(N1,VM,VR,CUT,GMR1)
   111  CALL PLAREF(N1,VC,VR,CUT,GCR1)
        IF(T(J).NE.0)THEN
          N1=N1-1
        ENDIF
        N=N1
   127  IF(MAR.EQ.0)THEN
          NPV=0
        ENDIF
        IF(MAR3.EQ.1) THEN
            IF(INC(I4).EQ.SP)THEN
```

```
                I4=I4+1
                GOTO 127
             ENDIF
             NPV=NPV1(I4)*A7
          ENDIF
  128     V=NPV
          CALL SUMAT(N,A,J,A7,T,QM)
          GEM=(COSP/((PV-COSR)*REC))*100
          GEP=((COSP+(FC+D*V)/CAP)/((PV-COSR)*REC))*100
          GER=(COSP/((PV-COSR-(FC+D*V)/CAR)*REC))*100
          CALL ENOC(GMC1,GMR1,GCR1,GEM,GEP,GER,OCG,MED,CHU)
  171     OCG=MED
          L=0
          DO 180 I=1,N
             IF(OCG.GE.A(I,1).AND.OCG.LT.A(I,2)) THEN
               L=I
               GOTO 184
             ELSE
               GOTO 180
             ENDIF
  180     CONTINUE
          IF(L.EQ.0) THEN
             DO 183 I=1,N
                IF(OCG.GT.A(I,1))  THEN
                    GOTO 183
                ELSE
                  L=I
                  GOTO 190
                ENDIF
  183        CONTINUE
          ENDIF
  184     DIF=ABS(A(L,1)-OCG)
  185     IF(DIF.LE.0.01) GOTO 190
          A1=A(L,2)-A(L,1)
          A2=A(L,2)-OCG
             A3=A2/A1
             POR=1-A3
             GOTO 300
  190     LA=L
          CALL TONCON(LA,N,A,J,A7,T,STC,REC,STREF,L1)
          GOTO 400
  300     CALL CALINT(N,L,J,M,B,A,OCG,POR)
C   FIND THE INTERVAL FOR THE OCG
          DO 1180 I=1,NS
             IF(OCG.GE.AS(I,1).AND.OCG.LT.AS(I,2))THEN
                 LS=I
                 GOTO 1190
             ELSE
```

```
            GOTO 1180
         ENDIF
1180     CONTINUE
1190     DIF=ABS(AS(LS,1)-OCG)
         IF(DIF.LE.0.01) GOTO 1191
         A1=AS(LS,2)-AS(LS,1)
         A2=AS(LS,2)-OCG
         A3=A2/A1
         POR=1-A3
         J3=3
         M3=3
         CALL CALINT(NS,LS,J3,M3,B,AS,OCG,POR)
         LS=LS+1
1191     LA=L+1
         CALL TONCON(LA,N,A,J,A7,T,STC,REC,STREF,L1)
 400     CALL TONA(QM,CM,STC,CP,STREF,CR,TP,QM1,QC1,QR1)
         IF(TP.LT.1) THEN
            CALL ASI3(QM,STC,STREF,TP,QM1,QC1,QR1,T1)
         ELSE
            T1=1
         ENDIF
         IF(MAR.EQ.1)THEN
            TP=TA
            T1=TA
         ENDIF
 492     P=(PV-COSR)*QR1-COSP*QC1-COSM*QM1-T1*FC
         IF(TP.LT.1) THEN
            NPV=P
         ELSE
            NPV=0
            CALL ASI3(QM,STC,QC1,QM1,QMT,STC4,QC4,QM4)
            TP4=TP
            PB=P
            MAR2=0
            CALL BONGO
            NPV=NPV+TNPB
         ENDIF
         IF(MAR.EQ.1)THEN
           CALL FREDE
           NPV=NPV+TNPF
           TP=TPA
         ENDIF
         CALL CALCTON
         NPV=NPV+TNPC
         IF(MAR.EQ.1)THEN
            TP=TA
         ENDIF
1009     REST=ABS(NPV-V)
```

```
      IF(REST.LE.0.009)THEN
         GOTO 500
      ENDIF
      IF(CHU.LE.0.009)THEN
         GOTO 500
      ENDIF
      IF(MAR.EQ.1)THEN
         GOTO 500
      ELSE
         IF(MAR3.EQ.1)THEN
           GOTO 500
         ENDIF
         CALL ENES(N,D1)
         CALL ENES(NS,DS)
         CALL CAMB(M,N,A,D1)
         CALL CAMB(M3,NS,AS,DS)
         GOTO 128
      ENDIF
C ******************* STOCK PILE ****************************
  500 IF(TP.LE.1)GOTO 3020
      DO 503 I=LD+1,NS
         IF(AS(I,3).NE.0)GOTO 504
  503 CONTINUE
      GOTO 3020
  504 DO 505 I=LD+1,NS
           IF(AS(I,3).EQ.0)THEN
               VAL=AS(I-1,2)
               GOTO 510
           ENDIF
  505 CONTINUE
  510 DO 515 I=1,N
         IF(VAL.GE.A(I,1).AND.VAL.LT.A(I,2))THEN
            L2=I
            GOTO 520
         ENDIF
  515 CONTINUE
  520 DIF1=ABS(VAL-A(L2,1))
      IF(DIF1.LE.0.01)GOTO 525
      A1=A(L2,2)-A(L2,1)
      A2=A(L2,2)-VAL
      A3=A2/A1
      POR=1-A3
      CALL CALINT(N,L2,J,M,B,A,VAL,POR)
      L2=L2+1
  525 CALL TONCON(LA,L2-1,A,J,A7,TS,STC1,REC,STR1,L1)
      QC11=(STC1/STC)*QC1
      QC12=QC1-QC11
      QR11=(STR1/STREF)*QR1
```

```
          QR12=QR1-QR11
          QM11=(QC11/STC)*QM1
          QM12=QM1-QM11
          F1=QM11/QM1
          F2=1-F1
          P1=(PV-COSR)*QR11-COSP*QC11-COSM*QM11-F1*FC
          IF(P1.EQ.0)GOTO 3020
          P2=P-P1
          STC2=STC-STC1
          QMSP=QM-STC1
C STOCK PILE START TO WORK
          CALL TONCON(LS,NS,AS,J3,A7,TS,SSTC,REC,SSTR,L1)
          IF(QC11.GT.SSTC)THEN
C  THERE ARE NOT ORE IN THE STOCK PILE
             PS=0
          ELSE
C FIND THE ANNUAL TONNAGE
             QMS=SSTC
             CALL TONA(QMS,QM11,SSTC,QC11,SSTR,CR,TPS,QMS1
     +       ,QCS1,QRS1)
             PS=(PV-COSR)*QRS1-COSP*QCS1-COSS*QMS1-F1*FC
          ENDIF
          IF(PS.GT.P1)THEN
C SUBSTRACT TONNAGE FROM STOCK PILE
             CALL RESP(AS,LS,NS,SSTC,QCS1)
C STORAGE OPTIMUM OUTPUT
             YEAR(I1)=K1
             TPE(I1)=K1
             INC(I1)=SP
             OPTM(I1)=OCG
             QM2(I1)=QMS1
             QC2(I1)=QCS1
             QR2(I1)=QRS1
             PRF(I1)=PS
             NPV1(I1)=NPV
             I1=I1+1
             QM1=QM12
             QC1=QC12
             QR1=QR12
             P=P2
             MS=1
             CALL ENES(N,A)
             CALL RESS(VAL,A,L2,J,STC2,QC1,QMSP,QM1,LD,AS,NS)
             CALL ENES(NS,AS)
             CALL CAMB(M3,NS,DS,AS)
             CALL RES1(A,L2,J,N,STC2,QC12,T,QMSP,QM12)
             CALL CAMB(M,N,D1,A)
             CALL PRI1(AS,NS,K1)
```

```
            GOTO 3020
C ******************* END STOCK PILE ************************
          ELSE
C    STORAGE OPTIMUM OUTPUT
 302  0     YEAR(I1)=K1
            TPE(I1)=K1
            INC(I1)=J-2
            OPTM(I1)=OCG
            QM2(I1)=QM1
            QC2(I1)=QC1
            QR2(I1)=QR1
            PRF(I1)=P
             NPV1(I1)=NPV
            I1=I1+1
            K1=K1+1
            IF(MS.EQ.1)THEN
              MS=0
              GOTO 127
            ENDIF
          ENDIF
          IF(MAR.EQ.0)THEN
             IF(TP.LE.1) THEN
                 CALL ENES(N,A)
                 CALL ENES(NS,AS)
                 CALL RESS(OCG,A,L,J,STC,QC1,QM,QM1,LD,AS,NS)
                 CALL RESTA(OCG,A,L,J,N,STC,QC1,T,QM,QM1)
                 CALL ENES(NS,AS)
                 CALL CAMB(M3,NS,DS,AS)
                 GOTO 600
             ENDIF
          ELSE
             GOTO 551
          ENDIF
          CALL ENES(N,A)
          CALL ENES(NS,AS)
          CALL RESS(OCG,A,L,J,STC,QC1,QM,QM1,LD,AS,NS)
          CALL RESTA(OCG,A,L,J,N,STC,QC1,T,QM,QM1)
   551    CALL ASI2(CAM,CAP,CAR,CM,CP,CR)
          CALL ENES(N,A)
          CALL ENES(NS,AS)
          CALL CAMB(M,N,D1,A)
          CALL CAMB(M3,NS,DS,AS)
          CALL PRI1(AS,NS,K1-1)
          MAR=0
          I4=I4+1
          MAR4=1
          GOTO 127
    60  0 K1=K1-1
```

