MULTI MINERAL CUTOFF GRADE OPTIMIZATION WITH OPTION TO STOCKPILE

By

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Abstract

The primary objective of a mining operation is to maximize the net present value (NPV). The cutoff grade policy has a very significant effect on this most important economic parameter. Therefore, the technique to find cutoff grade policy should be capable of maximizing NPV.

Cutoff grades which are the decisions of major economic significance, cannot be taken by a simple economic formula which equates marginal revenue to marginal cost. In fact, the optimum cutoff grade is influenced by the economic parameters, the capacities of several stages (mine, mill and refinery) in the mining operation, and the grade distribution of the deposit. These influences can interact in a complex way with the result that cutoff grade changes, sometimes widely, during the life of the operation. The theory of optimum cutoff grades for the deposits of one and two economic minerals is not simple, and the complexities increase if the stockpile is considered as a part of the mining system. Because of this optimum cutoff grade ideas are not widely used. However, this problem can be solved by the availability of computer programs.

In this study four computer programs have been developed to find the optimum cutoff grade policies which maximize the net present value. All of these programs provide the opportunity of analyzing a large number of alternatives for one mineral case, one mineral case with stockpiles, two minerals case, and two minerals case with stockpiles. The case studies for both one and two mineral case are conducted to demonstrate the difference between optimum cutoff grades that maximize the NPV of an operation and traditional cutoff grade calculation techniques. The case studies include the detailed cash flow analysis which incorporates the capital costs incurred as initial investments to prove that net present value can still be maximized within full cash flow.

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1. INTRODUCTION

Cutoff grade is defined as the grade that is used to discriminate between ore and waste within a given ore body. If mineral content is above cutoff grade the material is classified as ore. If the mineral content is less than the cutoff grade , the material is classified as waste. Depending upon the mining method, waste is either left in situ or sent to the waste dumps, whereas ore is sent to the treatment plant for further processing and eventual sale.

A unique feature of mining arises from the fact that profits and hence the net present value can be directly affected by the choice of cutoff grade. Its influence on economics of an operation is significant. Therefore, the technique to find the cutoff grades should be capable of maximizing the net present value of the operation.

The theory of present values has been discussed widely in the mining industry for valuing properties and evaluating new projects. However, its use as a mean to determine an optimum operating policy is less common.

Most of the time determination of cutoff grade policy is based on the conventional marginal analysis without taking time value of money into account. In this traditional case cutoff grade determined to be the break-even point at which revenue equals costs. The flaw associated with the technique is that it completely ignores the capacities of the mining system and related capital costs, which usually leads to sub-optimal exploitation of the resource.

The determination of cutoff grades based on break-even analysis maximizes the extraction of valuable mineral. This is usually proposed by the mineral rights owners and local governments. But the most important flaw occurs in the definition of valuable mineral. An extreme definition could be all the mineral or geological reserves should be extracted, but this ignores the opportunity cost of capital.

One argument in favor of this exploitation method is that in developing countries the governments prefer to provide employment opportunities to the people for a long time rather than considering the time value of money. These governments also wish to see the prolonged industrial activities for continuing taxes and royalties. Because, present value criterion is associated with higher grades and higher rates of mining which intern reduce the life of mine. The governmental policy makers may favor traditional approach while investment community favors the NPV approach.

A mining system may be viewed consisting of three main stages. These stages include mining, milling, and refining. These stages may limit the throughput of operation either by themselves or in pairs. The limitations of capacities of these stages and the grade distribution of the deposit have a very significant effect on the determination of cutoff grades that will maximize the net present value of cash flows coming from an operation. The basic algorithm to determine the cutoff grades which maximize the NPV of an operation subject to mining, milling, and refining capacities was proposed by Lane (1964, 1988). Although, the algorithm has been available for a long time but the approach has not used widely. This is mainly because of the computer programs which implement the idea are not available for general use of the industry.

The goal of this thesis is to develop the computer programs that will determine the optimum cutoff grade policy for a given project by modifying Lane's approach. The programs will be general enough to consider stockpiles as well as the evaluation of multi minerals deposits.

1.1 Traditional Cutoff Grades

Traditionally in open pit mining, a cutoff grade is determined if a block of material should be mined or not, and another cutoff grade determines if this block should be milled or sent to the waste dump.

The first cutoff grade is generally referred to as ultimate pit cutoff grade and defined as the break-even grade that equates cost of mining, milling and refining to the value of the block in terms of recovered metal and the selling price. The second cutoff grade is referred to as milling cutoff grade and defined as the break-even grade that equates the cost of milling and refining to the value of the block in terms of recovered metal and the selling price. In calculation of milling cutoff grade, mining cost is not included since this cutoff is applied to those blocks that are already selected for mining.

To demonstrate determination of these cutoff grades the data coming from a gold deposit, given in Dagdelen (1992), will be used. Table 1.1 shows economic parameters, and Table 1.2 gives the grade categories and tons available in the deposit. This data will be used to explain the difference between alternative techniques.

Using the symbols defined in Table 1.1,

The ultimate limit cutoff grade is:

$$g_{Pit} = \frac{m+c}{(P-s)*y}, \tag{1.1}$$

$$g_{Pit} = \frac{1.2+19.0}{(600-5)*0.9},$$

$$gPit = 0.038 \text{ oz/ton.}$$

The milling cutoff grade is:

$$g_{Mill} = \frac{c}{(P-s)*y}, \tag{1.2}$$

$$g_{Mill} = \frac{1.2}{(600-5)*0.9},$$

$$gMill = 0.035 \text{ oz/ton.}$$

Therefore, mining the deposit at milling cutoff grade of 0.035 oz/ton and 1.05M tons of milling capacity, exploitation schedule that can be achieved is shown in Table 1.3.

Table 1.1: Economic Parameters

Parameters	Symbol	Values
Price, ($/oz.)	P	600.00
Sales Cost, ($/oz.)	s	5.00
Processing Cost, ($/ton ore)	c	19.0
Mining Cost, ($/ton)	m	1.2
Fixed Cost, ($M/year)	f	8.35
Mining Capacity	M	Unlimited
Milling Capacity, (M tons)	C	1.05
Capital Costs, ($M)	CC	105
Recovery, (%)	y	90.00
Discount Rate, (%)	d	15.00

Table 1.2: Grade Tonnage Distribution of Deposit

Lower Limits of grade Category	Upper Limits of grade Category	Tons (1,000) in each grade Category
0.0	0.02	70,000
0.02	0.025	7,257
0.025	0.03	6,319
0.03	0.035	5,591
0.035	0.04	4,598
0.04	0.045	4,277
0.045	0.05	3,465
0.05	0.055	2,428
0.055	0.06	2,307
0.06	0.065	1,747
0.065	0.07	1,640
0.07	0.075	1,485
0.075	0.08	1,227
0.08	0.1	3,598
0.1	0.358	9,576

In Table 1.3, Q_m represents the amount of total material mined (in millions of tons); Q_c represents the ore tonnage (in millions) processed by mill; Q_r represents the recovered ounces (in thousands). The annual cash flows are given as profits in million of dollars and they are determined by using following equation:

$$Profits = (P - s) * Q_r - c * Q_c - m * Q_m - f \,. \tag{1.3}$$

A total of 36.7M tons at an average grade of 0.102 oz/ton is mined with a stripping ratio of 2.42 and processed by the mill during 35 years mine life. This schedule results in total un-discounted profits of \$1,154.2 million and NPV of \$218.5 million.

Some problems associated with traditional (break-even) cutoff grades are:

1- They are established to satisfy the objective of maximizing un-discounted profits, therefore, they do not take into account time value of money.
2- They do not consider the grade distribution of the deposit.
3- They are independent of physical mine, plant and marketing constraints.

1.2 Heuristic Cutoff Grades

As, traditional cutoff grades maximize only un-discounted profits. But, if the objective is to maximize net present value (NPV), the maximization of profits without taking into account any capacity constraints of mining system will result into sub-optimal NPV's. Realizing the fact many approaches have been suggested to modify the traditional cutoff grades technique. The heuristic technique is one of them.

The concept of using higher cutoff grades during the early years and then break-even cutoff grades during the later years is used in the industry for heuristic NPV optimization. This helps in the faster recovery of capital investments. The traditional cutoff grades are modified by including depreciation *(Dep)* , fixed costs and minimum profit per ton *(Mp)* for early years. After initial period minimum profit is removed from the equation. After the plant is paid off depreciation is also removed from the equation.

Table 1.3: Traditional Cutoff Grades

Years	COG	Avg. Grade	Q_m	Q_c	Q_r	Profit ($M)/year
1	0.035	0.102	3.6	1.05	96.3	24.68
2	0.035	0.102	3.6	1.05	96.3	24.68
3	0.035	0.102	3.6	1.05	96.3	24.68
4	0.035	0.102	3.6	1.05	96.3	24.68
5	0.035	0.102	3.6	1.05	96.3	24.68
6	0.035	0.102	3.6	1.05	96.3	24.68
7	0.035	0.102	3.6	1.05	96.3	24.68
8	0.035	0.102	3.6	1.05	96.3	24.68
9	0.035	0.102	3.6	1.05	96.3	24.68
10	0.035	0.102	3.6	1.05	96.3	24.68
11-34	0.035	0.102	3.6	1.05	96.3	24.68
35	0.035	0.102	3.6	1.05	96.3	23.13
Total			**125.8**	**36.7**	**3365.9**	**862.25**
						NPV ($M) 163.47

Assume that \$105M plant capital cost will be depreciated during first 10 years by straight line method:

$$\text{Depreciation cost per year} = \frac{105}{10} = \$10.5\text{M/year},$$

$$\text{Depreciation cost per ton} = \frac{10.5}{1.05} = \$10\text{/ton ore.}$$

Further, assume that a minimum profit of \$3.0 per ton will be imposed for the first five years.

Therefore, cutoff grades are:

Year 1-5,

$$g_{Mill} = \frac{c + Dep + Mp}{(P - s) * y}, \tag{1.4}$$

$$g_{Mill} = \frac{1.2 + 10 + 3}{(600 - 5) * 0.9},$$

$$gMill = 0.06 \text{ oz/ton},$$

Year 6-10,

$$g_{Mill} = \frac{c + Dep}{(P - s) * y}, \tag{1.5}$$

$$g_{Mill} = \frac{1.2 + 10}{(600 - 5) * 0.9},$$

$$gMill = 0.054 \text{ oz/ton},$$

Year 11-depletion,

Tradition cutoff grade which is,

$gMill = 0.035$ *oz/ton.*

The cutoff grades and schedule for this technique are given in Table 1.4. However, this does not include fixed costs. It can be observed that total un-discounted profits are increased by 1.9% and NPV is increased by 68.29% from that of traditional cutoff grades technique.

If fixed costs are also included in the equations following results can be achieved:

$$fa = \frac{f}{C}, \tag{1.6}$$

$$fa = \frac{8.35}{1.05},$$

$$fa \quad = 7.95 \text{ \$/ton},$$

Year 1-5,

$$g_{Mill} = \frac{c + Dep + Mp + f_a}{(P - s) * y}, \tag{1.7}$$

$$g_{Mill} = \frac{1.2 + 10 + 3 + 7.95}{(600 - 5) * 0.9},$$

$$gMill \quad = 0.075 \text{ oz/ton},$$

Year 6-10,

$$g_{Mill} = \frac{c + Dep + f_a}{(P - s) * y}, \tag{1.8}$$

$$g_{Mill} = \frac{1.2 + 10 + 7.95}{(600 - 5) * 0.9}$$

$$gMill \quad = 0.069 \text{ oz/ton},$$

Year 11-depletion,

$$g_{Mill} = \frac{c + f_a}{(P - s) * y}, \tag{1.8}$$

$$g_{Mill} = \frac{1.2 + 7.95}{(600 - 5) * 0.9},$$

$$gMill \quad = 0.050 \text{ oz/ton}.$$

Table 1.4: **Heuristic Cutoff Grades Without Fixed Costs**

Years	COG	Avg. Grade	Q_m	Q_c	Q_r	Profit ($M)/year
1	0.060	0.153	6.9	1.05	144.6	49.46
2	0.060	0.153	6.9	1.05	144.6	49.46
3	0.060	0.153	6.9	1.05	144.6	49.46
4	0.060	0.153	6.9	1.05	144.6	49.46
5	0.060	0.153	6.9	1.05	144.6	49.46
6	0.054	0.141	6.0	1.05	132.8	43.52
7	0.054	0.141	6.0	1.05	132.8	43.52
8	0.054	0.141	6.0	1.05	132.8	43.52
9	0.054	0.141	6.0	1.05	132.8	43.52
10	0.054	0.141	6.0	1.05	132.8	43.52
11-27	0.035	0.102	3.6	1.05	96.3	24.68
28	0.035	0.102	0.3	0.09	8.1	-5.55
Total			**125.8**	**28.04**	**3032.1**	**878.91**
						NPV ($M) 275.12

Table 1.5: **Heuristic Cutoff Grades With Fixed Costs**

Years	COG	Avg. Grade	Q_m	Q_c	Q_r	Profit ($M)/year
1	0.075	0.182	9.2	1.05	171.6	62.76
2	0.075	0.182	9.2	1.05	171.6	62.76
3	0.075	0.182	9.2	1.05	171.6	62.76
4	0.075	0.182	9.2	1.05	171.6	62.76
5	0.075	0.182	9.2	1.05	171.6	62.76
6	0.069	0.169	8.2	1.05	160.0	57.06
7	0.069	0.169	8.2	1.05	160.0	57.06
8	0.069	0.169	8.2	1.05	160.0	57.06
9	0.069	0.169	8.2	1.05	160.0	57.06
10	0.069	0.169	8.2	1.05	160.0	57.06
11-17	0.050	0.132	5.4	1.05	124.8	39.48
18	0.050	0.132	1.3	0.26	30.5	3.29
Total			**125.8**	**18.11**	**2562.5**	**878.75**
						NPV ($M) 346.36

The cutoff grades and schedule for the heuristic technique that includes fixed costs are given in Table 1.5. It can be observed that total un-discounted profits are increased by 1.9% and NPV is increased by 112% from that of the traditional cutoff grades technique.