```
        CALL ASI3(CM-QM1,CP-QC1,CR-QR1,1-TP,CM,CP,CR,TA)
        MAR=1
        CALL ASIG(N1,M,A,C,D1)
        I4=I4+1
        MAR4=1
  800 CONTINUE
      CALL PRI1(AS,NS,K1)
     CALL PRI2(I1,QM2,A7,QC2,QR2,PRF,NPV1,YEAR,INC,OPTM,NPF)
      DO 850 I=1,I1-1
          TPE1(I)=TPE(I)
  850 CONTINUE
      CALL ONPV(I1,TPE,NPV1,PRF,D)
      DO 2100 I=1,I1-1
         DOF=ABS(NPV1(I)-NPF(I))
         IF(DOF.LE.0.001) THEN
            GOTO 2100
         ELSE
            LA=I1-1
            CALL INTER(LA,NPF,NPV1)
            CALL CAMB(M,NC,A,C)
            CALL CAMB(M3,NC,AS,CS)
            CALL INTER(M,T,TC)
            CALL ASI2(CAM,CAP,CAR,CM,CP,CR)
            N=NC
            MAR3=1
            GOTO 4
         ENDIF
 2100 CONTINUE
C*************************************************************
C  USE THE LAST PART OF THE STOCK PILE AFTER THE PUSH BACK
C  IS FINISHED.
C*************************************************************
      J4=1
      OCG=0
      DO 2300 I=1,NS
        IF(AS(I,3).NE.0)THEN
           AS1(J4,1)=AS(I,1)
           AS1(J4,2)=AS(I,2)
           AS1(J4,3)=AS(I,3)
           J4=J4+1
        ENDIF
 2300 CONTINUE
      NS1=J4-1
      J=3
      I2=I1-1
      CALL BACUT(NS1,AS1,CUT,QM,J,A7,TS,QC)
C   CALCULA LEY PROMEDIO POR INTERVALO
        CALL AVRG(NS1,AS1,J,QR,TS,L1,A4,V)
```

```
C  CALCULA VALOR PRESENTE MINA PLANTA REF
         CA=1.0E+08
         DO 2350 I=1,NS1
         VM(I)=((PV-COSR)*QR(I)*REC-COSP*QC(I)-(COSS+(FC+D*V)/CAM)
      +  *QM)/CA
         VC(I)=((PV-COSR)*QR(I)*REC-(COSP+(FC+D*V)/CAP)*QC(I)
      +  -COSS*QM)/CA
         VR(I)=((PV-COSR-(FC+D*V)/CAR)*QR(I)*REC-COSP*QC(I)
      +  -COSS*QM)/CA
 2350    CONTINUE
C  FIND THE INTERSECCTION
         CALL MIPLA(NS1,VM,VC,CUT,GMC1)
         CALL MIREF(NS1,VM,VR,CUT,GMR1)
         CALL PLAREF(NS1,VC,VR,CUT,GCR1)
C   FIGURE ECONOMIC CUT OFF GRADES
 2400    NPV=0
         OCG=0
 2450    V=NPV
         CALL SUMAT(NS1,AS1,J,A7,TS,QM)
         GEM=(COSP/((PV-COSR)*REC))*100
         GEP=((COSP+(FC+D*V)/CAP)/((PV-COSR)*REC))*100
         GER=(COSP/((PV-COSR-(FC+D*V)/CAR)*REC))*100
         CALL ENOC(GMC1,GMR1,GCR1,GEM,GEP,GER,OCG,MED,CHU)
         OCG=MED
         L=0
         DO 2500 I=1,NS1
            IF(OCG.GE.AS1(I,1).AND.OCG.LT.AS1(I,2)) THEN
              L=I
              GOTO 2550
            ELSE
              GOTO 2500
            ENDIF
 2500    CONTINUE
 2550    DIF=ABS(AS1(L,1)-OCG)
         IF(DIF.LE.0.01) GOTO 2600
         A1=AS1(L,2)-AS1(L,1)
         A2=AS1(L,2)-OCG
            A3=A2/A1
            POR=1-A3
            GOTO 2650
 2600    CALL TONCON(L,NS1,AS1,J,A7,TS,STC,REC,STREF,L1)
         GOTO 2700
C   CALCULA INTERVALOS
         M=3
 2650    CALL CALINT(NS1,L,J,M,B,AS1,OCG,POR)
         LA=L+1
         CALL TONCON(LA,NS1,AS1,J,A7,TS,STC,REC,STREF,L1)
 2700    CALL TONA(QM,CM,STC,CP,STREF,CR,TP,QM1,QC1,QR1)
```

```
          QM1=QC1
          IF(MAR5.EQ.1)THEN
             TP=TA
             T1=TP
          ENDIF
          IF(TP.LT.1) THEN
             QM=STC
             IF(MAR5.EQ.0)THEN
                CALL ASI3(QM,STC,STREF,TP,QM1,QC1,QR1,T1)
             ENDIF
          ELSE
             T1=1
             GOTO 2750
          ENDIF
C  DETERMINAR PROFIT AND NPV
 2750     P=(PV-COSR)*QR1-COSP*QC1-COSS*QM1-T1*FC
          IF(TP.LT.1) THEN
             NPV=(PV-COSR)*QR1-COSP*QC1-COSS*QM1-(FC+D*P)*TP
          ELSE
             NPV=P*(((1+D)**TP-1)/(D*(1+D)**TP))
          ENDIF
          REST=ABS(NPV-V)
          IF(REST.LE.0.009)THEN
             GOTO 2800
          ENDIF
          IF(CHU.GT.0.005)THEN
             GOTO 2450
          ENDIF
 280  0     YEAR(I1)=K1
            TPE1(I1)=K1
            INC(I1)=SP
            OPTM(I1)=OCG
            QM2(I1)=QM1
            QC2(I1)=QC1
            QR2(I1)=QR1
            PRF(I1)=P
             NPV1(I1)=NPV
            I1=I1+1
            K1=K1+1
            IF(TP.LE.1) THEN
                IF(MAR5.EQ.1)THEN
                   MAR5=0
                   CALL ENES(NS1,AS1)
                   CALL RESTA(OCG,AS1,L,J,NAS1,STC,QC1,TS,QM,QM1)
                   CALL ASI2(CAM,CAP,CAR,CM,CP,CR)
                   GOTO 2400
                ENDIF
                GOTO 2850
```

```
          ENDIF
        CALL ENES(NS1,AS1)
        CALL RESTA(OCG,AS1,L,J,NS1,STC,QC1,TS,QM,QM1)
        CALL ASI2(CAM,CAP,CAR,CM,CP,CR)
        GOTO 2400
 2850   DO 2860 I=I2+1,I1-1
           NPV1(I)=NPV1(I)/A7
           PRF(I)=PRF(I)/A7
 2860   CONTINUE
        CALL ONPV(I1,TPE1,NPV1,PRF,D)
        DO 2900 I=1,I2
           QM2(I)=QM2(I)*A7
           QC2(I)=QC2(I)*A7
           QR2(I)=QR2(I)*1000
           PRF(I)=PRF(I)*A7
           NPV1(I)=NPV1(I)*A7
 2900   CONTINUE
        OPTM(I2+1)=OPTM(I2+2)
        DO 2910 I=I2+1,I1-1
           PRF(I)=PRF(I)*A7
           NPV1(I)=NPV1(I)*A7
 2910   CONTINUE
        CALL PRI2(I1,QM2,A7,QC2,QR2,PRF,NPV1,YEAR,INC,OPTM,NPV1)
        END
C*************************************************************
C     SUBROUTINE CALCTON
C   Figure out the contribution in the NPV for the increment
C   J+1 to N
C*************************************************************
      SUBROUTINE CALCTON
      COMMON A(50,10),L1(100),T(100),DIF,OCG,A7,STOT
      COMMON POR,I,J,L,M,N,PRO,REF,REC,K2,E2(50,10),MAR2
      COMMON TP,TP1,TP2,TP3,P,PV,T1,D,CM,CP,CR,FC,COSM
      COMMON COSP,COSR,TNPV,CAM,CAP,CAR,TPA,PB,TB(20)
      COMMON/BONG/QMT,STC4,QM4,QC4,TP4,QR4,DTP,J1
      COMMON TNPB,TNPC,TNPF
      DIMENSION  E1(50,10),TR(20)
      REAL L1,NP,NPA
      MAR2=1
      TE=TP
      MAR1=1
      TNP3=0
      CALL ASI3(1-DTP,CAM-QM4,CAP-QC4,CAR-QR4,TPA,CAM1,CAP1,CAR1)
      CALL CAMB(M,N,E1,A)
      CALL INTER(M,TR,T)
      DO 1500 J1=J+1,M
        TE =TE+TPA
        IF(MAR1.EQ.1)GOTO 1190
```

```
 1504    CALL RESTA(OCG,E1,L,J1,N,STCA,QC1A,TR,QMA,QM1A)
         TE=TE+0
 1190    DIF=ABS(E1(L,1)-OCG)
         IF(DIF.GT.0.0001) GOTO 1330
         CALL TONCON(L,N,E1,J1,A7,TR,STCA,REC,STAREF,L1)
         CALL SUMAT(N,E1,J1,A7,TR,QMA)
         GOTO 1459
 1330    LA=L+1
         CALL TONCON(LA,N,E1,J1,A7,TR,STCA,REC,STAREF,L1)
         CALL SUMAT(N,E1,J1,A7,TR,QMA)
 1459    CALL TONA(QMA,CAM1,STCA,CAP1,STAREF,CAR1,TPA,QM1A,
     +   QC1A,QR1A)
         IF(MAR1.EQ.1) THEN
            T1=1-DTP
         ELSE
            T1=1
         ENDIF
C  DETERMINAR PROFIT AND NPV
 1492    PA=(PV-COSR)*QR1A-COSP*QC1A-COSM*QM1A-T1*FC
         IF(PA.LE.0) THEN
           PA=0
         ENDIF
         IF(MAR1.EQ.1) THEN
            NP=PA
 1493       NPA=NP/(1+D)**TE
         ENDIF
         IF(MAR1.EQ.1) THEN
            CALL ASI2(CAM,CAP,CAR,CAM1,CAP1,CAR1)
            MAR1=0
            TNP3=TNP3+NPA
            GOTO 1504
         ELSE
            CALL ASI2(QM1A,STCA,TPA,QM4,STC4,TP4)
            CALL ASI2(QMA,QC1A,PA,QMT,QC4,PB)
            CALL CAMB(M,N,E2,E1)
            CALL INTER(M,TB,TR)
            CALL BONGO
            ES=TNPB
            ES=ES/(1+D)**TE
            TNP3=TNP3+ES
            CALL ASI2(CAM-QM4,CAP-QC4,CAR-QR4,CAM1,CAP1,CAR1)
            TE=TE+TPA
            TPA=1-DTP
            MAR1=1
         ENDIF
 1500 CONTINUE
      TNPC=TNP3
      RETURN
```