1.3 Optimum Cutoff Grades (Lane's Approach)

Lane (1964) was the first to come up with a cutoff grade theory which considers that mining system consists of three main stages. These are mine, mill or plant, and refinery or market. His theory takes into account the costs and capacities associated with these stages. Mine capacity is the maximum rate of mining the deposit, mill capacity is the maximum rate of processing ore, and market capacity is the maximum rate of production of final product. The determination of cutoff grade is based on the fact that either one of those stages will alone limit the total capacity of operation or the pair of stages may limit the entire operation. The theory also takes into account the grade distribution of the deposit and the opportunity cost (time costs) of mining low grade ore while high grade ore is still available in the deposit.

Hence, there are three limiting economic cutoff grades depending upon which capacity is actually the controlling one. If throughput is limited by the mining capacity, the opportunity costs have to be distributed per unit of material mined and the corresponding cutoff grade is called the mine limited economic cutoff grade, g_m. If the mill is limiting throughput, the opportunity costs have to be distributed per unit of ore processed and the corresponding cutoff grade is called the mill limited economic cutoff grade, g_c. Similarly, if refinery is subject to limitation, then the opportunity costs have to be distributed per unit of product and the corresponding cutoff grade is called the market limited economic cutoff grade, g_r.

However, the optimum cutoff grade at any moment is not necessarily a limiting economic cutoff grade. The reason for this is the interaction of all capacities. If more than one capacities are limited, then there should be a balancing point at which full capacity of both components can be utilized. Hence, there will be three balancing cutoff grades g_{mc}, g_{mr}, and g_{rc}. The optimum cutoff grade will be one of the six economic limiting and balancing cutoff grades. The procedure of determining optimum cutoff grade will be explained in the next chapter.

As in example, only milling capacity is limited. Therefore, the equation for milling cutoff grade using Lane's approach is:

$$g_{Mill} = \frac{c + \dfrac{(f + d * NPV)}{C}}{(P - s) * y}. \tag{1.9}$$

The profits will be calculated using this equation (1.3).

Table 1.6, gives the yearly tons and grade schedule resulting from Lane's approach. The optimum cutoff grade policy obtained by this technique gives 153% higher NPV and 13.8% lower un-discounted profits than that of traditional cutoff grades.

Even though the total tons mined are same between the traditional cutoff grades Table 1.3 and optimum cutoff grade policy Table 1.6, the amount of material milled is lower (i.e. 36.7M tons versus 9.45M tons), also the recovered ounces of gold are lower (i.e. 3.37M ounces versus 1.93M ounces).

The effect of optimization on the mine life is also significant. Shortening the mine life from 35 years in Table 1.3 to 10 years in Table 1.6 is the trade off between optimum NPV approach and traditional break-even approach.

Therefore, it is evident from the analysis that optimum cutoff grade policy is most acceptable. It considers the grade distribution of the deposit by incorporating the balancing cutoff grades which keep all stages of mining in balance at their maximum capacities according to grade distribution, and also fulfills the objective of maximizing the net present value by taking into account the time value of money. It is necessary to point out that if stockpiles are included in this optimum NPV approach, the NPV will be further maximized.

Years	COG	Avg. Grade	Q_m	Q_c	Q_r	Profit ($M)/year	NPV ($M)
1	0.161	0.259	18.0	1.05	245.2	95.9	413.8
2	0.152	0.255	17.2	1.05	241.0	94.4	380.0
3	0.142	0.250	16.5	1.05	236.4	92.6	342.6
4	0.131	0.245	15.7	1.05	231.3	90.5	301.4
5	0.120	0.239	14.9	1.05	225.7	88.1	256.1
6	0.107	0.232	14.1	1.05	219.6	85.4	206.4
7	0.092	0.213	12.1	1.05	200.9	76.7	152.0
8	0.079	0.188	9.8	1.05	177.9	65.9	98.1
9	0.065	0.163	7.6	1.05	153.6	53.9	46.9
Total			**125.8**	**9.45**	**1931.4**	**743.4**	
						NPV ($M) 413.8	

Table 1.6: Optimum Cutoff Grades (Lane's Approach)

1.4 Optimum Cutoff Grades For Two Minerals Deposit

Mineralized bodies containing more than one mineral are usually dealt by converting all minerals to their equivalent in terms of one basic mineral, and aggregating several values.

For example, lead and zinc often occur together; assuming zinc to have twice the value of lead. The lead content can be divided by two and added to the zinc content in order to obtain total zinc content. Then any analysis can be conducted exactly as if mineralization consists of single mineral.

If the minerals have fairly stable values, this procedure is valid and simple. However, if values fluctuate the procedure becomes complicated because equivalent grades have to be recalculated.

Further, if one of the mineral is subject to market constraints, then production in excess cannot be sold and hence ore cannot be valued on the basis of current price. Therefore in such a situation the procedure becomes invalid and minerals are needed to be dealt separately.

Keeping in view these issues, Lane (1988) also came up with a procedure to determine cutoff grades policy for two minerals. Although, the procedure is different from the one mineral case, but the purpose is same i.e. maximizing the net present value of operation.

This procedure depends upon the graphical approach for the determination of optimum cutoff grades. However, if only one of the capacity is limited then analytical determination is also possible.

Looking at the cutoff grades and production schedules generated in chapter 3 and chapter 5 by using Lane's approach, it is possible to see that a significant amount of material is sent to the waste dump during early years of production. Therefore, by incorporating stockpile option some of the marginal material may be good enough to send to the treatment plant in the later years and to get a fair amount of increase in the net present value .

1.5 Previous Work

The information about the methodology to find the optimum cutoff grades policy for two minerals is very limited. However, Lane (1988) explained the theory comprehensively. Also, the ideas given by different people with respect to optimum cutoff grade policy in one mineral case are very helpful in understanding the complexities involved in two minerals case.

Henning (1963), derived formulas to determine cutoff grades based on break-even analysis. He was the first one to show that true maximization of net present value is only possible by the declining cutoff grade. Lillico (1973), considered a cutoff grade strategy which maximizes the net present value. His theory is based on the dynamic cutoff grade rather than static cutoff grade policy. Taylor (1972), came up with a very similar approach as Lane. Three stages in the process were used. He also calculated balancing and economic cutoff grades. The only difference lies in the calculation of balancing cutoff grades. Taylor (1972) used some statistical parameters to describe the grade distribution.

It has been widely approved through early research that any theory which involves changing cutoff grades with time should consider the creation of stock piles, Mason (1984). Because, stockpile can end up at an average grade higher than the general cutoff grades at some time during the middle years of operation. However, the determination of minimum cutoff grade of material to be sent to stockpile and the suitable time of sending material from stockpile to mill are not well explained.

Taylor (1985), explained the use of stockpile system through some actual examples. At the craigmont Copper Mine, a substantial low grade stockpile was created at an average grade of 0.6% Cu from the initial high grade open pit. The operation then moved underground, where sub-level caving yielded a daily output of 4500 short tons at 1.8% Cu. For many years the stockpile the remaining 1500 short tons per day that were needed to feed the mill. However, Taylor (1985) did not give any information about the methodology to create stockpiles.

Lane (1988) explained the use of stockpile alternative in a very comprehensively. He makes the determination of lower cutoff grade for the stockpile based upon the cost of handling material. It is determined to be break-even cutoff grade. He provided a very good theoretical analysis to find the amount of material to be sent from stockpile to the concentrator.

Manuel G. Schellman (1989) in his thesis, used Lane's ideas of creating stockpiles. He came up with different alternatives of utilizing stockpiles (i.e. sending material from stockpile to the mill). This is also a very comprehensive work on the optimization of cutoff grades with option to stockpile, as it clearly explains that NPV can be significantly maximized if stockpiles are included in the operation.

Dr. Kadri Dagdelen (1992) thoroughly explained the general theory by comparing different techniques being used to calculate cutoff grades these days. He proved that a technique with declining cutoff grades with time is always capable of maximizing net present value rather than that of traditional and heuristic techniques. His work also favors the creation of stockpiles during early years of mine life. Dagdelen (1993) also introduced an analytical method to find the balancing cutoff grades instead of graphical method by modifying the Lane's approach which is a great contribution in making a quite complex problem a real simple one.

Fred Seymour (1994), in his publication mentioned that stockpiles can be created when mining ore from the rich portions of the deposit or production cutoff grade exceeds a threshold break-even cutoff grade that takes into account a re-handle charge and any difference in the metallurgical recovery. These can be re-handled when mining ore from lower grade portions of the deposit or production shortfall occurs. The re-handle charge can be incurred at that time.

Whittle (1995), in his publication followed the concept given by Lane (1964, 1988). However, he explained the idea of using opportunity cost in a better way. He introduced that, in addition to normal cash costs there are two pseudo costs which are also important. These are referred to as delay cost and the change cost. Both of these costs consider the delays caused by any mining or processing activities in the exploitation on the rest of the project.

Since, delay costs depend on the time taken rather than on the tons exploited, it is a type of time cost. If we wish to maximize the NPV of our project, we must consider the delay cost when making decisions, even though it never appears in the accounts.

Similarly, on behalf of change costs, we know that cash flows are higher if we exploit the resource when prices of product are high, and vice versa. Therefore, if we delay the exploitation to a period of low prices we reduce the cash flows and hence NPV of the resource. Since, this effect gets bigger with increasing delay, we again treat it as a type of time cost and we call it change cost. It is different from all other time costs, because if the price of product increases with delay, it will be negative, and if the economic circumstances are constant the change cost is zero.

Consequently, the delay cost which is always positive increases cut-off grade. While change cost can increase or decrease cut-off grade depending on the economic circumstances are improving or deteriorating. These two costs together are called opportunity costs, and a cutoff grade calculated from a break-even formula incorporating these costs and concerned limiting capacities is called a limiting economic cutoff grade.

1.6 Scope Of The Work

It has been mentioned before that there are many theories for the determination of cutoff grades. But most of the research done in the last two decades shows that cutoff grades determined with the objective of maximizing net present value are the most acceptable. The optimum cutoff grades theory introduced by Lane (1964, 1988) determines the cutoff grades year by year and maximizes the net present value of operation. This study will be based on the Lane's approach for both one and two minerals optimum cutoff grade policies. The reason for this choice is the first comprehensive approach which utilized all important parameters which effect the calculation of optimum cutoff grades.

This thesis will modify the Lane's algorithm by including the stockpiles. This modification consists of running the Lane's algorithm and picking up the lowest cutoff grade. The ore above this lowest cutoff grade will be sent to stockpiles. Therefore, the mineral which was going to waste dumps in the original program will go to stockpiles.

The computer programs are developed to find the optimum cutoff grades policy in both one and two minerals case. The original programs are then modified to include the stockpiles in both cases.

It was considered that the understanding of Lane's algorithm for one mineral is necessary to approach to two minerals problem. Therefore, Lane's algorithm for determination of optimum cutoff grade policy in one mineral case is explained in chapter 2. The computational program for this purpose is given in chapter 3. The chapter 4 deals with Lane's algorithm for two minerals. The computational program for two minerals case is discussed in chapter 5. The original Lane's algorithms for both one and two minerals case are modified to include stockpiles. This is explained in chapter 6. The computational programs for modified algorithms are discussed in chapter 7. Usually these optimum cutoff grade theories are based on the use of operating costs incurred in the project. Chapter 8 gives the detailed analysis of including capital costs and its effects on the net present value. Conclusions and recommendations for this study are given in chapter 9.

2. CUTOFF GRADE OPTIMIZATION IN DEPOSITS OF ONE ECONOMIC MINERAL

2.1 Introduction

The determination of optimum cutoff grade policy will be based on Lane's theory. The work done by Kadri Dagdelen will also be included. Lane's theory of cutoff grades considers that a mining system consists of three major stages. These are mining, milling, and refining. The mine is the area where ore and waste are extracted, mill is the area where ore is upgraded to a concentrate, and refinery is the place where finishing processes are conducted to produce the final product.

In order to select optimum cutoff grades, there should be a criteria for the comparison among different choices. Net present value is the criteria to be used for this selection. Therefore, attention will be focused on choosing a cutoff grade to maximize the net present value of the cash flows from the operation.

The formulae for three limiting economic cutoff grades are derived keeping in view that each stage alone limits the total capacity of operation. These cutoff grades depend directly on the price and costs but only indirectly on the grade distribution of the deposit.

Three balancing cutoff grades are also defined. These are the grades which just balance the capacities of each pair of stages. They are independent of economics and being determined by the grade distribution of the deposit.

Finally, the optimum is one of these six cutoff grades, either a limiting economic grade or a balancing grade.

2.2 The Model

Although, not all mining operations consist of all three stages identified and even some of them involve more. But, these three stages provide a good general model. Each stage is assumed to have its own associated unit cost and a limiting capacity. Following are the notations used in model (definitions of variables are adopted from Lane 1964).

M : Maximum material throughput per year or mining capacity in tons.

C : Maximum ore throughput per year or milling capacity in tons.

R : Maximum output of final product per year or refining capacity in tons.

S : Price per ton of product.

r : Marketing and sales cost per ton of product.

m : Mining cost per ton of material.

c : Processing cost per ton of ore.

f : Fixed or administrative costs per year.

y : Metallurgical Recovery.

d : Discount rate.

2.2.1 Limiting Economic Cutoff Grades

In order to understand the effect of cutoff grades on the economics of mining operation, a basic profit expression is formulated. This expression is used in coming up with a net present value expression, and from this in turn, conclusions about optimum limiting economic cutoff grades are derived.

The profit expression is formulated by considering the next unit of material to be mined which is Q_m. Therefore, the quantity Q_m will be mined at a cost of $m \times Q_m$. A proportion of Q_m will be sent to mill as ore, the resulting quantity of ore is Q_c and cost to be incurred to process this quantity will be $c \times Q_c$. The refining costs will be incurred on mineral product. If quantity to be refined is Q_r , then cost is $r \times Q_r$.

The mining, concentrating and refining of the material will take certain length of time. Therefore, some amount of fixed costs will be spent during that period. If time is considered to be T, then corresponding cost will be $f \times T$.

Hence the profit equation is :

$$P = (S - r) * Q_r - c * Q_c - m * Q_m - f * T \quad . \tag{2.1}$$

This expression calculates the profit obtained by mining the next Q_m of material. However, the ultimate goal is to maximize net present value of the future profits rather than just the total of these profits. The best way of achieving this is to assume that maximum possible present value of future profits is V. Assume also that the maximum possible present value of future profits after the next Q_m of material has been mined is W.

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

From the definition of present value:

$$V = P + \frac{W}{(1+d)^T} \quad . \tag{2.2}$$

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

$$V - W = P - (d * V * T) . \tag{2.3}$$

V - W is increase in present value achieved by mining the next Q_m of material. If this increase in present value is v then by writing the equation in full:

$$v = (S - r) * Q_r - c * Q_c - m * Q_m - (f + d * V) * T . \tag{2.4}$$

This is the basic present value expression. It differs from the profit expression by the added fixed cost term $d \times V$. This can be regarded as the opportunity cost of taking low grade when higher grade material is still available.

By using the present value expression, three limiting economic cutoff grades can be found by first assuming that mine, concentrator, and refinery in turn limit the total operation.

a. Mine Limit:

$$T = \frac{Q_m}{M}, \tag{2.5}$$

$$v_m = (S - r) * Q_r - c * Q_c - \left(m + \frac{f + d * V}{M} \right) * Q_m. \tag{2.6}$$

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

$$(S - r) * Q_r - c * Q_c, \tag{2.7}$$

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

$$(S - r) * y * g_m = c, \tag{2.8}$$

$$g_m = \frac{c}{(S - r) * y}. \tag{2.9}$$

b. Concentrating Limit:

$$T = \frac{Qc}{C}, \tag{2.10}$$

$$v_c = (S - r) * Q_r - \left(c + \left(\frac{f + d * V}{C} \right) \right) * Q_c - m * Q_m, \tag{2.11}$$

$$g_c = \frac{c + \dfrac{f + d * V}{C}}{(S - r) * y}. \tag{2.12}$$

c. Refining Limit:

$$T = \frac{Qr}{R}, \tag{2.13}$$

$$v_r = \left(S - r - \left(\frac{f + d * V}{R}\right)\right) * Q_r - c * Q_c - m * Q_m, \tag{2.14}$$

$$g_r = \frac{c}{\left(S - r - \frac{f + d * V}{R}\right) * y} . \tag{2.15}$$

2.2.2 Balancing Cutoff Grades

The optimum cutoff grade at any moment is not necessarily a limiting economic cutoff grade. The reason for this is the interaction of all stages. If more than one capacities are limited, then there should be a balancing point at which full capacity of both components can be utilized.

If maximum capacity to mine material is M tons per year and maximum capacity of mill to handle ore is C tons per year, these two components will be in balance when quantity of ore obtained from a given quantity of mineralized material is in ratio of $C : M$; in other words, the ore material ratio is C/M. Then there will be a point on commulative grade distribution graph at which proportion of mineralized material above corresponding grade will exactly equal to ratio C/M. The grade at this point is called balancing cutoff grade for mine and mill, g_{mc}. Operating at this cutoff grade will keep the two components at full capacity. This is shown in Figure 2.1.

If the market capacity is R tons of product per year, then the market and mine will balance when recoverable mineral per unit material mined equals the ratio R/M. This point is called balancing cutoff grade between mine and market, g_{mr}. This is shown in Figure 2.2.

Similarly, mill and market will be in balance when recoverable mineral per unit of ore is equal to ratio R/C. This point is called balancing cutoff grade between mill and market, g_{cr}. This is also shown in Figure 2.3.

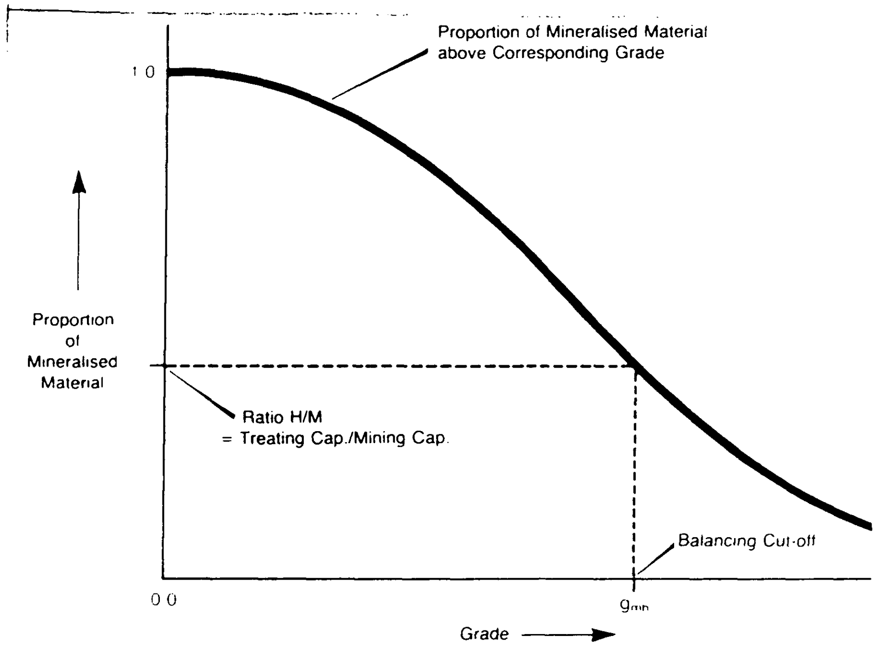

Figure 2.1: Commulative Grade Distribution For a Given Push-Back.

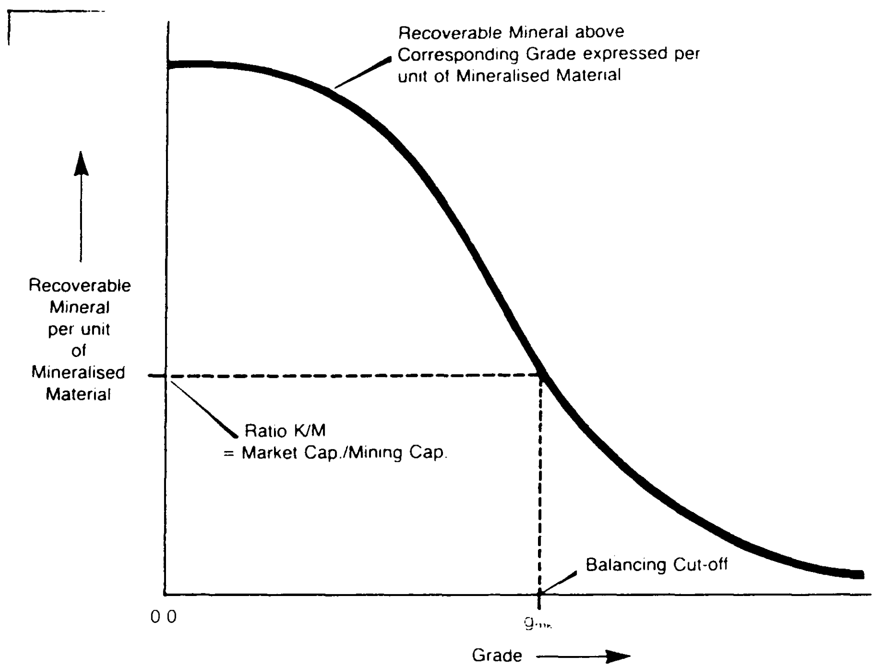

Figure 2.2: Recoverable Mineral Per Unit of Mineralized Material as a Function of Grade

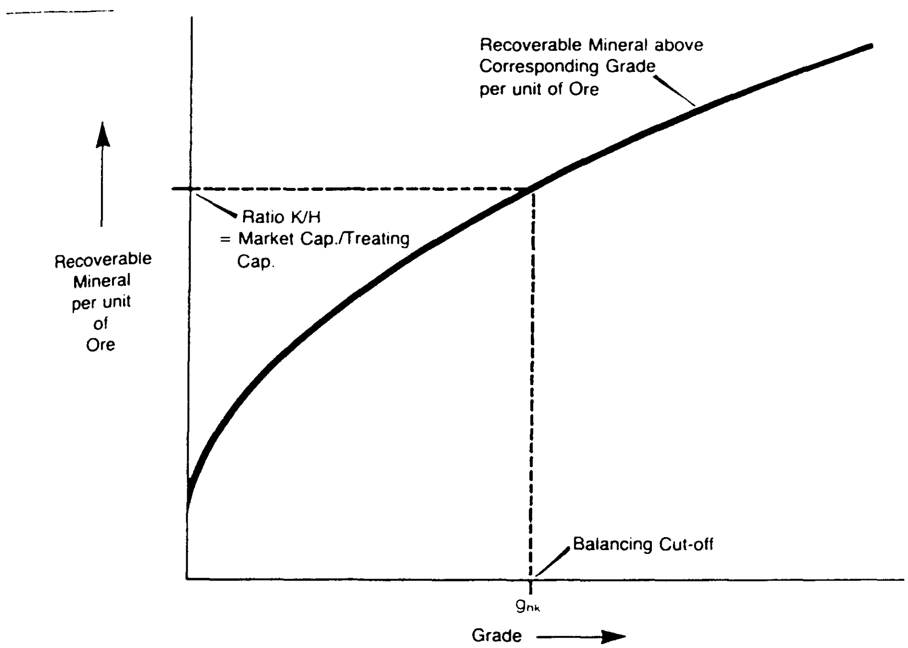

Figure 2.3: Recoverable Mineral Per Unit of ore as a Function of Grade

Dagdelen 1993, came up with the technique to find these balancing cutoff grades analytically. Following is the procedure to find these balancing cutoff grades.

Let us assume that grade-tonnage distribution in a given push-back consists of *"K"* individual grade cells.