```
      END
C  ***************************************************
C     SUBROUTINE FREDE
C  It is used when begin the develop of a new increment
C  ***************************************************
      SUBROUTINE FREDE
      COMMON A(50,10),L1(100),T(100),DIF,OCG,A7,STOT
      COMMON POR,I,J,L,M,N,PRO,REF,REC,K2,E2(50,10),MAR2
      COMMON TP,TP1,TP2,TP3,P,PV,T1,D,CM,CP,CR,FC,COSM
      COMMON COSP,COSR,TNPV,CAM,CAP,CAR,TPA,PB,TB(20)
      COMMON /FRED/ STC,QC1,QM,QM1
      COMMON/BONG/QMT,STC4,QM4,QC4,TP4,QR4,DTP,J1
      COMMON TNPB,TNPC,TNPF
      REAL L1,NP,NPA
      MAR2=0
      CALL ENES(N,A)
      CALL ENES(NS,AS)
      CALL RESS(OCG,A,L,J,STC,QC1,QM,QM1,LD,AS,NS)
      CALL RESTA(OCG,A,L,J,N,STC,QC1,T,QM,QM1)
      TE=TP
      TPA=0
      TNP4=0
      J1=J
      TE =TE+TPA
      DIF=ABS(A(L,1)-OCG)
      IF(DIF.GT.0.0001) GOTO 2330
      CALL TONCON(L,N,A,J1,A7,T,STCA,REC,STAREF,L1)
      CALL SUMAT(N,A,J1,A7,T,QMA)
      GOTO 2459
 2330   LA=L+1
        CALL TONCON(LA,N,A,J1,A7,T,STCA,REC,STAREF,L1)
        CALL SUMAT(N,A,J1,A7,T,QMA)
 2459   CALL TONA(QMA,CAM,STCA,CAP,STAREF,CAR,TPA,QM1A,QC1A,QR1A)
        IF(TPA.LT.1) THEN
           CALL ASI3(QMA,STCA,STAREF,TPA,QM1A,QC1A,QR1A,T1)
        ELSE
           T1=1
           GOTO 2492
        ENDIF
 2492   PA=(PV-COSR)*QR1A-COSP*QC1A-COSM*QM1A-T1*FC
        IF(TPA.LT.1) THEN
           NP=(PV-COSR)*QR1A-COSP*QC1A-COSM*QM1A-(FC+D*PA)*TPA
        ENDIF
        CALL ASI2(QMA,STCA,QM1A,QMT,STC4,QM4)
        CALL ASI2(QC1A,TPA,PA,QC4,TP4,PB)
        CALL BONGO
        TNP4=TNPB
        TNPF=TNP4+NPA
```

```
      RETURN
      END
C*************************************************************
C       SUBROUTINE BONGO
C  figure out profit and NPV corresponding to the decimal
C   part for each increment
C*************************************************************
      SUBROUTINE BONGO
      COMMON A(50,10),L1(100),T(100),DIF,OCG,A7,STOT
      COMMON POR,I,J,L,M,N,PRO,REF,REC,K2,E2(50,10),MAR2
      COMMON TP,TP1,TP2,TP3,P,PV,T1,D,CM,CP,CR,FC,COSM
      COMMON COSP,COSR,TNPV,CAM,CAP,CAR,TPA,PB,TB(20)
      COMMON/BONG/ QMT,STC4,QM4,QC4,TP4,QR4,DTP,J1
      COMMON TNPB,TNPC,TNPF
      REAL L1,NPV2
      IF(MAR2.EQ.0) THEN
         CALL CAMB(M,N,E2,A)
         CALL INTER(M,TB,T)
      ENDIF
      IF(MAR2.EQ.0) THEN
         J1=J
      ENDIF
      TNP2=0
      NTP=TP4
      DTP=TP4-NTP
      NPV2=PB*(((1+D)**NTP-1)/(D*(D+1)**NTP))
      QM3=QM4*NTP
      QC3=QC4*NTP
      CALL RESTA(OCG,E2,L,J1,N,STC4,QC3,TB,QMT,QM3)
      DIF=ABS(E2(L,1)-OCG)
      IF(DIF.GT.0.0001) GOTO 2330
       CALL TONCON(L,N,E2,J1,A7,TB,STCA,REC,STA,L1)
       CALL SUMAT(N,E2,J1,A7,TB,QMA)
       GOTO 2459
 2330   LA= L+1
        CALL TONCON(LA,N,E2,J1,A7,TB,STCA,REC,STA,L1)
        CALL SUMAT(N,E2,J1,A7,TB,QMA)
 2459   QC4=STCA
        QM4=QMA
        QR4=STA
        T2=DTP
        P1=(PV-COSR)*QR4-COSP*QC4-COSM*QM4-T2*FC
        TNP2=P1/(1+D)**TP4
         TNP2=TNP2+NPV2
        TNPB=TNP2
        RETURN
        END
C *************************************************************
```

```
C     SUBROUTINE ASIG
C  Assign the original matrix A to an auxiliar matrix C & D1
C ********************************************************
      SUBROUTINE ASIG(N,M,C,A,D1)
      DIMENSION A(50,10),C(50,10),D1(50,10)
      DO 9 I=1,N
          DO 8 J=1,M
             C(I,J)=A(I,J)
             D1(I,J)=A(I,J)
    8     CONTINUE
    9 CONTINUE
      RETURN
      END
C ************************************************************
C     SUBROUTINE MIPLA
C   Figure out the balancing cut off grade corresponding to mine
C   and concentrator
C ************************************************************
      SUBROUTINE MIPLA(N1,VM,VC,CUT,GMC1)
      DIMENSION VM(200),VC(200),CUT(100)
      REAL M1,M2
      DO 90 I=1,N1
         M1=(VM(I)-VM(I+1))/(CUT(I)-CUT(I+1))
         M2=(VC(I)-VC(I+1))/(CUT(I)-CUT(I+1))
         B1=VM(I)-M1*CUT(I)
         A1=M1
         B2=VC(I)-M2*CUT(I)
           A2=M2
         IF((M2-M1).EQ.0) GOTO 90
         X=(B2-B1)/(A1-A2)
         Y=A1*((B2-B1)/(A1-A2))+B1
         IF(CUT(I).LE.X.AND.CUT(I+1).GE.X) GOTO 95
         GOTO 90
   8 0   IF(VM(I).LE.Y.OR.VM(I+1).GE.Y) GOTO 95
   90 CONTINUE
   95 IF(X.LE.0) THEN
          D3=ABS(VM(N1)-VC(N1))
          D2=ABS(VM(1)-VC(1))
          IF(D2.GT.D3) THEN
             GMC1=CUT(N1)
          ELSE
             GMC1=0
          ENDIF
      ELSE
          GMC1=X
      ENDIF
      RETURN
      END
```

```
C ****************************************************
C     SUBROUTINE MIREF
C  Figure out the balancing cut off grade corresponding
C  to mine and refinery
C ****************************************************
      SUBROUTINE MIREF(N1,VM,VR,CUT,GMR1)
      DIMENSION VM(200),VR(200),CUT(100)
      REAL M1,M2
      DO 105 I=1,N1
          M1=(VM(I)-VM(I+1))/(CUT(I)-CUT(I+1))
          M2=(VR(I)-VR(I+1))/(CUT(I)-CUT(I+1))
          B1=VM(I)-M1*CUT(I)
          A1=M1
          B2=VR(I)-M2*CUT(I)
          A2=M2
          IF((M2-M1).EQ.0) GOTO 105
          X=(B2-B1)/(A1-A2)
          Y=A1*((B2-B1)/(A1-A2))+B1
          IF(CUT(I).LE.X.AND.CUT(I+1).GE.X) GOTO 110
          GOTO 105
  10  0   IF(VM(I).LE.Y.OR.VM(I+1).GE.Y) GOTO 110
  105 CONTINUE
  110 IF (X.LE.0) THEN
            D3=ABS(VM(N1)-VR(N1))
            D2=ABS(VM(1)-VR(1))
            IF(D2.GT.D3) THEN
                GMR1=CUT(N1)
            ELSE
                GMR1=0
            ENDIF
      ELSE
            GMR1=X
      ENDIF
      RETURN
      END
C ****************************************************
C     SUBROUTINE PLAREF
C  Figure out the balancing cut off grade corrsponding
C  to concentrator and refinery
C ****************************************************
      SUBROUTINE PLAREF(N1,VC,VR,CUT,GCR1)
      DIMENSION VC(200),VR(200),CUT(100)
      REAL M1,M2
      DO 120 I=1,N1
          M1=(VC(I)-VC(I+1))/(CUT(I)-CUT(I+1))
          M2=(VR(I)-VR(I+1))/(CUT(I)-CUT(I+1))
          B1=VC(I)-M1*CUT(I)
          A1=M1
```

```
          B2=VR(I)-M2*CUT(I)
          A2=M2
          IF((M2-M1).EQ.0) GOTO 120
          X=(B2-B1)/(A1-A2)
          Y=A1*((B2-B1)/(A1-A2)) +B1
          IF(CUT(I).LE.X.AND.CUT(I+1).GE.X) GOTO 125
          GOTO 120
  115     IF(VC(I).LE.Y.AND.VC(I+1).LE.Y) GOTO 125
  120 CONTINUE
  125 IF(X.LE.0.0001) THEN
           D3=ABS(VC(N1)-VR(N1))
           D2=ABS(VC(1)-VR(1))
           IF(D2.GT.D3) THEN
               GCR1=CUT(N1)
           ELSE
                 GCR1=0
           ENDIF
      ELSE
           GCR1=X
      ENDIF
      RETURN
      END
C ***************************************************
C     SUBROUTIINE SUMAT
C  Figure out the tonnage by increment
C ***************************************************
      SUBROUTINE SUMAT(N,A,J,A7,T,QM)
      DIMENSION A(50,10),T(100)
      QM=0
      DO 129 I=1,N
         QM=QM+A(I,J)*A7
  129 CONTINUE
      QM=QM+T(J)*A7
      RETURN
      END
C ***********************************************************
C     SUBROUTINE ENOC
C  Find the optimum cut off grade OCG
C ***********************************************************
      SUBROUTINE ENOC(GMC1,GMR1,GCR1,GEM,GEP,GER,OCG,MED,CHU)
      REAL MED,MAY
      IF(GMC1.LE.GEM)THEN
           GMC=GEM
      ENDIF
      IF(GMC1.GE.GEP)THEN
           GMC=GEP
      ELSE
           GMC=GMC1
```