[{ g(1), g(2) }, { g(2), g(3) }, --------------, { g(K-1), g(K) }]

By using the lower grade limit *g(k)* for a given cell *{ g(k), g(k+1) }* as the cut-off grade representing interval k^* , calculate the tons above cutoff grade i.e. ore tons, tons below cutoff grade i.e. waste tons, and the average grade of ore above cutoff grade. These can be represented by the following equations:

$$T_o(k^*) = \sum_{k=k^*}^{K} T_k , \tag{2.16}$$

$$g_{avg}(k^*) = \frac{\sum_{k=k^*}^{K}\left(T_k * \left[\frac{g(k)+g(k+1)}{2}\right]\right)}{\sum_{k=k^*}^{K} T_k}, \tag{2.17}$$

$$T_w(k^*) = \sum_{k=1}^{k^*} T_k . \tag{2.18}$$

Knowing ore tons, waste tons and average grade of ore, the ratio of ore tons to total tons mined *"mc"*, the ratio of quantity of metal to total tons *"rm"*, and quantity of metal *"rc"* can be calculated. The equations for these ratios are given below :

$$mc(k^*) = \frac{T_o(k^*)}{T_o(k^*) + T_w(k^*)}, \tag{2.19}$$

$$mc(k^*) = \frac{T_o(k^*) * g_{avg}(k^*) * y}{T_o(k^*) + T_w(k^*)}, \tag{2.20}$$

$$rc(k^*) = g_{avg}(k^*) * y . \tag{2.21}$$

The determination of balancing cutoff grades g_{mc}, g_{rm}, g_{rc} is as follows :

a. Mine and Mill Balancing Cutoff grade "g_{mc}":

Determine the ratio *(C/M)*, then locate the grade interval such that

$$mc(k^*) \geq (C/M) \geq mc(k^* + 1), \tag{2.22}$$

Then determine

$$\Delta_{mc} = \frac{mc(k^*) - (C/M)}{mc(k^*) - mc(k^* + 1)}, \tag{2.23}$$

and

$$g_{mc} = g(k^*) + \Delta_{mc} * (g(k^* + 1) - g(k^*)). \tag{2.24}$$

b. Mine and Refinery Balancing Cutoff grade "g_{mr}":

Determine the ratio *(R/M)*, then locate the grade interval such that

$$mr(k^*) \geq (R/M) \geq mr(k^* + 1), \tag{2.25}$$

Then determine

$$\Delta_{mr} = \frac{mr(k^*) - (R/M)}{mr(k^*) - mr(k^* + 1)}, \tag{2.26}$$

and

$$g_{mr} = g(k^*) + \Delta_{mr} * (g(k^* + 1) - g(k^*)). \tag{2.27}$$

c. Mill and Refinery Balancing Cutoff grade "g_{rc}":

Determine the ratio *(R/C)*, then locate the grade interval such that

$$rc(k^* + 1) \geq (R/C) \geq rc(k^*), \tag{2.28}$$

Then determine

$$\Delta_{rc} = \frac{(R/C) - rc(k^*)}{rc(k^* + 1) - rc(k^*)}, \tag{2.29}$$

and

$$g_{mc} = g(k^*) + \Delta_{mc} * (g(k^* + 1) - g(k^*)). \tag{2.30}$$

The balancing cutoff grades are independent of economic factors entirely and they are dynamic in the sense that they depend upon the grade distribution of the deposit.

2.2.3 Optimum Cutoff Grades

The overall optimum cutoff grade is one of the six cutoff grades consisting of the three limiting economic cutoff grades and the three balancing cutoff grades. To discover the actual optimum, it is best to consider each pair of stages in turn.

Assuming that mine and concentrator are limiting the throughput. Knowing the equations 2.6 and 2.11 for v_m and v_c, as the cutoff grade varies Q_r and Q_c vary and hence v_m and v_c. At low cutoff grades v_m is larger than v_c and at high cutoff grades v_m is smaller than v_c. This is graphically shown in Figure 2.4.

The point of intersection corresponds to balancing cutoff grade g_{mc}. It is also obvious from the graph that when g_{mc} is less than g_m the mine is really bottleneck in the operation and g_m is the optimum cutoff grade. On the other hand, when g_{mc} is greater than g_c, the concentrator is bottleneck and g_c is the optimum cutoff grade. Figures 2.5 and 2.6 explain this graphically. Therefore, the feasible form of v at any cutoff grade, is always the lower of two curves. It is shown as bold line in Figure 2.4, 2.5 and 2.6.

Thus, the following rule may be formulated for an operation limited by mine and concentrator.

For mine and concentrator :

$$
\begin{aligned}
G_{mc} &= g_m \ \ if\ g_{mc} \le g_m, \\
&= g_c \ \ if\ g_{mc} \ge g_c, \\
&= g_{mc} \ \ otherwise.
\end{aligned}
$$

Similarly by considering the other pair of stages.

For mine and refinery :

$$
G_{mr} = g_m \ \ if\ g_{mr} \le g_m,
$$

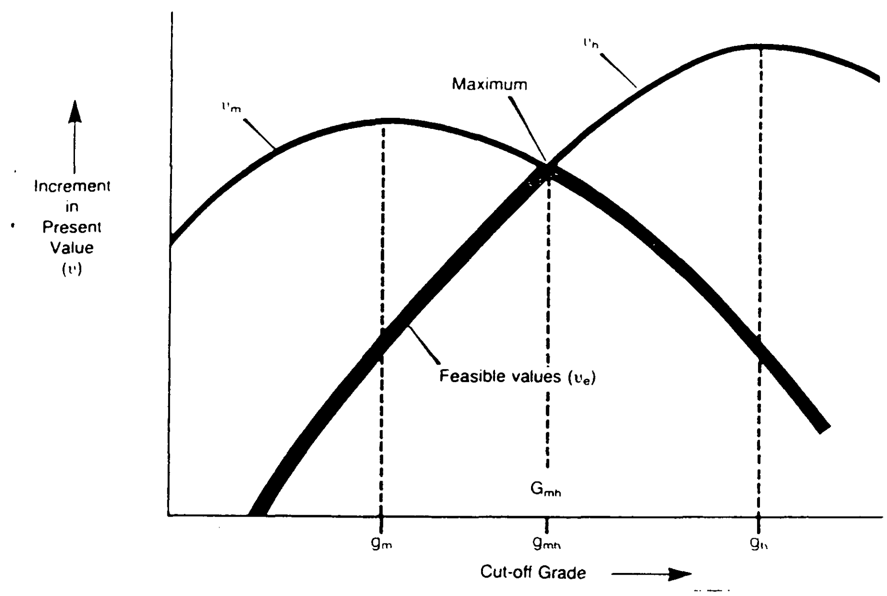

Figure 2.4: Increment In Present Value vs. Cutoff Grade Two Components (Mine & Mill) With Balancing Optimum

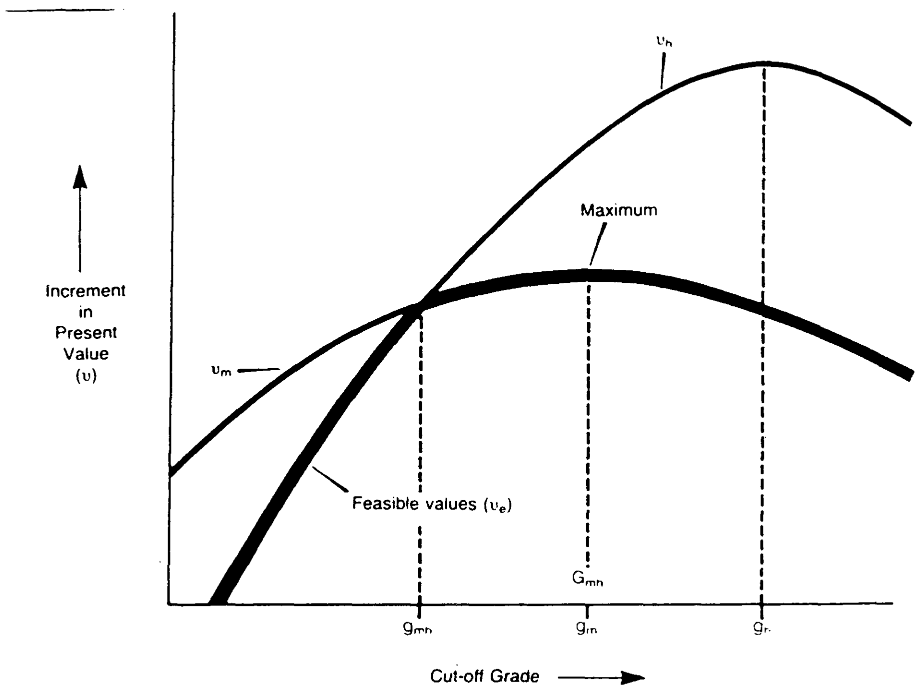

Figure 2.5: Increment In Present Value vs. Cutoff Grade Two Components (Mine & Mill) With Mine Limiting Optimum

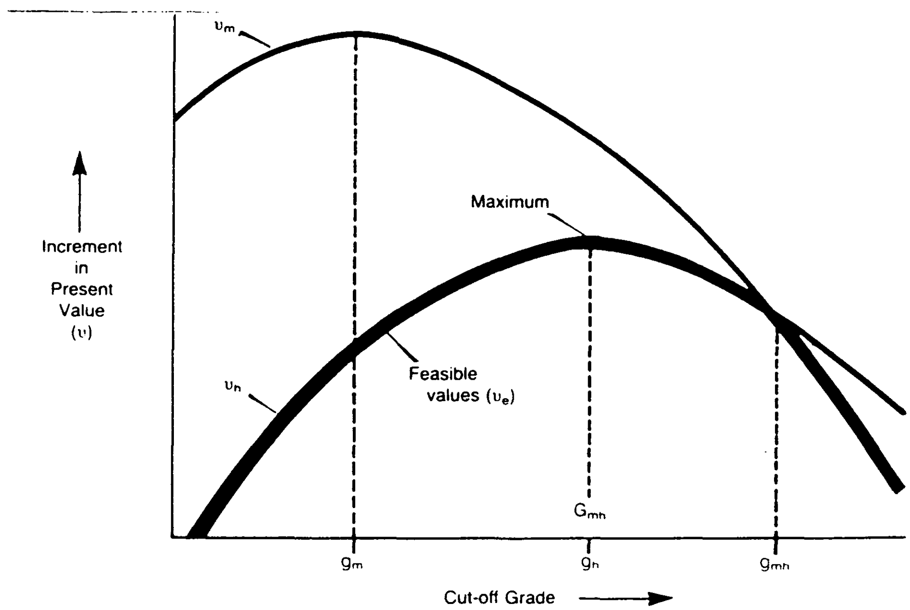

Figure 2.6: Increment In Present Value vs. Cutoff Grade Two Components (Mine & Mill) With Mill Limiting Optimum

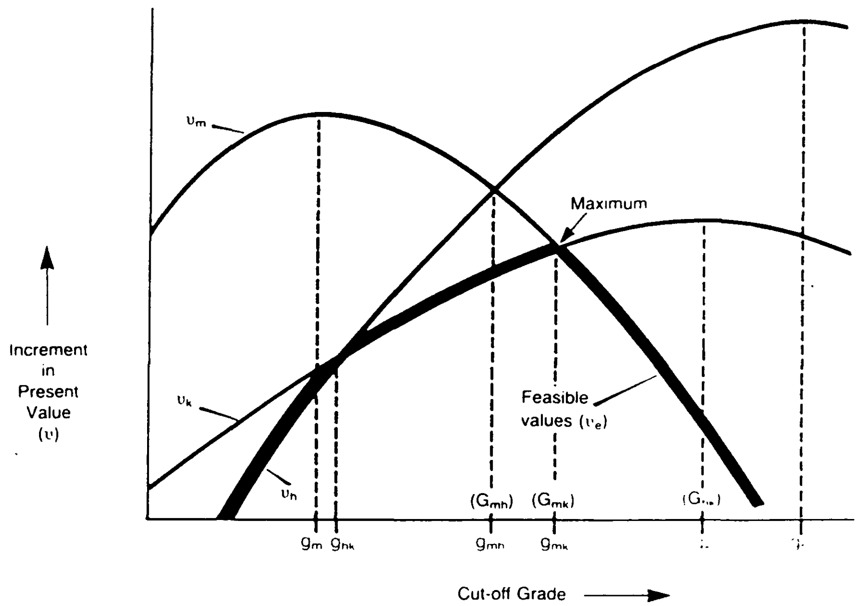

Figure 2.7: Increment In Present Value vs. Cutoff Grade Three Components Final Optimum Cutoff Grade

$= g_r \quad if \quad g_{mr} \geq g_r,$

$= g_{mr} \quad otherwise.$

For concentrator and refinery :

$G_{rc} \quad = g_c \quad if \quad g_{cr} \leq g_c,$

$= g_r \quad if \quad g_{rc} \geq g_r,$

$= g_{rc} \quad otherwise.$

The overall optimum is now one of three, G_{mc}, G_{mr}, and G_{rc}. This is also explained graphically in Figure 2.7.

The largest increase in present value that can be achieved at any cutoff grade, allowing for the capacity restriction, is actually the least of v_m, v_c, and v_r . This is the curved triangle shown by bold line in Figure 2.7. The optimum cutoff grade corresponds to the highest point on these segments, and it can be shown that it always occurs at the middle value of G_{mc}, G_{mr}, and G_{rc}. Thus, the effective optimum cutoff grade is :

$= Middle\ value\ (G_{mc}, G_{mr}, G_{rc})$

2.3 Steps Of The Algorithm

The Following are the necessary steps to determine optimum cutoff grade policy.

Step 1-

Read the input files, which include price, costs, recovery, capacities, grade categories in each push-back, and tonnages associated with each grade category.

Step 2-

Compute the reserves available in the push-back "Tpush".

Step 3-

Compute the reserves available in the deposit "Tdep". If "Tdep" is equal to zero then go to step 12. Otherwise go to next step.

Step 4-

Set $V = NPV$, the initial net present value $NPV = 0$.

Step 5-

Determine the optimum cutoff grade *"OPT"* by using the procedure described in the previous section.

Step 6-

Determine the tons of ore T_O, tons of waste T_W, and average grade g_{avg} of ore associated with optimum cutoff grade *"OPT"*. Also, compute the quantities to be mined Q_m, milled Q_c, and refined Q_r and find the limiting capacity.

Step 7-

Determine the annual profit for the life of mine using following expression.

$$P = (S - r) * Q_r - c * Q_c - m * Q_m - f * T. \tag{2.31}$$

Step 8-

Find the life of deposit *"deplife"*. Also, find the net present value NPV, by discounting profits at given interest rate d for the time *"deplife"*. This relationship can be used.

$$NPV = \frac{P * \left[(1+d)^{deplife} - 1\right]}{d * (1+d)^{deplife}}. \tag{2.32}$$

Compare this NPV with the previous V (step 4). If the computed NPV is not within some tolerance (say ± \$500,000) of V, go to step 4. Otherwise go to next step.

Step 9-

Adjust the grade tonnage curve of the deposit by subtracting ore tons Q_C from the grade distribution intervals above optimum cutoff grade *"OPT"* and the waste tons *"Q_m-Q_C"* from the intervals below optimum cutoff grade *"OPT"* in proportionate amount such that the distribution is not changed.

Step 10-

Check, if the current push-back is finished then go to next step, if not, go to step 2.

Step 11-

Check if all the push-backs are depleted then go to step 3. If not, then go to step 2 and start next push-back.

Step 12-

If it is first iteration then knowing the profits obtained in each year, find the net present value year by year by discounting back those profits and go to step 13. If it is second iteration then stop. .

Step 13-

Use the net present values obtained in step 12, as initial NPV's for each corresponding year for second iteration.

The cutoff grades obtained in this iteration will give the optimum cutoff grades policy for the mine life. Write the *Year, Push-back, Cutoff grade,* Q_m, Q_c, Q_r, *Profit, and* NPV as output.

2.4 Solution Of Manual Example

This example shows that how algorithm works.

2.4.1 Data

Description		Value
Mine Capacity, M	(Tons / Year)	20,000,000.00
Mill Capacity, C	(Tons / Year)	10,000,000.00
Refinery Capacity, R	(Tons / Year)	90,000.00
Sale Price, S	($ / Ton)	550.00
Mining Cost, m	($ / Ton)	0.50
Milling Cost, c	($ / Ton)	0.60
Sales Cost, r	($ / Ton)	50.00
Fixed Cost, f	($ / year)	4,000,000
Recovery, y	(%)	90.00
Discount Rate, d	(%)	15.00

Table 2.1: Economic Parameters For Manual Example

Table 2.1, shows the economic parameters and Table 2.2 is presenting the grade categories and tons available in each category, for the push-back under study in manual example. It can be observed that we have thirteen intervals of grade categories.

2.4.2 Solution

Step 1-

The input files are given in Tables 2.1 and Table 2.2.

Step 2-

Tons in Push-back = 100,000,000.00

Step 3-

Tons in Deposit = 100,000,000.00

Step 4-

V = NPV = 0.0

Step 5-

Using lower limits as the cutoff grades, tons of ore, tons of waste, and average grade can be calculated by following equations. The results have been shown in Table 2.3.

$$T_o(k^*) = \sum_{k=k^*}^{K} T_k ,$$

$$g_{avg}(k^*) = \frac{\sum_{k=k^*}^{K}\left(T_k * \left[\frac{g(k)+g(k+1)}{2}\right]\right)}{\sum_{k=k^*}^{K} T_k},$$

$$T_w(k^*) = \sum_{k=1}^{k^*} T_k .$$

Using following equations the ratio of ore tons to total tons mc, ratio of quantity of metal to total tons, and quantity of metal can be calculated. The results are provided in Table 2.4.

Table 2.2: Grade Tonnage Distribution Of Deposit

S.No	Lower Limit of Grade Categories	Upper Limit of Grade Categories	Tons in each Grade Category
1	0.0	0.0015	14,400,000
2	0.0015	0.002	4,600,000
3	0.002	0.0025	4,400,000
4	0.0025	0.003	4,300,000
5	0.003	0.0035	4,200,000
6	0.0035	0.004	4,100,000
7	0.004	0.0045	3,900,000
8	0.0045	0.005	3,800,000
9	0.005	0.0055	3,700,000
10	0.0055	0.006	3,600,000
11	0.006	0.0065	3,400,000
12	0.0065	0.007	3,300,000
13	0.007	.0156	42,300,000

Table 2.3: Tons of Ore, Tons of Waste, and Average Grade

Cutoff Grade	T_o	T_W	g_{avg}
0.0	100,000,000	0	0.00666
0.0015	85,600,000	14,400,000	0.00765
0.002	81,000,000	19,000,000	0.00799
0.0025	76,600,000	23,400,000	0.00832
0.003	72,300,000	27,700,000	0.00865
0.0035	68,100,000	31,900,000	0.00898
0.004	64,000,000	36,000,000	0.00932
0.0045	60,100,000	39,000,000	0.00965
0.005	56,300,000	43,700,000	0.00998
0.0055	52,600,000	47,400,000	0.01031
0.006	49,000,000	51,000,000	0.01064
0.0065	45,600,000	54,400,000	0.01097
0.007	42,300,000	57,700,000	0.0113

Table 2.4: Ratios, MC, RM, RC As a Function Of Cutoff Grade

Cutoff Grade	MC	RM	RC
0.0	1.00	0.0060	0.0060
0.0015	0.856	0.0059	0.0069
0.002	0.810	0.0058	0.0072
0.0025	0.766	0.0057	0.0075
0.003	0.723	0.0056	0.0078
0.0035	0.681	0.0055	0.0081
0.004	0.640	0.0054	0.0084
0.0045	0.606	0.0053	0.0087
0.005	0.563	0.0051	0.0089
0.0055	0.526	0.0049	0.0093
0.006	0.490	0.0047	0.0096
0.0065	0.456	0.0045	0.0099
0.007	0.423	0.0043	0.0101

$$mc(k^*) = \frac{T_o(k^*)}{T_o(k^*) + T_w(k^*)},$$

$$mc(k^*) = \frac{T_o(k^*) * g_{avg}(k^*) * y}{T_o(k^*) + T_w(k^*)},$$

$$rc(k^*) = g_{avg}(k^*) * y.$$

Now, ratio of mill to mine capacity is C / M:

$$= \frac{10{,}000{,}000}{20{,}000{,}000},$$

$$= 0.5.$$

Ratio of refinery to mine capacity is R / M:

$$= \frac{90{,}000}{20{,}000{,}000},$$

$$= 0.0045.$$

Ratio of refinery to mill capacity is R / C:

$$= \frac{90{,}000}{10{,}000{,}000},$$

$$= 0.009.$$

Balancing cutoff grade between mine and mill can be determined as follows.

Locate the grade interval such that

$$mc(k^*) \geq ({}^{C}\!/_{M}) \geq mc(k^* + 1).$$

In Table 2.4, It is clear that ratio C / M occurs between 0.526 at grade of 0.0055 and 0.49 at a grade of 0.006, therefore:

$$\Delta_{mc} = \frac{mc(k^*) - ({}^{C}\!/_{M})}{mc(k^*) - mc(k^* + 1)},$$

$$\Delta_{mc} = \frac{0.526 - 0.5}{0.526 - 0.49},$$

$\Delta_{mc} = 0.722,$

and

$$g_{mc} = g(k^*) + \Delta_{mc} * (g(k^* + 1) - g(k^*)),$$

$$g_{mc} = 0.0055 + 0.722 * (0.006 - 0.0055),$$

$$g_{mc} = 0.00586.$$

Balancing cutoff grade between mine and refinery can be determined as follows. Locate the grade interval such that

$$mr(k^*) \geq (R/M) \geq mr(k^* + 1).$$

In Table 2.4, It is clear that ratio R / M occurs between 0.0045 at grade of 0.0065 and 0.0043 at a grade of 0.007, therefore:

$$\Delta_{mr} = \frac{mr(k^*) - (R/M)}{mr(k^*) - mr(k^* + 1)},$$

$$\Delta_{mr} = \frac{0.0045024 - .0045}{.0045024 - .0043},$$

$$\Delta_{mr} = 0.0119,$$

and

$$g_{mr} = g(k^*) + \Delta_{mr} * (g(k^* + 1) - g(k^*)),$$

$$g_{mr} = 0.0065 + .0119 * (0.007 - 0.0065),$$

$$g_{mr} = 0.00651.$$

Balancing cutoff grade between mill and refinery can be determined as follows. Locate the grade interval such that

$$rc(k^* + 1) \geq (R/C) \geq rc(k^*).$$

In Table 2.4, It is clear that ratio R / C occurs between 0.0089 at grade of 0.005 and 0.0093 at a grade of 0.0055, therefore:

$$\Delta_{rc} = \frac{(R/C) - rc(k^*)}{rc(k^* + 1) - rc(k^*)},$$

$$\Delta_{rc} = \frac{0.009 - 0.0089}{0.0093 - 0.0089},$$

$\Delta_{rc} = 0.0727,$

and

$$g_{rc} = g(k^*) + \Delta_{rc} * (g(k^* + 1) - g(k^*)),$$

$$g_{rc} = 0.005 + 0.0727 * (0.0055 - 0.005),$$

$g_{rc} = 0.00504.$

The limiting economic cutoff grades can be found by following equations:

Initial $V = 0.0,$

$$g_m = \frac{c}{(S - r) * y},$$

$$g_m = \frac{0.6}{(550 - 50) * 0.9},$$

$g_m = 0.00133,$

$$g_c = \frac{c + \dfrac{f + d * V}{C}}{(S - r) * y},$$

$$g_c = \frac{0.6 + \dfrac{4{,}000{,}000 + 0.15 * 0.0}{10{,}000{,}000}}{(550 - 50) * 0.9},$$

$g_c = 0.00222,$

$$g_r = \frac{c}{\left(S - r - \dfrac{f + d * V}{R}\right) * y},$$

$$g_r = \frac{0.6}{\left(550 - 50 - \frac{4{,}000{,}000 + 0.15 * 0.0}{90{,}000}\right) * 0.9},$$

$g_r \quad = 0.00146.$

Considering the rules set up in section 2.1.5 (optimum cutoff grades).

For mine and concentrator :

$G_{mc} \quad = 0.00222.$

For mine and refinery:

$G_{mr} \quad = 0.00146.$

For refinery and concentrator :

$G_{cr} \quad = 0.00222.$

By taking the middle value overall optimum cutoff grade G can be determined:

$G \quad = 0.00222.$

Step 6-

For this value of *G*, we need to find tons of ore, tons of waste and average grade. As this cutoff grade occurs in interval *"k = 3"* (0.002 - 0.0025) of grade categories (Table 2.2) , therefore tons of waste in this interval can be found by linear interpolation:

$$X = \left(\frac{G - g(k)}{g(k+1) - g(k)}\right) * T_k,$$

$$X = \left(\frac{0.00222 - 0.002}{0.0025 - 0.002}\right) * 4{,}400{,}000.$$

where X is the tons of waste and T_k (Table 2.2).are total tons in this interval.

$X \quad = 1953600.00$ *tons* ,

$Y \quad = 4{,}400{,}000 - X,$

where Y is the tons of ore in this interval,

$Y \quad = 2446400.00.$

Total Tons of ore at this cutoff grade (above $k = 3$) can be determined as :

$$T_o = Y + \sum_{k=4}^{13} T_k \,,$$

$$T_o = 2446400 + \sum (4300000 + 4200000 + \text{☹} + 42300000) \,,$$

$$T_O \quad = 79046400.00 \text{ tons.}$$

Total Tons of waste at this cutoff grade (below $k = 3$) can be determined as :

$$T_w = X + \sum_{k=1}^{2} T_k \,,$$

$$T_w = 1953600 + \sum_{1} 14400000 + 4600000 \,,$$

$$T_W \quad = 20953600.00 \text{ tons.}$$

Average grade of ore can be calculated as :

$$g_{avg} = \frac{\left(\frac{G + g(k+1)}{2} * Y \right) + \sum_{k=4}^{13} \left(\frac{g(k) + g(k+1)}{2} * T_k \right)}{Y + \sum_{k=4}^{13} T_k} \,,$$

$$g_{avg} \quad = 0.00813.$$

Stripping ratio can be calculated as :

$$SR = \frac{T_w}{T_o} \,,$$

$$SR = \frac{20953600}{79046400} \,,$$

$$SR \quad = 0.265.$$

The quantities Q_m, Q_c, and Q_r can be computed as follows :

$$Q_m = M \,,$$

$$Q_m \quad = 20{,}000{,}000.00 \text{ tons,}$$

$$Q_c = \frac{Q_m}{1+SR},$$

$$Q_c = \frac{20,000,000}{1+0.265},$$

Qc = *15809280.00 tons,*

$$Q_r = Q_c * g_{avg} * y,$$

$$Q_r = 15809280 * 0.00813 * 0.9,$$

Qr = *115720.37 tons.*

As Qc is greater than milling capacity, therefore:

$$Q_c = C,$$

Qc = *10,000,000.00 tons,*

$$Q_m = Q_c * (1+SR),$$

$$Q_m = 10,000,000 * (1+0.265),$$

Qm =*12650798.00 tons,*

$$Q_r = Q_c * g_{avg} * y,$$

$$Q_r = 10,000,000 * 0.00813 * 0.9,$$

Qr = *73197.49 tons.*

All quantities are within limits and mill is the limiting capacity.