```
      ENDIF
      IF(GMR1.LE.GEM)THEN
           GMR=GEM
      ENDIF
      IF(GMR1.GE.GER)THEN
           GMR =GER
      ELSE
           GMR=GMR1
      ENDIF
      IF(GCR1.LE.GER)THEN
          GCR=GER
      ENDIF
      IF(GCR1.GE.GEP)THEN
           GCR=GEP
      ELSE
           GCR=GCR1
      ENDIF
      MAY=GMC
      IF(MAY.GE.GMR) GOTO 130
      MAY=GMR
  130 IF(MAY.GE.GCR) GOTO 135
      MAY=GCR
  135 IF(GMC.EQ.MAY) GOTO 140
      IF(GMR.EQ.MAY) GOTO 145
      IF(GMC.LE.GMR) GOTO 150
      MED=GMC
      GOTO 170
  140 IF(GMR.LE.GCR) GOTO 160
      MED=GMR
      GOTO 170
  145 IF(GMC.LE.GCR) GOTO 160
      MED=GMC
      GOTO 170
  150 MED=GMR
      GOTO 170
  160 MED=GCR
      GOTO 170
  170 CHU=ABS(OCG-MED)
      RETURN
      END
C *******************************************************
C     SUBROUTINE TONCON
C  Figure out the total tonnage to send to  concentrator
C  and total tonnage refining
C *******************************************************
      SUBROUTINE TONCON(LA,N,A,J,A7,T,STC,REC,STREF,L1)
      DIMENSION A(50,10),T(100)
      REAL L1(100)
```

```
      STC=0
      DO 200 I=LA,N
          STC=STC+A(I,J)*A7
  200 CONTINUE
      STC=STC+T(J)*A7
      STREF=0
      DO 210 I=LA,N
           PRO=(A(I,1)+A(I,2))/2
           REF=A(I,J)*PRO*10000*REC
           STREF=STREF+REF
  210 CONTINUE
      STREF=STREF+T(J)*L1(J)*10000*REC
      RETURN
      END
C ***************************************************************
C     SUBROUTINE TONA
C  Figure out annual tonnage and time
C ***************************************************************
      SUBROUTINE TONA(QM,CM,STC,CP,STREF,CR,TP,QM1,QC1,QR1)
        TP1=QM/CM
        TP2=STC/CP
        TP3=STREF/CR
        IF(TP1.GE.TP2.AND.TP1.GE.TP3) GOTO 460
        IF(TP2.GE.TP1.AND.TP2.GE.TP3) GOTO 470
        IF(TP3.GE.TP1.AND.TP3.GE.TP2) GOTO 480
  460   QM1=QM/TP1
        QC1=STC/TP1
        QR1=STREF/TP1
        TP=TP1
        GOTO 490
  470   QM1=QM/TP2
        QC1=STC/TP2
        QR1=STREF/TP2
        TP=TP2
        GOTO 490
  480   QM1=QM/TP3
        QC1=STC/TP3
        QR1=STREF/TP3
          TP=TP3
  490   RETURN
        END
C ***************************************************
C       SUBROUTINE CAMB
C  Actualization matrix
C ***************************************************
        SUBROUTINE CAMB(M,N,A,D1)
        DIMENSION A(50,10),D1(50,10)
        DO 494 I3=1,M
```

```
            DO 493 I5=1,N
                 A(I5,I3)=D1(I5,I3)
  493       CONTINUE
  494     CONTINUE
          RETURN
          END


C *******************************************************
C         SUBROUTINE RESTA
C  Subtrac the total annual tonnage and the concentrator
C  tonnage to the increment.
C *******************************************************
          SUBROUTINE RESTA(OCG,A,L,J,N,STC,QC1,T,QM,QM1)
          DIMENSION A(50,10),T(100)
C  HACER LAS RESTAS DE TONELAJES POR INTERVALO
          DIFE=ABS(OCG-A(L,1))
          IF(DIFE.LE.0.01) GOTO 520
C   CASO NUEVO INTERVALO
          DO 505 I=L+1,N
             A(I,J)=A(I,J)-(A(I,J)/STC)*QC1
  505     CONTINUE
          T(J)=T(J)-(T(J)/STC)*QC1
          DO 510 I=1,L
             A(I,J)=A(I,J)-(A(I,J)/(QM-STC))*(QM1-QC1)
  510     CONTINUE
          GOTO 550
C  CASO EXACTO
  520     DO 525 I=L,N
             A(I,J)=A(I,J)-(A(I,J)/STC)*QC1
  525     CONTINUE
          T(J)=T(J)-(T(J)/STC)*QC1
          DO 530 I=1,L-1
             A(I,J)=A(I,J)-(A(I,J)/(QM-STC))*(QM1-QC1)
  530     CONTINUE
  550     RETURN
          END
C *******************************************************
C         SUBROUTINE INTER
C Actualization vector
C *******************************************************
          SUBROUTINE INTER(M,TB,TR)
          DIMENSION TB(100),TR(100)
          DO 2130 J1=1,M
              TB(J1)=TR(J1)
 2130     CONTINUE
          RETURN
```

```
      END
C ******************************************************
C    SUBROUTINE BACUT
C  Find the total and concentrator tonnage as a function
C  of the cut off grade
C ******************************************************
      SUBROUTINE BACUT(N1,A,CUT,QM,J,A7,T,QC)
      DIMENSION A(50,10),CUT(100),T(100),QC(100)
        DO 30 I=1,N1
          CUT(I)=A(I,1)
   30   CONTINUE
        CUT(N1+1)=0.70
C  TOTAL TONS IN THE INC.
        QM=0
        DO 35 I=1,N1
         QM=QM + A(I,J)*A7
   35   CONTINUE
        M1=1
        IF(T(J).EQ.0) GOTO 37
         QM=QM+T(J)*A7
   3 7    DO 50 I=1,N1
          ST=0
              DO 40 L=M1,N1
             ST=ST+A(L,J)*A7
   40       CONTINUE
          QC(I)=ST+T(J)*A7
          M1=M1+1
   50   CONTINUE
        QC(N1+1)=T(J)*A7
      RETURN
      END
C ******************************************************
C     SUBROUTINE AVRG
C  Find the refining tonnage as a function of the
C  cutoff grade
C ******************************************************
      SUBROUTINE AVRG(N1,A,J,QR,T,L1,A4,V)
      DIMENSION A(50,10),T(100),QR(200)
      REAL L1(100),LP(100)
        DO 60 I=1,N1
          LP(I)=(A(I,1)+A(I,2))/2
   60   CONTINUE
        M1=1
        DO 65 I=1,N1
          ST=0
          DO 63 L=M1,N1
            FINO=A(L,J)*LP(L)*10000
               ST=ST+FINO
```

```
   63      CONTINUE
           QR(I)=ST + T(J)*L1(J)*10000
           M1=M1+1
   65    CONTINUE
         IF(T(J).EQ.0) GOTO 70
         QR(N1+1)=T(J)*L1(J)*10000
         N1=N1+1
   70    A4=0
         V=0.
       RETURN
       END
C ************************************************
C    SUBROUTINE INI1
C  Initiation of variables one time in the program
C ************************************************
       SUBROUTINE INI1(M,T,TC,NC,N,MAR4,MAR3)
       DIMENSION T(100),TC(20)
       DO 2 J=1,M
          TC(J)=T(J)
     2 CONTINUE
       NC=N
       MAR4=0
       MAR3=0
       RETURN
       END
C ********************************************
C   SUBROUTINE INI2
C  Initiayion of variables by each iteration.
C ********************************************
       SUBROUTINE INI2(I4,I1,MAR2,A7,K1,MAR,N1,N)
       I4=1
       I1=1
       MAR2=0
       A7=1000000.
       K1=1
       MAR=0
       N1=N
       RETURN
       END
C ****************************************
C    SUBROUTINE ASI2
C  Assign variables 3
C ****************************************
       SUBROUTINE ASI2(CM,CP,CR,CAM,CAP,CAR)
       CAM=CM
       CAP=CP
       CAR=CR
       RETURN
```

```
      END
C ****************************************************
C    SUBROUTINE ASI3
C  Assign variables 4
C ****************************************************
      SUBROUTINE ASI3(QM,STC,STREF,TP,QM1,QC1,QR1,T1)
      QM1=QM
      QC1=STC
      QR1=STREF
      T1=TP
      RETURN
      END
C ****************************************************
C     SUBROUTINE CALINT
C  Find and create the interval for the op. cut. grade
C ****************************************************
      SUBROUTINE CALINT(N,L,J,M,B,A,OCG,POR)
      DIMENSION A(50,10),B(50,10)
      K2=0
        DO 320 I=1,N
           K2=K2+1
           IF(I.EQ.L) GOTO 310
           B(K2,1)=A(I,1)
           B(K2,2)=A(I,2)
           DO 301 J1=J,M
              B(K2,J1)=A(I,J1)
  301      CONTINUE
           GOTO 320
  310      B(L,1)=A(I,1)
           B(L,2)=OCG
           DO 311 J1=J,M
              B(L,J1)=A(I,J1)*POR
  311      CONTINUE
           B(L+1,1)=OCG
           B(L+1,2)=A(I,2)
           DO 312 J1=J,M
              B(L+1,J1)=A(I,J1)-A(I,J1)*POR
  312      CONTINUE
           K2=K2+1
  320   CONTINUE
        N=N+1
        DO 321 I=1,N
           A(I,1)=B(I,1)
           A(I,2)=B(I,2)
           DO 313 J1=J,M
              A(I,J1)=B(I,J1)
  313      CONTINUE
  321   CONTINUE
```

```
      RETURN
      END
C *****************************************
C    SUBROUTINE PRI1
C  Print the Stock pile grade categories
C *****************************************
      SUBROUTINE PRI1(AS,NS,K1)
      DIMENSION AS(50,10)
      SUM=0
      WRITE(200,*)
      WRITE(200,100)
      WRITE(200,105)K1
      WRITE(200,110)
      WRITE(200,120)
      WRITE(200,130)
      DO 10 I=1,NS
         IF(AS(I,3).NE.0)THEN
           PROM=(AS(I,1)+AS(I,2))/2
           WRITE(200,140)AS(I,1),AS(I,2),PROM,AS(I,3)
           SUM=SUM+AS(I,3)
         ENDIF
   10 CONTINUE
      WRITE(200,150)
      WRITE(200,160)SUM
  100 FORMAT(22X,'STOCK PILE GRADE DISTRIBUTION')
  105 FORMAT(22X,'          YEAR  ',I2)
  110 FORMAT(28X,'GRADE')
  120 FORMAT(25X,'CATEGORIES  AVRG TONNAGE')
  130 FORMAT(28X,'%')
  140 FORMAT(24X,F5.3,1X,F5.3,1X,F5.3,1X,F5.1)
  150 FORMAT(24X,'---------------------------')
  160 FORMAT(36X,'TOTAL:',1X,F6.1)
      RETURN
      END
C *****************************************
C     SUBROUTINE PRI2
C       Print the final optimum output
C *****************************************
      SUBROUTINE PRI2(I1,QM2,A7,QC2,QR2,PRF,NPV1,YEAR,
     +INC,OPTM,NPF)
      DIMENSION QM2(100),QC2(100),QR2(100),PRF(100)
      DIMENSION YEAR(100),OPTM(100)
      REAL NPV1(100),INC(100),NPF(100)
C  PRINT THE FINAL OUTPUT
      WRITE(200,*)
      WRITE(200,*)
      WRITE(200,*)
      WRITE(200,1080)
```