Step 7-

$$Life = \frac{T_o}{C},$$

$$Life = \frac{79046400}{10,000,000},$$

Life = *8 years.*

The annual profit is determined as follows :

$$P = (S-r) * Qr - c * Qc - m * Qm - f,$$

$P = (550-50)*73197.49 - 0.6*10{,}000{,}000 - 0.5*12{,}650{,}798 - 4{,}000{,}000,$

$P \quad = \$\ 20273475.79\,/\,year.$

Step 8-

Net present value is calculated as :

$$V = \frac{P*\left[(1+d)^{life}-1\right]}{d*(1+d)^{life}},$$

$$V = \frac{20273475.79*\left[(1+0.15)^{8}-1\right]}{0.15*(1+0.15)^{8}},$$

$V \quad = \$\ 90380806.01.$

As this V is not in tolerance of (± 500,000) of the previous $V = 0.0$, therefore the limiting economic cutoff grades can be recalculated by using this calculated V. However, the balancing cutoff grades will remain same throughout the life of push-back as they are only depending upon the grade distribution of the deposit.

Step 4-

V = NPV = 90380806.01

Step 5-

The limiting economic cutoff grades are :

$$g_m = \frac{0.6}{(550-50)*0.9},$$

$g_m \quad = 0.00133,$

$$g_c = \frac{0.6 + \dfrac{4{,}000{,}000 + 0.15*90380806.01}{10{,}000{,}000}}{(550-50)*0.9},$$

$g_c \quad = 0.00523,$

$$g_r = \frac{0.6}{\left(550-50-\dfrac{4{,}000{,}000+0.15*90380806.01}{90{,}000}\right)*0.9},$$

g_r = 0.00219.

Considering the rules set up in section 2.1.5 for optimum cutoff grades.

For mine and concentrator :

G_{mc} = *0.00523.*

For mine and refinery:

G_{mr} = *0.00219.*

For refinery and concentrator :

G_{cr} = *0.00504.*

By taking the middle value overall optimum cutoff grade G can be determined:

G = *0.00504.*

Step 6-

For this value of *G*, we need to find tons of ore, tons of waste and average grade. As this cutoff grade occurs in interval *"k = 9"* (.005 - .0055) of grade categories (Table 2.2) , therefore tons of waste in this interval can be found by linear interpolation:

$$X = \left(\frac{G - g(k)}{g(k+1) - g(k)}\right) * T_k,$$

$$X = \left(\frac{0.00504 - .005}{0.0055 - 0.005}\right) * 3{,}600{,}000.$$

where X is the tons of waste and T_k (Table 2.2) are total tons in this interval.

X *=268620.00 tons* ,

Y *= 4,400,000 - X,*

where Y is the tons of ore in this interval,

Y *= 3431380.00.*

Total Tons of ore at this cutoff grade (above $k = 9$) are :

T_o *=56031380.00 tons.*

Total Tons of waste at this cutoff grade (below $k = 9$) are :

$T_W \quad = 43968620.00 \text{ tons.}$

Average grade of ore is :

$g_{avg} \quad = 0.0099.$

Stripping ratio is :

$SR \quad = 0.785.$

The quantities Q_m, Q_c, and Q_r are :

$Q_m \quad = 20,000,000.00 \text{ tons,}$

$Q_c \quad =11206276.00 \text{ tons,}$

$Q_r \quad = 100852.56 \text{ tons.}$

As Q_c is greater than milling capacity, therefore:

$Q_c \quad = 10,000,000.00 \text{ tons,}$

$Q_m \quad =17847142.00 \text{ tons,}$

$Q_r \quad =89996.50 \text{ tons.}$

All quantities are within limits and mill is the limiting capacity.

Step 7-

Life = *6 years.*

Annual profit is :

$P \quad = \$\ 26074680.13/\text{year.}$

Step 8-

Net present value is :

$V \quad =\$\ 94393008.22.$

As this V is not in tolerance of ($\pm$ 500,000) of the previous V =*90380806.01*, therefore the limiting economic cutoff grades can be recalculated by using this calculated V.

Step 4-

V = NPV = 94393008.22

Step 5-

The limiting economic cutoff grades are :

$$g_m = \frac{0.6}{(550-50)*0.9},$$

$$g_m \quad = 0.00133,$$

$$g_c = \frac{0.6 + \dfrac{4{,}000{,}000 + 0.15*94393008.22}{10{,}000{,}000}}{(550-50)*0.9},$$

$$g_c \quad = 0.00537,$$

$$g_r = \frac{0.6}{\left(550 - 50 - \dfrac{4{,}000{,}000 + 0.15*94393008.22}{90{,}000}\right)*0.9},$$

$$g_r \quad = 0.0022.$$

The optimum cutoff grades are as follows.

For mine and concentrator :

$$G_{mc} \quad = 0.00537.$$

For mine and refinery:

$$G_{mr} \quad = 0.0022.$$

For refinery and concentrator :

$$G_{cr} \quad = 0.00504.$$

By taking the middle value overall optimum cutoff grade G can be determined as:

$$G \quad = 0.00504.$$

Step 6-

For this value of G, we need to find tons of ore, tons of waste and average grade. As this cutoff grade occurs in interval *"k = 9"* (0.005 - 0.0055) of grade categories (Table 2.2) , therefore tons of waste in this interval can be found by linear interpolation:

$$X = \left(\frac{G - g(k)}{g(k+1) - g(k)}\right) * T_k,$$

$$X = \left(\frac{0.00504 - .005}{0.0055 - 0.005} \right) * 3{,}600{,}000,$$

where X is the tons of waste and T_k (Table 2.2) are total tons in this interval.

$X \quad = 268620.00 \textit{ tons},$

$Y \quad = 4{,}400{,}000 - X,$

where Y is the tons of ore in this interval,

$Y \quad = 3431380.00.$

Total Tons of ore at this cutoff grade (above $k = 9$) are :

$T_o \quad = 56031380.00 \textit{ tons}.$

Total Tons of waste at this cutoff grade (below $k = 9$) are :

$T_w \quad = 43968620.00 \textit{ tons}.$

Average grade of ore is :

$g_{avg} \quad = 0.0099.$

Stripping ratio is :

$SR \quad = 0.785.$

The quantities Q_m, Q_c, and Q_r are :

$Q_m \quad = 20{,}000{,}000.00 \textit{ tons},$

$Q_c \quad = 11206276.00 \textit{ tons},$

$Q_r \quad = 100852.56 \textit{ tons}.$

As Q_c is greater than milling capacity, therefore:

$Q_c \quad = 10{,}000{,}000.00 \textit{ tons},$

$Q_m \quad = 17847142.00 \textit{ tons},$

$Q_r \quad = 89996.50 \textit{ tons}.$

All quantities are within limits and mill is the limiting capacity.

Step 7-

Life $= 6$ *years.*

Annual profit is :

$P \quad = \$ \ 26074680.13/year.$

Step 8-

Net present value is :

$V \quad =\$ \ 94393008.22.$

As the calculated V is equal to previous V, therefore V has been converged and this is the maximum NPV that can be achieved.

Step 9-

As Qm of material has been mined, therefore, tons in the grade categories will be adjusted. This can be done as follows.

Tons to be adjusted in the interval where optimum cutoff grade G occurred.

Tons of waste subtracted from the interval ($k = 9$) :

$$Tb = \frac{(G - g(k)) * T_k}{g(k+1) - g(k)} * \frac{Q_m - Q_c}{T_w},$$

$$Tb = \frac{(0.00504 - 0.005) * 3600000}{0.0055 - 0.005} * \frac{17847142 - 10000000}{43968620},$$

$$Tb \quad = 47940.99 \text{ tons.}$$

Tons of ore subtracted from the interval ($k = 9$) :

$$Ta = \frac{(g(k+1) - G) * T_k}{g(k+1) - g(k)} * \frac{Q_c}{T_o},$$

$$Ta = \frac{(0.0055 - 0.00504) * 3600000}{0.0055 - 0.005} * \frac{10000000}{56031380},$$

$$Ta \quad = 612403.26 \text{ tons.}$$

Tons in the interval ($k = 9$) :

$$T_k = T_k - (Ta + Tb),$$

$$T_k = 3600000 - (612403.26 + 47940.99),$$

$$Tk \quad =3039655.74 \text{ tons.}$$

Tons to be adjusted in the intervals below optimum cutoff grade G ($k = 1$ *to* 8).

Tons of waste subtracted from the intervals ($k = 1\ to\ 8$) :

$$Tadj_k = T_k * \frac{Q_m - Q_c}{T_{push} - T_o}.$$

Tons to be adjusted in the intervals above optimum cutoff grade G ($k = 10\ to\ 13$).

Tons of ore subtracted from the intervals ($k = 10\ to\ 13$) :

$$Tadj_k = T_k * \frac{Q_c}{T_o}.$$

Remaining tons in grade categories are shown in Table 2.5.

Step 10-

Now, push-back life can be determined as :

$$Plife1 = \frac{T_o + T_w}{Q_m}, \qquad Plife2 = \frac{T_o}{Q_c}, \qquad Plife3 = \frac{T_o * g_{avg} * y}{Q_r}.$$

$$Plife1 = \frac{56031380 + 43968620}{17847142}, \qquad Plife1 = 6.$$

$$Plife2 = \frac{56031380}{10{,}000{,}000}, \qquad Plife2 = 6.$$

$$Plife3 = \frac{56031380 * 0.0099 * 0.9}{89996.5}, \qquad Plife3 = 6.$$

$$Plife = Max(Plife1, Plife2, Plife3),$$

$$Plife = 6\ years.$$

As in this example the deposit has only one push-back, therefore, Life of deposit "*Life*" and the push-back life "*Plife*" are same. Otherwise, obviously "*Plife*" will be less than "*Life*". However, in a deposit of more than one push-back when the "*Plife*" will be less than one year, then program will start next push-back as mentioned in the step 11 of previous section.

Step 11-

In the deposit of more than one push-back, the program will accumulate the tons available. If this sum is equal to zero then it will go to step 12. Otherwise, it will start next available push-back.

Step 12-

In the manual example, we have to compute optimum cutoff grades for the rest of mine life following the same procedure. That is, starting with V = 0.0 and doing successive iterations. So in step 12, Once the profits for the mine life are obtained. They will be discounted back to find the corresponding NPV in each year and then program goes to step 13 as explained in the previous section. However, this step will be approached only once by the program (during first iteration "see step 12 in previous section").

Step 13-

Whole process will be repeated using yearly NPV's obtained in step 12 instead of V = 0.0. The output obtained in this step gives the cutoff grade policy and the production schedule shown in Table 2.6.

Table 2.5:` Grade Tonnage Distribution After One Year

S.No	Lower Limit of Grade Categories	Upper Limit of Grade Categories	Tons in each Grade Category
1	0.0	0.0015	11,830,012
2	0.0015	0.002	3,779,031
3	0.002	0.0025	3,614,726
4	0.0025	0.003	3,532,573
5	0.003	0.0035	3,450,420
6	0.0035	0.004	3,368,267
7	0.004	0.0045	3,203,961
8	0.0045	0.005	3,121,809
9	0.005	0.0055	3,039,656
10	0.0055	0.006	2,957,503
11	0.006	0.0065	2,793,197
12	0.0065	0.007	2,711,044
13	0.007	.0156	34,750,659

Table 2.6: Final Schedule For Manual Example

Year	C.O.G. (%)	Q_m (M. tons)	Q_c (M. tons)	Q_r (1000's T)	Profit ($M)	NPV ($M)
1	0.50	17.8	10.0	90.0	26.1	95.8
2	0.50	17.8	10.0	90.0	26.1	84.1
3	0.46	16.8	10.0	87.3	25.3	70.6
4	0.41	15.8	10.0	84.3	24.3	55.9
5	0.36	14.8	10.0	81.3	23.2	40.0
6	0.30	13.8	10.0	77.9	22.0	22.8
7	0.24	3.0	2.3	17.1	4.8	4.2

3. DEVELOPMENT OF COMPUTER PROGRAM FOR CUTOFF GRADE OPTIMIZATION IN ONE MINERAL DEPOSITS

The calculation of a single optimum cutoff grade for one particular set of conditions is not very difficult. But, the calculation of a complete cutoff grade policy is a different matter. Because, in that case one needs to take care of many issues simultaneously.

The OPTI1.FOR program is developed to cope with the complex computations involved in solving the algorithm. This program is included on the diskette given at the end of the thesis as appendix C. FORTRAN 77 is used for this purpose, however, the program can also be compiled with a FORTRAN 90 compiler.

3.1 Summary Of Routines

The routines of the program can be divided into three major types. These are optimum cutoff grade routines, the net present value routines, and the routines which analyze the adjustment of grade tonnage curves after the quantities of material are assigned with respect to mine, mill, and refinery. These quantities are the function of optimum cutoff grades for current period.

The optimum cutoff grade routines use the economic parameters such as price, costs and capacities associated with mine, mill, and refinery, and the metallurgical recoveries. These economic parameters are involved in calculation of limiting economic cutoff grades. The balancing cutoff grades use the grade tonnage distribution of the deposit. The optimum cutoff grade is determined by using the criteria defined in chapter 2 in a different subroutine.

The net present value convergence routines use the optimum cutoff grade as a main input, because, all the analysis conducted by them is function of optimum cutoff grade. These routines find the life of deposit based on the assumption that whole deposit will be mined by using this optimum cutoff grade. The life of mine is also a function of the limiting capacity during this period. The annual profit for the life of mine is calculated, and then net present value is determined by discounting back those annual profits for the life of mine. If the net present value determined is converged i.e. within some tolerance of the previous net present value used in the analysis, then the operation of the program is handed over to the grade tonnage curve adjustment routines. Usually it takes three to five iterations to converge to the optimum net present value.

The grade tonnage curve adjustment routines use the information obtained from the previous two major portions of the program. The push-back life is determined based on the quantities being sent to the mine, mill, and refinery. The tons of ore, waste and final product handled in the period are subtracted from the grade tonnage distribution such that the shape of the distribution is not changed. If the material required for the current period is not available in the push-back, then the next available push-back is incorporated in this period by the program. However, if the push-backs in the deposit are finished then the program ends. The general logic and structure of the program is given in Figure 3.1.

The program is capable of handling any number of increments given in the grade tonnage distribution. This choice is given according to the need of the user in the input file. The number of push-backs can also be defined by the user in the input file. The size of arrays can also be modified by the user according to the requirement. All of the subroutines are less than a page in length, and easily understanding. This program consists of the 1600 lines in 32 subroutines, it takes less than a minute to execute the program and obtain the final output.

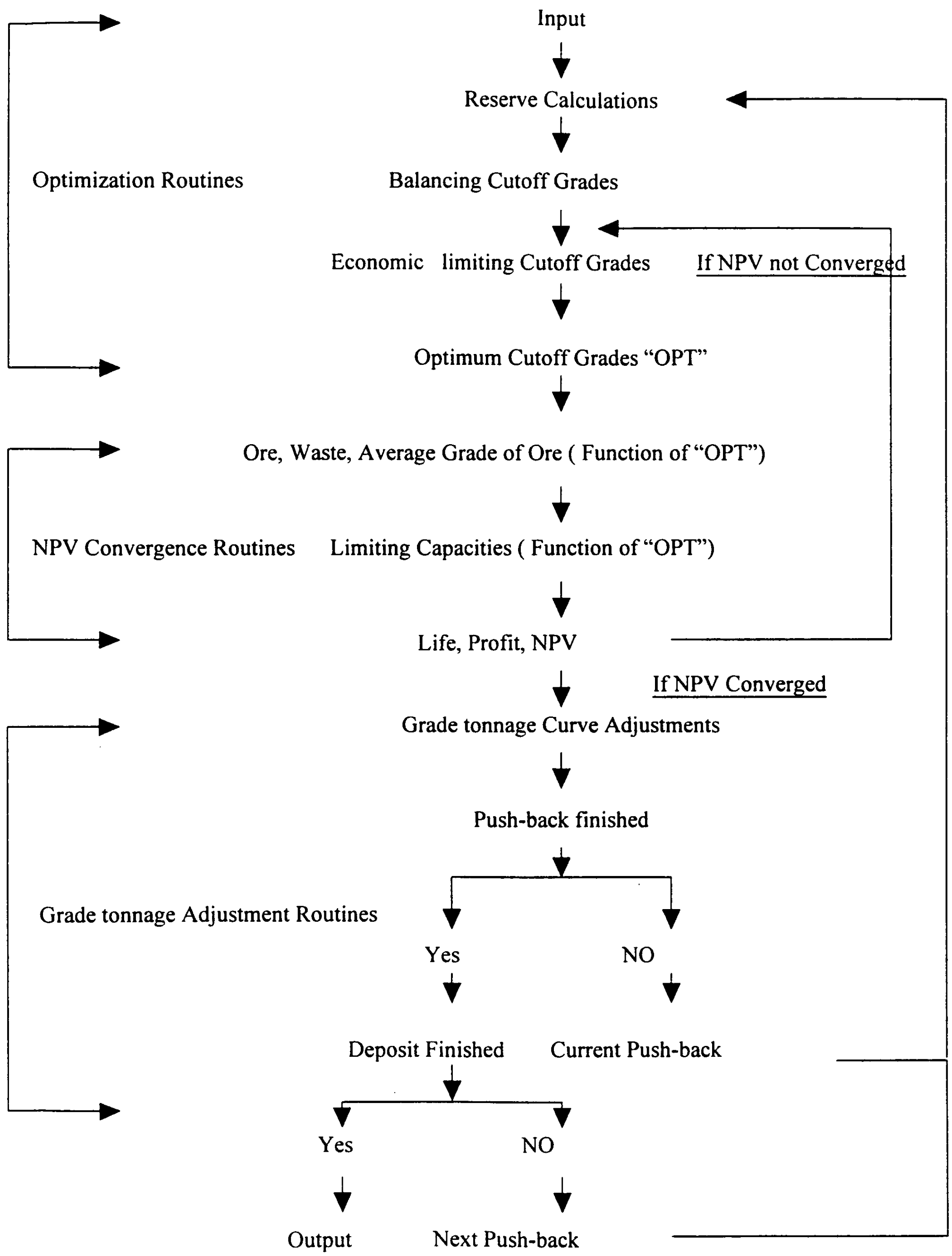

Figure 3.1: Flow Diagram of the Program OPTI1.FOR

3.2 Input

For the example to be demonstrated, the input data is shown in Table 3.1 and Table 3.2. This data is coming from the example problem in Lane's (1964) publication. The structure of the input files used by the program is given in the Table 3.3 and Table 3.4. These files are also included on the diskette with program "OPTI1.FOR" under the name "aopti1.dat" and "bopti1.dat" in appendix C.

The first line in the Table 3.3 is the capacities associated mine, mill, and refinery respectively.

The second line has price, refinery or marketing cost, milling cost, mining cost, recovery, discount rate, and the fixed cost respectively.

In the third line of Table 3.3, user can define the number of push-backs and the number of increments in the grade distribution respectively.

The fourth line is a logical input for the program, this defines whether the grades are in percent or in any other unit. If the grades are given in percent then this input will be ".TRUE.".

The rest of the input file has the lower and upper limits of grade increments with respect to each push-back. For the demonstration example, there are six push-backs and thirteen increments in the grade distribution. Therefore, the lower and upper grade increments have six lines, and each line corresponds to the grade distribution of each push-back.

The Tons available in each increment of each push-back are given in Table 3.4. Therefore, each line in this data corresponds to the reserves in different push-backs.

3.3 Output

The output of this program is divided into two parts. The detailed output of the program consists of a huge file, this includes the year by year analysis done by each subroutine in the program. This output gives a broader picture of the program. The output which shows the complete cutoff grade policy consists of years in the column 1, push-back in this year in column 2, optimum cutoff grades in column 3, quantities to be mined Q_m (in million tons) in column 4, quantities to be milled Q_c (in million tons) in column 5, and quantities to be refined Q_r (in thousand tons) in column 6, the profit (in $M) in column 7, and net present value (in $M) in column 8. This output of the demonstration example is shown in Table 3.5. The results obtained in this output show that mill and refinery were in balance from year 1 to 6 for the push-back 1. The cutoff grade during these years is balancing cutoff grade for mill and refinery. Therefore, it is same in these years. For push-back 2 mine and mill are in balance, and the cutoff grade is same from year 7 to 11, and this is the balancing cutoff grade for mine and mill. Same situation exists for the third push-back. However, for the rest of mine life mill is bottleneck i.e. limiting throughout. Therefore, the cut-off grades during these years are mill limiting cutoff grades.

Description	**Value**
Mining Capacity, tons per year	20,000,000
Milling Capacity, tons per year	10,000,000
Refining Capacity (Copper), tons per year	90,000
Mining Cost, dollars per ton	0.5
Milling Cost, dollars per ton	0.6
Marketing Cost (Copper), dollars per ton	50.00
Fixed Costs, dollars per ton	4,000,000
Price (Copper), dollars per ton	550.00
Recovery (Copper), %	90
Discount Rate, %	15

Table 3.1: Economic Parameters For The Program OPTI1.FOR

Table 3.2: Grade Tonnage Distribution Of Deposit

Lower limits of grade categories (%)	Upper limits of grade categories (%)	Tons(in millions) in each Push-back					
		1	2	3	4	5	6
0.0	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	0.25	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.	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
0.70	+ 0.70	42.3	37.5	31.6	25.0	17.4	9.0
Last upper grade category for each Push-back		1.56	1.44	1.30	1.16	1.04	0.90

Table 3.3: Structure Of Input File of Economic Parameters and Grades For "OPTI1.FOR"

```
20000000.,10000000.,90000.0
550.,50.,0.6,0.5,0.90,0.15,4000000.
6,13
.TRUE.
Lower bounds of grade increments
0.0,0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7
0.0,0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7
0.0,0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7
0.0,0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7
0.0,0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7
0.0,0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7
Upper bounds of grade increments
0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7,1.56
0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7,1.44
0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7,1.30
0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7,1.16
0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7,1.04
0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7,0.90
```

Table 3.4: Structure Of Input File of Reserves For "OPTI1.FOR"

Tons for each grade increment
14.4,4.6,4.4,4.3,4.2,4.1,3.9,3.8,3.7,3.6,3.4,3.3,42.3
15.9,5.1,4.9,4.7,4.5,4.4,4.3,4.1,3.9,3.8,3.6,3.5,37.3
17.9,5.5,5.4,5.3,4.9,4.7,4.6,4.5,4.2,3.9,3.8,3.7,31.6
20.3,6.3,6.0,5.6,5.5,5.3,4.9,4.8,4.5,4.2,3.9,3.7,25.0
23.4,7.2,6.7,6.4,6.2,5.6,5.4,5.1,4.6,4.4,4.0,3.6,17.4
27.7,8.3,7.7,7.3,6.7,6.3,5.7,5.3,4.7,4.3,3.7,3.3,9.00

Table 3.5: **Complete Cutoff Grade Policy For Demonstration Example By "OPTI1.FOR"**

Year	Push-back	COG.	Q_m (M's)	Q_c (M's)	Q_r (1000's)	Profit ($M)	NPV ($M)
1	1	0.50	17.9	10.0	90.0	26.1	150.2
2	1	0.50	17.9	10.0	90.0	26.1	146.7
3	1	0.50	17.9	10.0	90.0	26.1	142.6
4	1	0.50	17.9	10.0	90.0	26.1	137.9
5	1	0.50	17.9	10.0	90.0	26.1	132.5
6	1	0.50	10.7	6.0	54.1	15.7	126.3
6	2	0.53	8.0	4.0	34.2	9.1	126.3
7	2	0.53	20.0	10.0	85.8	22.9	120.4
8	2	0.53	20.0	10.0	85.8	22.9	115.6
9	2	0.53	20.0	10.0	85.8	22.9	110.1
10	2	0.53	20.0	10.0	85.8	22.9	103.7
11	2	0.53	12.2	6.1	52.2	13.9	96.3
11	3	0.47	7.8	3.9	29.8	7.1	96.3
12	3	0.47	20.0	10.0	76.0	18	89.8
13	3	0.47	20.0	10.0	76.0	18	85.2
14	3	0.47	20.0	10.0	76.0	18	80
15	3	0.47	20.0	10.0	76.0	18	73.9
16	3	0.44	12.3	6.4	48.0	11.4	67
16	4	0.41	7.1	3.6	23.7	4.7	67
17	4	0.41	20.0	10.0	66.4	13.2	60.9
18	4	0.41	20.0	10.0	66.4	13.2	56.8
19	4	0.39	19.4	10.0	65.5	13.1	52.1
20	4	0.38	18.7	10.0	64.4	12.9	46.8
21	4	0.36	14.8	8.3	52.2	10.4	41
21	5	0.35	3.5	1.7	9.9	1.5	41
22	5	0.34	19.4	10.0	56.4	8.5	35.2
23	5	0.33	18.8	10.0	55.7	8.4	32
24	5	0.31	18.2	10.0	54.8	8.3	28.4
25	5	0.30	17.7	10.0	54.0	8.2	24.4
26	5	0.28	17.1	10.0	53.0	8	19.9
27	5	0.27	5.3	3.2	16.8	2.5	14.9
27	6	0.27	12.6	6.8	31.1	2.5	14.9
28	6	0.26	18.2	10.0	45.6	3.7	12.1
29	6	0.25	17.9	10.0	45.3	3.7	10.2
30	6	0.25	17.6	10.0	44.8	3.6	8.1
31	6	0.24	17.2	10.0	44.3	3.5	5.7
32	6	0.23	16.5	9.8	43.0	3.4	3

4. CUTOFF GRADE OPTIMIZATION IN DEPOSITS OF TWO ECONOMIC MINERALS

The determination of optimum cutoff grade policy for two minerals deposit will be based on Lane's algorithm (Lane 1988). The development of this algorithm also considers that the mining system consists of three main stages. These are mining, milling and refining. However, in case of two minerals deposit the second refinery for mineral 2 will be additional.