```
      DO 810 I=1,I1-1
      QM2(I)=QM2(I)/A7
      QC2(I)=QC2(I)/A7
      QR2(I)=QR2(I)/1000
      PRF(I)=PRF(I)/A7
      NPV1(I)=NPV1(I)/A7
      WRITE(200,1090)YEAR(I),INC(I),OPTM(I),QM2(I),QC2(I)
     +,QR2(I),PRF(I),NPF(I)
  810 CONTINUE
      WRITE(200,*)
      WRITE(200,1095)
 1080 FORMAT('YEAR',3X,'INC',3X,'COG',6X,'QM',7X,'QC',7X,
     +,'QR',5X,'PROF',8X,'NPV')
 1090 FORMAT(F3.0,3X,F4.2,F6.2,3X,F6.1,3X,F6.1,4X,F5.1
     +,3X,F5.1,7X,F8.2)
 1095 FORMAT('****:MINERAL FROM STOCK PILE')
      RETURN
      END
C*************************************************************
C     SUBROUTINE ONPV
C  This subroutine figure out the optimum NPV considering
C  all profits
C*************************************************************
      SUBROUTINE ONPV(I1,TPE,NPV1,PRF,D)
      DIMENSION TPE(100),PRF(100)
      REAL NPV1(100)
      DO 1200 K3=1,I1-1
         SP=0
         IF(TPE(K3).EQ.0) THEN
              NPV1(K3)=NPV1(K3-1)
         ELSE
            DO 1999 I=K3,I1-1
               SP=SP+PRF(I)/(1+D)**TPE(I)
 1999       CONTINUE
            NPV1(K3)=SP
            IF(TPE(K3).GE.1) THEN
               DO 2001 I=1,I1-1
                  TPE(I)=TPE(I)-1
 2001          CONTINUE
            ENDIF
         ENDIF
 1200 CONTINUE
      RETURN
      END
C *************************************************************
C       SUBROUTINE RESS
C  Substrac the total annual tonnage and the concentrator
C  tonnage to the increment, and create the stock pile.
```

```
C ******************************************************
      SUBROUTINE RESS(OCG,A,L,J,STC,QC1,QM,QM1,LD,AS,NS)
      DIMENSION A(50,10),T(100),AS(50,10)
      DIFE=ABS(OCG-A(L,1))
      IF(DIFE.LE.0.01) GOTO 520
      I4=LD+1
      DO 515 I=LD+1,L
        IF(A(I,1).EQ.AS(I4,1).AND.A(I,2).EQ.AS(I4,2))THEN
            AS(I,3)=((A(I,J)/(QM-STC))*(QM1-QC1))+AS(I,3)
            I4=I4+1
        ELSE
          DO 516 I2=I4,NS
            IF(A(I,2).EQ.AS(I2,2))THEN
              AMT=A(I,2)-A(I,1)
              DO 517 I3=I4,I2
               POR1=(AS(I3,2)-AS(I3,1))/AMT
               AS(I3,3)=(POR1*(A(I,J)/(QM-STC))*(QM1-QC1))
     +          +AS(I3,3)
  517         CONTINUE
              I4=I2+1
              GOTO 515
            ELSE
              GOTO 516
            ENDIF
  516     CONTINUE
        ENDIF
  515 CONTINUE
      GOTO 550
C ***************** CASE EXACT ****************
  520 I4=LD+1
      DO 535 I=LD+1,L-1
        IF(A(I,1).EQ.AS(I4,1).AND.A(I,2).EQ.AS(I4,2))THEN
             AS(I,3)=((A(I,J)/(QM-STC))*(QM1-QC1))+AS(I,3)
             I4=I4+1
        ELSE
          DO 536 I2=I4,NS
            IF(A(I,2).EQ.AS(I2,2))THEN
              AMT=A(I,2)-A(I,1)
              DO 537 I3=I4,I2
               POR1=(AS(I3,2)-AS(I3,1))/AMT
               AS(I3,3)=(POR1*(A(I,J)/(QM-STC))*(QM1-QC1))
     +          +AS(I3,3)
  537         CONTINUE
              I4=I2+1
              GOTO 535
            ELSE
              GOTO 536
            ENDIF
```

```
  536        CONTINUE
            ENDIF
  535     CONTINUE
  550     RETURN
          END
C ******************************************************
C       SUBROUTINE RESP
C  Substract the annual tonnage from the stock pile.
C ******************************************************
        SUBROUTINE RESP(AS,LS,L2,SSTC,QCS1)
        DIMENSION AS(50,10)
        DO 100 I=LS,L2
           AS(I,3)=AS(I,3)-((AS(I,3)/SSTC)*QCS1)
  100 CONTINUE
        RETURN
        END
C ******************************************************
C       SUBROUTINE ENES
C   Determine the exact length of the matrix A & AS
C ******************************************************
        SUBROUTINE ENES(N,A)
        DIMENSION A(50,10)
        DO 10 I=1,N
           IF(A(I,2).EQ.0.7)THEN
              N=I
              RETURN
           ELSE
              GOTO 10
           ENDIF
   10 CONTINUE
        RETURN
        END
C ******************************************************
C         SUBROUTINE RES1
C  Subtrac the total annual tonnage and the concentrator
C  tonnage to the increment when the stock pile is used.
C ******************************************************
          SUBROUTINE RES1(A,L2,J,N,STC,QC1,T,QM,QM1)
          DIMENSION A(50,10),T(100)
          DO 505 I=L2,N
             A(I,J)=A(I,J)-(A(I,J)/STC)*QC1
  505     CONTINUE
          T(J)=T(J)-(T(J)/STC)*QC1
          DO 510 I=1,L2-1
             A(I,J)=A(I,J)-(A(I,J)/(QM-STC))*(QM1-QC1)
  510     CONTINUE
  550     RETURN
          END
```

APPENDIX D

OUTPUT FROM THE PROGRAM SP.FOR

STOCK PILE GRADE DISTRIBUTION
YEAR 1

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	.5
.250	.300	.275	.8
.300	.350	.325	.7
.350	.400	.375	.7
.400	.450	.425	.7
.450	.500	.475	.7
		TOTAL:	4.1

STOCK PILE GRADE DISTRIBUTION
YEAR 2

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	.9
.250	.300	.275	1.5
.300	.350	.325	1.5
.350	.400	.375	1.5
.400	.450	.425	1.4
.450	.500	.475	1.3
		TOTAL:	8.1

STOCK PILE GRADE DISTRIBUTION
YEAR 3

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	1.4
.250	.300	.275	2.3
.300	.350	.325	2.2
.350	.400	.375	2.2
.400	.450	.425	2.1
.450	.500	.475	2.0
		TOTAL:	12.2

STOCK PILE GRADE DISTRIBUTION
YEAR 4

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	1.9
.250	.300	.275	3.1
.300	.350	.325	3.0
.350	.400	.375	2.9
.400	.450	.425	2.8
.450	.500	.475	2.7
		TOTAL:	16.3

STOCK PILE GRADE DISTRIBUTION
YEAR 5

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	2.3
.250	.300	.275	3.8
.300	.350	.325	3.7
.350	.400	.375	3.6
.400	.450	.425	3.5
.450	.500	.475	3.4
		TOTAL:	20.4

STOCK PILE GRADE DISTRIBUTION
YEAR 6

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	2.6
.250	.300	.275	4.3
.300	.350	.325	4.2
.350	.400	.375	4.1
.400	.450	.425	3.9
.450	.500	.475	3.8
		TOTAL:	22.9

STOCK PILE GRADE DISTRIBUTION
YEAR 7

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	3.2
.250	.300	.275	5.2
.300	.350	.325	5.1
.350	.400	.375	5.0
.400	.450	.425	4.8
.450	.500	.475	4.6
.500	.528	.514	.4
		TOTAL:	28.4

STOCK PILE GRADE DISTRIBUTION
YEAR 8

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	3.8
.250	.300	.275	6.2
.300	.350	.325	6.0
.350	.400	.375	5.9
.400	.450	.425	5.6
.450	.500	.475	5.4
.500	.528	.514	.9
		TOTAL:	33.8

STOCK PILE GRADE DISTRIBUTION
YEAR 9

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	4.4
.250	.300	.275	7.1
.300	.350	.325	6.9
.350	.400	.375	6.7
.400	.450	.425	6.5
.450	.500	.475	6.3
.500	.528	.514	1.3
		TOTAL:	39.2

STOCK PILE GRADE DISTRIBUTION
YEAR 10

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	5.0
.250	.300	.275	8.1
.300	.350	.325	7.8
.350	.400	.375	7.6
.400	.450	.425	7.3
.450	.500	.475	7.1
.500	.528	.514	1.8
		TOTAL:	44.6

STOCK PILE GRADE DISTRIBUTION
YEAR 11

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	5.4
.250	.300	.275	8.7
.300	.350	.325	8.4
.350	.400	.375	8.2
.400	.450	.425	7.9
.450	.469	.459	2.9
.469	.500	.484	4.7
.500	.528	.514	2.0
		TOTAL:	48.1

STOCK PILE GRADE DISTRIBUTION
YEAR 12

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	6.0
.250	.300	.275	9.7
.300	.350	.325	9.3
.350	.400	.375	9.1
.400	.450	.425	8.8
.450	.469	.459	3.2
.469	.500	.484	4.7
.500	.528	.514	2.0
		TOTAL:	53.0

STOCK PILE GRADE DISTRIBUTION
YEAR 13

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	6.7
.250	.300	.275	10.8
.300	.350	.325	10.3
.350	.400	.375	10.1
.400	.450	.425	9.7
.450	.469	.459	3.6
.469	.500	.484	4.7
.500	.528	.514	2.0
		TOTAL:	57.9

STOCK PILE GRADE DISTRIBUTION
YEAR 14

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	7.3
.250	.300	.275	11.8
.300	.350	.325	11.3
.350	.400	.375	11.0
.400	.450	.425	10.6
.450	.469	.459	3.9
.469	.500	.484	4.7
.500	.528	.514	2.0
		TOTAL:	62.7

STOCK PILE GRADE DISTRIBUTION
YEAR 15

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	7.9
.250	.300	.275	12.9
.300	.350	.325	12.3
.350	.400	.375	11.9
.400	.450	.425	11.5
.450	.469	.459	4.2
.469	.500	.484	4.6
.500	.528	.514	2.2
		TOTAL:	67.5

STOCK PILE GRADE DISTRIBUTION
YEAR 16

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	8.4
.250	.300	.275	13.6
.300	.350	.325	12.9
.350	.400	.375	12.5
.400	.410	.405	2.5
.410	.450	.430	9.7
.450	.469	.459	4.4
.469	.500	.484	4.6
.500	.528	.514	2.2
		TOTAL:	70.7

STOCK PILE GRADE DISTRIBUTION
YEAR 17

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	9.1
.250	.300	.275	14.7
.300	.350	.325	14.0
.350	.400	.375	13.6
.400	.410	.405	2.7
.410	.450	.430	9.7
.450	.469	.459	4.4
.469	.500	.484	4.6
.500	.528	.514	2.2
		TOTAL:	74.9

STOCK PILE GRADE DISTRIBUTION
YEAR 18

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	9.8
.250	.300	.275	15.8
.300	.350	.325	15.1
.350	.400	.375	14.7
.400	.410	.405	2.9
.410	.450	.430	9.7

.450	.469	.459	4.4
.469	.500	.484	4.6
.500	.528	.514	2.2
		TOTAL:	79.1

STOCK PILE GRADE DISTRIBUTION
YEAR 19

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	10.5
.250	.300	.275	16.9
.300	.350	.325	16.2
.350	.400	.375	15.7
.400	.410	.405	3.1
.410	.450	.430	9.7
.450	.469	.459	4.4
.469	.500	.484	4.6
.500	.528	.514	2.2
		TOTAL:	83.3

STOCK PILE GRADE DISTRIBUTION
YEAR 20

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	11.2
.250	.300	.275	18.0
.300	.350	.325	17.3
.350	.400	.375	16.7
.400	.410	.405	3.3
.410	.450	.430	9.4
.450	.469	.459	4.3
.469	.500	.484	5.1
.500	.528	.514	2.0
		TOTAL:	87.2

STOCK PILE GRADE DISTRIBUTION
YEAR 21

GRADE CATEGORIES %		AVRG	TONNAGE

.230	.250	.240	11.7
.250	.300	.275	18.8
.300	.350	.325	18.0
.350	.400	.375	17.5
.400	.410	.405	3.4
.410	.450	.430	9.4
.450	.469	.459	4.3
.469	.500	.484	5.1
.500	.528	.514	2.0
		TOTAL:	90.2

STOCK PILE GRADE DISTRIBUTION
YEAR 22

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	12.5
.250	.300	.275	20.1
.300	.350	.325	19.3
.350	.400	.375	17.5
.400	.410	.405	3.4
.410	.450	.430	9.4
.450	.469	.459	4.3
.469	.500	.484	5.1
.500	.528	.514	2.0
		TOTAL:	93.5

STOCK PILE GRADE DISTRIBUTION
YEAR 23

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	13.3
.250	.300	.275	21.3
.300	.350	.325	20.5
.350	.400	.375	17.5
.400	.410	.405	3.4
.410	.450	.430	9.4
.450	.469	.459	4.3
.469	.500	.484	5.1
.500	.528	.514	2.0
		TOTAL:	96.8

STOCK PILE GRADE DISTRIBUTION
YEAR 24

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	14.1
.250	.300	.275	22.6
.300	.350	.325	21.7
.350	.400	.375	17.5
.400	.410	.405	3.4
.410	.450	.430	9.4
.450	.469	.459	4.3
.469	.500	.484	5.1
.500	.528	.514	2.0
		TOTAL:	100.1

STOCK PILE GRADE DISTRIBUTION
YEAR 25

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	14.9
.250	.300	.275	23.8
.300	.350	.325	22.9
.350	.400	.375	18.5
.400	.410	.405	3.6
.410	.450	.430	8.5
.450	.469	.459	4.4
.469	.500	.484	4.8
.500	.528	.514	1.6
		TOTAL:	103.0

STOCK PILE GRADE DISTRIBUTION
YEAR 26

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	15.5
.250	.293	.272	21.4
.293	.300	.297	3.4
.300	.350	.325	23.8
.350	.400	.375	18.5
.400	.410	.405	3.6
.410	.450	.430	8.5

.450	.469	.459	4.4
.469	.500	.484	4.8
.500	.528	.514	1.6
		TOTAL:	105.5

STOCK PILE GRADE DISTRIBUTION
YEAR 27

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	16.4
.250	.293	.272	22.6
.293	.300	.297	3.4
.300	.350	.325	23.8
.350	.400	.375	18.5
.400	.410	.405	3.6
.410	.450	.430	8.5
.450	.469	.459	4.4
.469	.500	.484	4.8
.500	.528	.514	1.6
		TOTAL:	107.7

STOCK PILE GRADE DISTRIBUTION
YEAR 28

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	17.3
.250	.293	.272	23.9
.293	.300	.297	3.4
.300	.350	.325	23.8
.350	.400	.375	18.5
.400	.410	.405	3.6
.410	.450	.430	8.5
.450	.469	.459	4.4
.469	.500	.484	4.8
.500	.528	.514	1.6
		TOTAL:	109.8

STOCK PILE GRADE DISTRIBUTION
YEAR 29

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	18.3
.250	.293	.272	25.2
.293	.300	.297	3.4
.300	.350	.325	23.8
.350	.400	.375	18.5
.400	.410	.405	3.6
.410	.450	.430	8.5
.450	.469	.459	4.4
.469	.500	.484	4.8
.500	.528	.514	1.6
		TOTAL:	112.0

STOCK PILE GRADE DISTRIBUTION
YEAR 30

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	19.1
.250	.293	.272	26.3
.293	.300	.297	3.3
.300	.350	.325	23.1
.350	.400	.375	18.2
.400	.410	.405	3.5
.410	.450	.430	8.6
.450	.469	.459	4.9
.469	.500	.484	5.0
.500	.528	.514	1.5
		TOTAL:	113.6

STOCK PILE GRADE DISTRIBUTION
YEAR 31

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	19.9
.250	.293	.272	27.3
.293	.300	.297	3.3
.300	.350	.325	23.1
.350	.400	.375	18.2

.400	.410	.405	3.5
.410	.450	.430	8.6
.450	.469	.459	4.9
.469	.500	.484	5.0
.500	.528	.514	1.5
		TOTAL:	115.4

STOCK PILE GRADE DISTRIBUTION
YEAR 31

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	19.9
.250	.293	.272	27.3
.293	.300	.297	3.3
.300	.350	.325	23.1
.350	.400	.375	18.2
.400	.410	.405	3.5
.410	.450	.430	8.6
.450	.469	.459	4.9
.469	.500	.484	5.0
.500	.528	.514	1.5
.500	.528	.514	4.4
.528	.550	.539	4.8
		TOTAL:	124.5

STOCK PILE GRADE DISTRIBUTION
YEAR 32

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	19.5
.250	.284	.267	21.3
.284	.293	.289	5.5
.293	.300	.297	3.2
.300	.350	.325	22.7
.350	.400	.375	17.9
.400	.410	.405	3.5
.410	.450	.430	8.5
.450	.469	.459	4.8
.469	.500	.484	4.9
.500	.528	.514	1.4
.500	.528	.514	4.3
.528	.550	.539	4.7

.550	.600	.575	1.6
		TOTAL:	123.9

STOCK PILE GRADE DISTRIBUTION
YEAR 33

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	19.5
.250	.278	.264	17.6
.278	.284	.281	3.8
.284	.293	.289	5.5
.293	.300	.297	3.2
.300	.350	.325	19.7
.350	.400	.375	15.5
.400	.410	.405	3.0
.410	.450	.430	7.3
.450	.469	.459	4.1
.469	.500	.484	4.3
.500	.528	.514	1.3
.500	.528	.514	3.7
.528	.550	.539	4.1
.550	.600	.575	1.4
		TOTAL:	113.9

STOCK PILE GRADE DISTRIBUTION
YEAR 34

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	19.5
.250	.271	.261	13.3
.271	.278	.275	4.2
.278	.284	.281	3.8
.284	.293	.289	5.5
.293	.300	.297	3.2
.300	.350	.325	16.6
.350	.400	.375	13.0
.400	.410	.405	2.5
.410	.450	.430	6.2
.450	.469	.459	3.5
.469	.500	.484	3.6
.500	.528	.514	1.1
.500	.528	.514	3.1

.528	.550	.539	3.4
.550	.600	.575	1.2
		TOTAL:	103.9

STOCK PILE GRADE DISTRIBUTION
YEAR 35

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	19.5
.250	.265	.258	9.4
.265	.271	.268	4.0
.271	.278	.275	4.2
.278	.284	.281	3.8
.284	.293	.289	4.7
.293	.300	.297	2.7
.300	.350	.325	14.0
.350	.400	.375	11.0
.400	.410	.405	2.1
.410	.450	.430	5.2
.450	.469	.459	2.9
.469	.500	.484	3.0
.500	.528	.514	.9
.500	.528	.514	2.6
.528	.550	.539	2.9
.550	.600	.575	1.0
		TOTAL:	93.9

STOCK PILE GRADE DISTRIBUTION
YEAR 36

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	19.5
.250	.265	.258	9.4
.265	.271	.268	4.0
.271	.278	.275	4.2
.278	.284	.281	3.1
.284	.293	.289	3.8
.293	.300	.297	2.3
.300	.350	.325	11.5
.350	.400	.375	9.1
.400	.410	.405	1.8
.410	.450	.430	4.3

.450	.469	.459	2.4
.469	.500	.484	2.5
.500	.528	.514	.7
.500	.528	.514	2.2
.528	.550	.539	2.4
.550	.600	.575	.8
		TOTAL:	83.9

STOCK PILE GRADE DISTRIBUTION
YEAR 37

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.250	.240	19.5
.250	.261	.256	7.2
.261	.265	.263	2.2
.265	.271	.268	4.0
.271	.278	.275	3.4
.278	.284	.281	2.5
.284	.293	.289	3.1
.293	.300	.297	1.8
.300	.350	.325	9.3
.350	.400	.375	7.3
.400	.410	.405	1.4
.410	.450	.430	3.5
.450	.469	.459	2.0
.469	.500	.484	2.0
.500	.528	.514	.6
.500	.528	.514	1.8
.528	.550	.539	1.9
.550	.600	.575	.7
			73.9

STOCK PILE GRADE DISTRIBUTION
YEAR 38

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.245	.238	15.0
.245	.250	.248	4.5
.250	.261	.256	7.2
.261	.265	.263	1.7
.265	.271	.268	3.1
.271	.278	.275	2.7

.278	.284	.281	2.0
.284	.293	.289	2.4
.293	.300	.297	1.4
.300	.350	.325	7.3
.350	.400	.375	5.7
.400	.410	.405	1.1
.410	.450	.430	2.7
.450	.469	.459	1.5
.469	.500	.484	1.6
.500	.528	.514	.5
.500	.528	.514	1.4
.528	.550	.539	1.5
.550	.600	.575	.5
		TOTAL:	63.9

STOCK PILE GRADE DISTRIBUTION
YEAR 39

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.245	.238	15.0
.245	.250	.248	4.5
.250	.261	.256	5.5
.261	.265	.263	1.3
.265	.271	.268	2.4
.271	.278	.275	2.1
.278	.284	.281	1.5
.284	.293	.289	1.9
.293	.300	.297	1.1
.300	.350	.325	5.7
.350	.400	.375	4.4
.400	.410	.405	.9
.410	.450	.430	2.1
.450	.469	.459	1.2
.469	.500	.484	1.2
.500	.528	.514	.4
.500	.528	.514	1.1
.528	.550	.539	1.2
.550	.600	.575	.4
		TOTAL:	53.9

STOCK PILE GRADE DISTRIBUTION
YEAR 40

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.245	.238	12.3
.245	.250	.248	3.6
.250	.261	.256	4.5
.261	.265	.263	1.1
.265	.271	.268	2.0
.271	.278	.275	1.7
.278	.284	.281	1.2
.284	.293	.289	1.5
.293	.300	.297	.9
.300	.350	.325	4.6
.350	.400	.375	3.6
.400	.410	.405	.7
.410	.450	.430	1.7
.450	.469	.459	1.0
.469	.500	.484	1.0
.500	.528	.514	.3
.500	.528	.514	.9
.528	.550	.539	1.0
.550	.600	.575	.3
		TOTAL:	43.9

STOCK PILE GRADE DISTRIBUTION
YEAR 41

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.245	.238	9.5
.245	.250	.248	2.8
.250	.261	.256	3.5
.261	.265	.263	.8
.265	.271	.268	1.5
.271	.278	.275	1.3
.278	.284	.281	1.0
.284	.293	.289	1.2
.293	.300	.297	.7
.300	.350	.325	3.6
.350	.400	.375	2.8
.400	.410	.405	.5
.410	.450	.430	1.3
.450	.469	.459	.8
.469	.500	.484	.8

.500	.528	.514	.2
.500	.528	.514	.7
.528	.550	.539	.7
.550	.600	.575	.3
		TOTAL:	33.9

STOCK PILE GRADE DISTRIBUTION
YEAR 42

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.245	.238	6.7
.245	.250	.248	2.0
.250	.261	.256	2.5
.261	.265	.263	.6
.265	.271	.268	1.1
.271	.278	.275	.9
.278	.284	.281	.7
.284	.293	.289	.8
.293	.300	.297	.5
.300	.350	.325	2.5
.350	.400	.375	2.0
.400	.410	.405	.4
.410	.450	.430	.9
.450	.469	.459	.5
.469	.500	.484	.5
.500	.528	.514	.2
.500	.528	.514	.5
.528	.550	.539	.5
.550	.600	.575	.2
		TOTAL:	23.9

STOCK PILE GRADE DISTRIBUTION
YEAR 43

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.245	.238	3.9
.245	.250	.248	1.2
.250	.261	.256	1.4
.261	.265	.263	.3
.265	.271	.268	.6
.271	.278	.275	.5
.278	.284	.281	.4

.284	.293	.289	.5
.293	.300	.297	.3
.300	.350	.325	1.5
.350	.400	.375	1.1
.400	.410	.405	.2
.410	.450	.430	.5
.450	.469	.459	.3
.469	.500	.484	.3
.500	.528	.514	.1
.500	.528	.514	.3
.528	.550	.539	.3
.550	.600	.575	.1
.431	.444	.438	2.9
		TOTAL:	16.8

STOCK PILE GRADE DISTRIBUTION
YEAR 44

GRADE CATEGORIES %		AVRG	TONNAGE
.230	.245	.238	1.6
.245	.250	.248	.5
.250	.261	.256	.6
.261	.265	.263	.1
.265	.271	.268	.3
.271	.278	.275	.2
.278	.284	.281	.2
.284	.293	.289	.2
.293	.300	.297	.1
.300	.350	.325	.6
.350	.400	.375	.5
.400	.410	.405	.1
.410	.450	.430	.2
.450	.469	.459	.1
.469	.500	.484	.1
.500	.528	.514	.0
.500	.528	.514	.1
.528	.550	.539	.1
.550	.600	.575	.0
.431	.444	.438	2.9
		TOTAL:	8.6

YEAR	INC	COG	QM	QC	QR	PROF	NPV
1.	1.00	.50	17.8	10.0	89.8	26.0	150.56
2.	1.00	.50	17.8	10.0	89.8	26.0	147.13
3.	1.00	.50	17.8	10.0	89.8	26.0	143.19
4.	1.00	.50	17.8	10.0	89.8	26.0	138.66
5.	1.00	.50	17.8	10.0	89.8	26.0	133.45
6.	1.00	.50	11.2	6.3	56.6	16.4	127.46
6.	2.00	.53	7.4	3.7	31.8	8.5	127.46
7.	2.00	.53	20.0	10.0	85.9	23.0	121.69
8.	2.00	.53	20.0	10.0	85.9	23.0	116.97
9.	2.00	.53	20.0	10.0	85.9	23.0	111.55
10.	2.00	.53	20.0	10.0	85.9	23.0	105.31
11.	2.00	.53	12.8	6.4	55.0	14.7	98.14
11.	3.00	.47	7.2	3.6	27.4	6.5	98.14
12.	3.00	.47	20.0	10.0	76.1	18.0	91.66
13.	3.00	.47	20.0	10.0	76.1	18.0	87.37
14.	3.00	.47	20.0	10.0	76.1	18.0	82.42
15.	****	.47	1.0	1.0	4.6	1.2	76.74
15.	3.00	.47	18.7	9.0	71.5	17.2	76.74
16.	3.00	.47	13.1	6.4	48.8	11.4	69.82
16.	4.00	.41	6.9	3.5	23.1	4.6	69.82
17.	4.00	.41	20.0	10.0	66.5	13.2	64.28
18.	4.00	.41	20.0	10.0	66.5	13.2	60.70
19.	4.00	.41	20.0	10.0	66.5	13.2	56.58
20.	****	.41	2.2	2.2	9.2	2.2	51.83
20.	4.00	.41	17.3	7.8	57.0	11.7	51.83
21.	4.00	.41	13.6	6.6	43.8	8.4	45.64
21.	5.00	.35	6.4	3.2	18.3	2.8	45.64
22.	5.00	.35	20.0	10.0	57.2	8.6	41.35
23.	5.00	.35	20.0	10.0	57.2	8.6	38.94
24.	5.00	.35	20.0	10.0	57.2	8.6	36.17
25.	****	.35	3.7	3.7	15.4	3.7	32.99
25.	5.00	.35	15.6	6.3	42.5	6.6	32.99
26.	5.00	.35	14.7	7.2	40.5	5.6	27.60
26.	6.00	.29	5.3	2.6	12.6	1.0	27.60
27.	6.00	.29	20.0	10.0	47.6	3.8	25.09
28.	6.00	.29	20.0	10.0	47.6	3.8	25.04
29.	6.00	.29	20.0	10.0	47.6	3.8	24.99
30.	****	.29	5.5	5.5	18.8	3.6	24.92
30.	6.00	.29	13.6	4.5	27.6	1.6	24.92
31.	6.00	.29	16.0	7.8	36.7	2.5	23.52
31.	****	.31	2.2	2.2	6.8	.8	23.52
32.	****	.31	10.0	10.0	36.5	6.0	23.81
33.	****	.30	10.0	10.0	36.5	6.0	21.38
34.	****	.29	10.0	10.0	35.1	5.3	18.58
35.	****	.28	10.0	10.0	34.4	5.0	16.09
36.	****	.27	10.0	10.0	33.6	4.6	13.54

37.	****	.26	10.0	10.0	32.4	3.9	11.01
38.	****	.25	10.0	10.0	30.9	3.2	8.73
39.	****	.24	10.0	10.0	27.5	1.5	6.86
40.	****	.24	10.0	10.0	27.5	1.5	6.38
41.	****	.23	10.0	10.0	27.5	1.5	5.83
42.	****	.23	10.0	10.0	27.5	1.5	5.20
43.	****	.23	10.0	10.0	29.6	2.5	4.48
44.	****	.22	8.6	8.6	27.0	3.0	2.62

****:MINERAL FROM STOCK PILE

APPENDIX E

COMPLETE OUTPUT FROM THE MANUAL EXAMPLE

```
          YEAR= 1
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .4000           GER= .1600
OP.CUT.GRADE= .4000
QM= 83.3333  QC= 50.0000  QR= 35.0000
TIME=12.00  PROFIT=216.7  NPV= 1174.5

          YEAR= 1
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .5762           GER= .2470
OP.CUT.GRADE= .5000
QM=100.0000  QC= 50.0000  QR= 37.5000
TIME=10.00  PROFIT=250.0  NPV= 1254.7

          YEAR= 1
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .5882           GER= .2566
OP.CUT.GRADE= .5000
QM=100.0000  QC= 50.0000  QR= 37.5000
TIME=10.00  PROFIT=250.0  NPV= 1254.7

          YEAR= 2
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .4000           GER= .1600
OP.CUT.GRADE= .4000
QM= 83.3333  QC= 50.0000  QR= 35.0000
TIME=10.80  PROFIT=216.7  NPV= 1125.2

          YEAR= 2
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .5688           GER= .2415
OP.CUT.GRADE= .5000
QM=100.0000  QC= 50.0000  QR= 37.5000
TIME= 9.00  PROFIT=250.0  NPV= 1192.9
```

```
          YEAR= 2
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .5789           GER= .2492
OP.CUT.GRADE= .5000
QM=100.0000  QC= 50.0000  QR= 37.5000
TIME= 9.00  PROFIT=250.0  NPV= 1192.9

          YEAR= 3
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .4000           GER= .1600
OP.CUT.GRADE= .4000
QM= 83.3333  QC= 50.0000  QR= 35.0000
TIME= 9.60  PROFIT=216.7  NPV= 1066.9

          YEAR= 3
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .5600           GER= .2353
OP.CUT.GRADE= .5000
QM=100.0000  QC= 50.0000  QR= 37.5000
TIME= 8.00  PROFIT=250.0  NPV= 1121.8

          YEAR= 3
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .5683           GER= .2412
OP.CUT.GRADE= .5000
QM=100.0000  QC= 50.0000  QR= 37.5000
TIME= 8.00  PROFIT=250.0  NPV= 1121.8

          YEAR= 4
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .4000           GER= .1600
OP.CUT.GRADE= .4000
QM= 83.3333  QC= 50.0000  QR= 35.0000
TIME= 8.40  PROFIT=216.7  NPV=  997.9
```

```
          YEAR= 4
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .5497           GER= .2284
OP.CUT.GRADE= .5000
QM=100.0000  QC= 50.0000  QR= 37.5000
TIME= 7.00  PROFIT=250.0  NPV= 1040.1

          YEAR= 4
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .5560           GER= .2326
OP.CUT.GRADE= .5000
QM=100.0000  QC= 50.0000  QR= 37.5000
TIME= 7.00  PROFIT=250.0  NPV= 1040.1

          YEAR= 5
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .4000           GER= .1600
OP.CUT.GRADE= .4000
QM= 83.3333  QC= 50.0000  QR= 35.0000
TIME= 7.20  PROFIT=216.7  NPV=  916.4

          YEAR= 5
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .5375           GER= .2207
OP.CUT.GRADE= .5000
QM=100.0000  QC= 50.0000  QR= 37.5000
TIME= 6.00  PROFIT=250.0  NPV=  946.1

          YEAR= 5
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .5419           GER= .2234
OP.CUT.GRADE= .5000
QM=100.0000  QC= 50.0000  QR= 37.5000
TIME= 6.00  PROFIT=250.0  NPV=  946.1
```

```
          YEAR= 6
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000          GEP= .4000          GER= .1600
OP.CUT.GRADE= .4000
QM= 83.3333  QC= 50.0000  QR= 35.0000
TIME= 6.00  PROFIT=216.7  NPV=  820.0

          YEAR= 6
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000          GEP= .5230          GER= .2122
OP.CUT.GRADE= .5000
QM=100.0000  QC= 50.0000  QR= 37.5000
TIME= 5.00  PROFIT=250.0  NPV=  838.0

          YEAR= 6
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000          GEP= .5257          GER= .2137
OP.CUT.GRADE= .5000
QM=100.0000  QC= 50.0000  QR= 37.5000
TIME= 5.00  PROFIT=250.0  NPV=  838.0

          YEAR= 7
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000          GEP= .4000          GER= .1600
OP.CUT.GRADE= .4000
QM= 83.3333  QC= 50.0000  QR= 35.0000
TIME= 4.80  PROFIT=216.7  NPV=  705.9

          YEAR= 7
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000          GEP= .5059          GER= .2030
OP.CUT.GRADE= .5000
QM=100.0000  QC= 50.0000  QR= 37.5000
TIME= 4.00  PROFIT=250.0  NPV=  713.7
```

```
          YEAR= 7
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .5071           GER= .2036
OP.CUT.GRADE= .5000
QM=100.0000  QC= 50.0000  QR= 37.5000
TIME= 4.00  PROFIT=250.0  NPV=  713.7

          YEAR= 8
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .4000           GER= .1600
OP.CUT.GRADE= .4000
QM= 83.3333  QC= 50.0000  QR= 35.0000
TIME= 3.60  PROFIT=216.7  NPV=  571.1

          YEAR= 8
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .4857           GER= .1931
OP.CUT.GRADE= .4857
QM= 97.2127  QC= 50.0000  QR= 37.1416
TIME= 3.09  PROFIT=245.6  NPV=  573.7

          YEAR= 8
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .4861           GER= .1933
OP.CUT.GRADE= .4857
QM= 97.2127  QC= 50.0000  QR= 37.1416
TIME= 3.09  PROFIT=245.6  NPV=  573.7

          YEAR= 9
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .4000           GER= .1600
OP.CUT.GRADE= .4000
QM= 83.3333  QC= 50.0000  QR= 35.0000
TIME= 2.43  PROFIT=216.7  NPV=  416.4
```

```
          YEAR= 9
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .4625           GER= .1828
OP.CUT.GRADE= .4625
QM= 93.0173  QC= 50.0000  QR= 36.5616
TIME= 2.18  PROFIT=238.2  NPV=  417.1

          YEAR= 9
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .4626           GER= .1829
OP.CUT.GRADE= .4625
QM= 93.0173  QC= 50.0000  QR= 36.5616
TIME= 2.18  PROFIT=238.2  NPV=  417.1

          YEAR=10
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .4000           GER= .1600
OP.CUT.GRADE= .4000
QM= 83.3333  QC= 50.0000  QR= 35.0000
TIME= 1.32  PROFIT=216.7  NPV=  242.9

          YEAR=10
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .4364           GER= .1726
OP.CUT.GRADE= .4364
QM= 88.7204  QC= 50.0000  QR= 35.9108
TIME= 1.24  PROFIT=229.5  NPV=  243.0

          YEAR=10
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000           GEP= .4364           GER= .1726
OP.CUT.GRADE= .4364
QM= 88.7204  QC= 50.0000  QR= 35.9108
TIME= 1.24  PROFIT=229.5  NPV=  243.0
```

YEAR=11
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000 GEP= .4000 GER= .1600
OP.CUT.GRADE= .4000
QM= 21.0496 QC= 12.6297 QR= 8.8408
TIME= .25 PROFIT= 54.7 NPV= 52.7

YEAR=11
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000 GEP= .4079 GER= .1626
OP.CUT.GRADE= .4079
QM= 21.0496 QC= 12.4635 QR= 8.7737
TIME= .25 PROFIT= 54.7 NPV= 52.7

YEAR=11
GMC= .5000
GMR= .4444
GCR= .6000
GEM= .1000 GEP= .4079 GER= .1626
OP.CUT.GRADE= .4079
QM= 21.0496 QC= 12.4635 QR= 8.7737
TIME= .25 PROFIT= 54.7 NPV= 52.7

YEAR	COG	QM	QC	QR	PROF	NPV
1.	.50	100.0	50.0	37.5	250.0	1254.7
2.	.50	100.0	50.0	37.5	250.0	1192.9
3.	.50	100.0	50.0	37.5	250.0	1121.8
4.	.50	100.0	50.0	37.5	250.0	1040.1
5.	.50	100.0	50.0	37.5	250.0	946.1
6.	.50	100.0	50.0	37.5	250.0	838.0
7.	.50	100.0	50.0	37.5	250.0	713.7
8.	.49	97.2	50.0	37.1	245.6	573.7
9.	.46	93.0	50.0	36.6	238.2	417.1
10.	.44	88.7	50.0	35.9	229.5	243.0
11.	.41	21.0	12.5	8.8	54.7	52.7

APPENDIX F

DESCRIPTION OF THE INPUT DATA FOR THE PROGRAM COG.FOR

- Read the dimension of the ore reserve inventory matrix.

Rows	Columns
13	8

- Read the ore reserve inventory matrix

Grade Categories %	Pit increments in mining sequence Tons x 10E+6 1	2	3	4	5	6
0.00 0.15	14.4	15.9	17.9	20.3	23.4	27.7
0.15 0.20	4.6	5.1	5.5	6.3	7.2	8.3
0.20 0.23	1.76	1.96	2.16	2.4	2.68	3.08
0.23 0.25	2.64	2.94	3.24	3.6	4.02	4.62
0.25 0.30	4.3	4.7	5.3	5.6	6.4	7.3
0.30 0.35	4.2	4.5	4.9	5.5	6.2	6.7
0.35 0.40	4.1	4.4	4.7	5.3	5.6	6.3
0.40 0.45	3.9	4.3	4.6	4.9	5.4	5.7
0.45 0.50	3.8	4.1	4.5	4.8	5.1	5.3
0.50 0.55	3.7	2.9	4.2	4.5	4.6	4.7
0.55 0.60	3.6	2.8	3.9	4.2	4.4	4.3
0.60 0.65	3.4	2.6	3.8	3.9	4.0	3.7
0.65 0.70	3.3	2.5	3.7	3.7	3.6	3.3

- Read tonnages and grades above the intervals.(for I=1,M)

Tonnages Tons*10E+6	Grade %
0.	0.
0.	0.
42.3	1.13
25.5	1.07
31.6	1.00
25.0	0.93
17.4	0.87
9.0	0.80

- Read Mine capacity, Plant capacity, Refinery capacity (In millions of tons), refinery stage Index, and the upper value of grade above the grade intervals. If we have no refinery stage, we use an index equal to zero, and if we have refinery stage, an index equal 1. The upper grade value above the grade intervals in this case is

0.60 %

20000000 10000000 90000 1. 0.70

- Read the Unit cost for the Mine, Plant and Refinery, the Fixed cost, the Sold price, the Recovery value, and the Discount ratio. The Unit costs are ex pressed in $/ton.

  If we have no refinery stage, we have to use the selling cost as a refinery cost. The selling price is expressed in $/ton which in this case, is:

  550 $/ton.

  The fixed cost is in millions of dollars. The recovery value and the discount rate are expressed as a unit fraction.

0.50 0.60 50 4000000 550 0.90 0.15

Table 21 shows how the input data must be prepared.

Table 25 input data for the program COG.FOR

```
13 8
0. 0.15 14.4 15.9 17.9 20.3 23.4 27.7
0.15 0.20 4.6 5.1 5.5 6.3 7.2 8.3
0.20 0.23 1.76 1.96 2.16 2.4 2.68 3.08
0.23 0.25 2.64 2.94 3.24 3.6 4.02 4.62
0.25 0.30 4.3 4.7 5.3 5.6 6.4 7.3
0.30 0.35 4.2 4.5 4.9 5.5 6.2 6.7
0.35 0.40 4.1 4.4 4.7 5.3 5.6 6.3
0.40 0.45 3.9 4.3 4.6 4.9 5.4 5.7
0.45 0.50 3.8 4.1 4.5 4.8 5.1 5.3
0.50 0.55 3.7 2.9 4.2 4.5 4.6 4.7
0.55 0.60 3.6 2.8 3.9 4.2 4.4 4.3
0.60 0.65 3.4 2.6 3.8 3.9 4.0 3.7
0.65 0.70 3.3 2.5 3.7 3.7 3.6 3.3
0. 0.
0. 0.
42.3 1.13
25.5 1.07
31.6 1.00
25.0 0.93
17.4 0.87
9.0  0.80
20000000. 10000000. 90000. 1 0.70
0.5 0.6  50. 4000000. 550. 0.9 0.15
```