The criteria for selection of optimum cutoff grades will be same i.e. maximizing the net present value of project operating cash flows.

In order to find the cutoff grades for two minerals there are different techniques available to apply, but as Lane explains the situation is different for their application. Following is the brief discussion of these techniques.

4.1 Parametric Cutoff Grades

A cutoff grade is called parametric if it is only indirectly related to the grade distribution of the deposit. These parametric cutoff grades are not uncommon and one of their cause is the presence of minor minerals whose equivalent values are simply added to the main mineral of the deposit.

Take an example of copper mineralized body which also contains some molybdenum. The original grade categories may well have been defined in terms of both copper and molybdenum but, because molybdenum is of minor importance, the complexities of a two dimensional grade analysis are avoided by calculating the copper equivalent of the molybdenum in each copper category and adding this to the copper content.

This involves a compromise between accuracy and practicability, of course. In theory, either the two dimensional grade distribution should be retained or the reserve should be recompiled on the basis of the combined minerals. The latter considers the adding of one mineral to its equivalent of the other to form the combination at some earlier stage in the compilation of the mineralized reserve.

As a consequence, the categories of distribution which are defined by one mineral are no longer directly related to the distribution itself which is based upon the combined minerals. In the example quoted earlier, the categories are still the original copper categories but the average grades are the copper equivalents of the total of the copper and molybdenum.

The fact that a cutoff grade is parametric introduces no fundamental new considerations into cutoff grade theory but care has to be exercised in certain areas. In particular, the distribution becomes inconsistent if the cutoff is altered marginally, the grade of marginal material is not necessarily near the cutoff. This invalidates the derivation of limiting economic cutoff grades.

This problem can be handled by establishing the relationship between the actual distribution variable and the parametric measure. In the example this would involve finding a relationship between the copper equivalent values of the combined minerals and the original copper values themselves. Sometimes quite simple relationships can be established. For instance, if the molybdenum is randomly distributed, its effect might be to add a constant copper equivalent throughout the range. Or, if it is strongly correlated the effect might be to add a constant percentage. Once, a relationship is established the limiting economic cutoff grade formulae will be valid, but the cutoff grades derived must be converted via the relationship to the parametric measure.

4.2 Grid Search Technique

The approach of converting all minerals to their equivalent in terms of one basic mineral and aggregating the several values has some problems associated with it. If minerals have fairly stable values this procedure is valid and simplifies the problem. If the relative values fluctuate, the procedure is still valid but is often complicated because the equivalent grades have to be recalculated.

Further, if one of the mineral is subject to market limitation this technique becomes invalid. Because, the production in excess of the contracts for that mineral cannot be sold and therefore ore cannot be valued on the basis of contract price. Therefore, it is the influence of capacities in general both plant and market which invalidate the combined value criterion.

Grid search technique involves the finding of maxima which is insensitive to the parametric measure. Although, this alternative is less elegant but it can be more robust and better suited to calculation by computer. As this technique is more general and can be applied comprehensively even if the second mineral is of minor importance, therefore, it is selected to be used for the determination of optimum cutoff grades in this thesis.

The definition of a single material cutoff is well understood. In two mineral case the idea of grade distribution remains valid. But, the distributions are know two dimensional. Instead of a curve, the distribution is a surface and may be represented in series of contours. Figure 3.1 gives an idea of the two dimensional distribution.

A cutoff is a boundary between ore and waste and therefore a line in Figure 4.1. In theory, any kind of line may be considered but in this study only straight lines are examined. The simplest way to specify a cutoff line is by means of its intercepts γ_1, γ_2 on the grade axes. The value γ_1 is actually the cutoff grade for mineral 1 in the absence of mineral 2 and γ_2 is the cutoff grade for mineral 2 in the absence of mineral 1. The problem of determining an optimum cutoff policy for a two mineral deposit is therefore the problem of determining the sequence of pairs of values for the cutoff intercepts γ_1, γ_2 which maximizes the present value of operation.

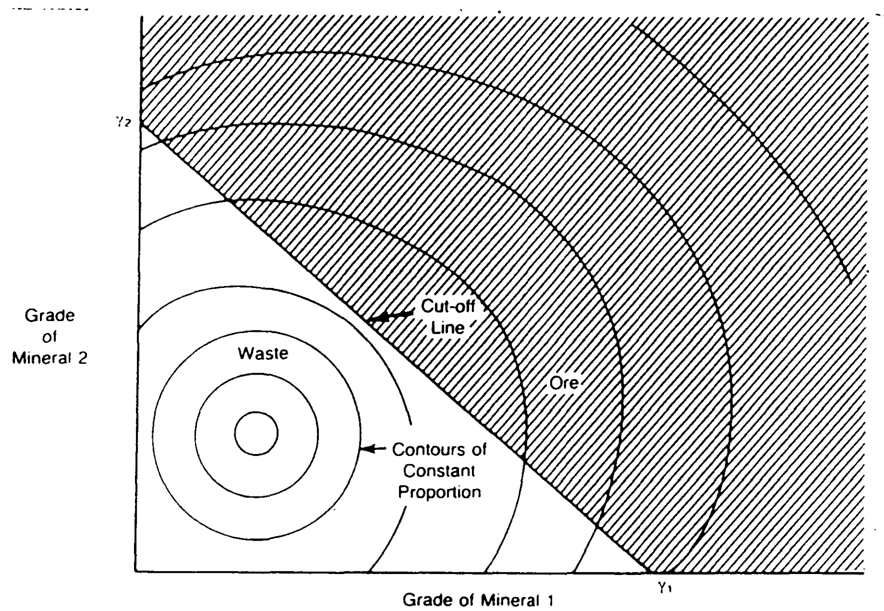

Figure 3.1: Two Dimensional Grade Tonnage Distribution For Two Minerals In A Given Push-Back

4.3 The Model

The derivation of formulae is parallel to the derivation of the single mineral formulae. The detail is not repeated. Following is the notation for this two minerals case.

M : Mining capacity in units of material per period

C : Concentrator capacity in units of ore per period

R1 : Refinery capacity for mineral 1 in units of product per period

R2 : Refinery capacity for mineral 2 in units of product per period

S1 : Selling price for mineral 1 per unit of product

S2 : Selling price for mineral 2 per unit of product

m : Mining cost per unit of material

c : Milling cost per unit of ore

r1 : Marketing cost for mineral 1 per unit of product

r2 : Marketing cost for mineral 2 per unit of product

f : Fixed cost per period

y1 : Recovery of mineral 1 from the ore

y2 : Recovery of mineral 2 from the ore

d : Discount rate

Considering the next unit of material mined is Q_m, unit of ore to be processed is Q_c, unit of mineral 1 refined is Q_{r1}, and unit of mineral 2 refined is Q_{r2}. The revenue to be generated is:

$$\frac{[Q_{r1} * (S1 - r1)] + [Q_{r2} * (S2 - r2)]}{Q_m}, \tag{5.1}$$

and the costs are:

$$\frac{c * Q_c}{Q_m} + m + f * T. \tag{5.2}$$

where T is the time taken to handle the next unit of material mined.

The implicit profitability is therefore:

$$\frac{[Q_{r1} * (S1 - r1)] + [Q_{r1} * (S1 - r1)] - [c * Q_c]}{Q_m} - m - f * T. \tag{5.3}$$

However, the quantity to be maximized is present value rather than profit and the increment in present value is given by a similar expression except that the time costs must cover the full opportunity costs, F which is *"f+d*V"*, where *V* is the net present value to be obtained by mining next unit of material.

$$v = \frac{[Q_{r1} * (S1 - r1)] + [Q_{r1} * (S1 - r1)] - [c * Q_c]}{Q_m} - m - F * T. \tag{5.4}$$

This is the fundamental formula and all the cutoff grade optima can be deduced from it. The time taken *T* is related to the constraining capacity. Four cases arise depending upon which of the four capacities is actually limiting the throughput.

Let us assume that grade-tonnage distribution in a given push-back consists of *K* individual grade cells for mineral one.

$\{[g_1(1), g_1(2)], [g_1(2), g_1(3)],$ ---------- $, [g_1(K-1), g_1(K)]\}$

Therefore, this push-back will have K number of grade distributions for mineral 2. Each of the grade distribution for mineral 2 will have M individual cells.

$\{[g_2(1), g_2(2)], [g_2(2), g_2(3)],$ ---------- $, [g_2(M-1), g_2(M)]\}$

By using the lower grade limit $g_1(k)$ for a given cell $[g_1(k), g_1(k+1)]$ as the cutoff grade of mineral 1 representing interval k^*, go to the grade distribution of mineral 2 which corresponds to the cell $[g_1(k), g_1(k+1)]$. Then by using the lower grade limit $g_2(m)$ for a given cell $[g_2(m), g_2(m+1)]$ as the cutoff grade for mineral 2 representing interval m^*, calculate ore tons, waste tons, average grade of mineral 1, and average grade of mineral 2 using following equations.

Tons of ore:

$$T_o(k^*, m^*) = \sum_{k=k^*}^{K}\left[\sum_{m=m^*}^{M} T_{(k,m)}\right]. \tag{5.5}$$

Tons of waste:

$$T_w(k^*, m^*) = \sum_{k=1}^{k^*}\left[\sum_{m=1}^{m^*} T_{(k,m)}\right]. \tag{5.6}$$

Average grade of mineral 1:

$$g_{avg1}(k^*) = \frac{\sum_{k=k^*}^{K}\left[\left(\sum_{m=m^*}^{M} T_{(k,m)}\right) * \left(\frac{g_1(k) + g_1(k+1)}{2}\right)\right]}{\sum_{k=k^*}^{K}\left[\left(\sum_{m=m^*}^{M} T_{(k,m)}\right)\right]}. \tag{5.7}$$

Average grade of mineral 2:

$$g_{avg2}(m^*) = \frac{\sum_{k=k^*}^{K}\left[\sum_{m=m^*}^{M}\left[T_{(k,m)} * \left(\frac{g_2(m) + g_2(m+1)}{2}\right)\right]\right]}{\sum_{k=k^*}^{K}\left[\sum_{m=m^*}^{M} T_{(k,m)}\right]}. \tag{5.8}$$

Knowing the tons of ore, tons of waste, and average grades of both minerals, the value equations for each stage can be obtained as follows.

If ratio of ore tons T_O to tons of material (T_O+T_W) is w, then:

$$w = \frac{T_o}{T_o + T_w}. \tag{5.9}$$

a. Mine Limiting:

$$T = \frac{1}{M}, \tag{5.10}$$

$$V_m = w * \left[\left(g_{avg1} * y1 * (S1 - r1)\right) + \left(g_{avg2} * y2 * (S2 - r2)\right) - c\right] - m - \frac{f + d * V}{M}. \tag{5.11}$$

b. Mill Limiting:

$$T = \frac{w}{C}, \tag{5.12}$$

$$V_c = w * \left[\left(g_{avg1} * y1 * (S1 - r1)\right) + \left(g_{avg2} * y2 * (S2 - r2)\right) - \left(c + \frac{f + d * V}{C}\right) \right] - m. \tag{5.13}$$

c. Refinery 1 Limiting:

$$T = \frac{w * g_{avg1} * y1}{R1}, \tag{5.14}$$

$$V_{r1} = w * \left[\left(g_{avg1} * y1 * \left(S1 - r1 - \frac{f + d * V}{R1} \right) \right) + \left(g_{avg2} * y2 * (S2 - r2)\right) - c \right] - m, \tag{5.15}$$

d. Refinery 2 Limiting:

$$T = \frac{w * g_{avg2} * y2}{R2}, \tag{5.16}$$

$$V_{r2} = w * \left[\left(g_{avg1} * y1 * (S1 - r1)\right) + \left(g_{avg2} * y2 * \left(S2 - r2 - \frac{f + d * V}{R2} \right) \right) - c \right] - m. \tag{5.17}$$

Now, for any pair of values of γ_1, γ_2, it is possible to calculate the corresponding V_m, V_c, V_{r1}, and V_{r2}. The controlling capacity is always the one corresponding to the least of these four and this, therefore, is the increment in present value resulting from the cut-off line γ_1, γ_2. Therefore, this figure has to be maximized. That is:

$$v(\max) = Max\left[Min(V_m, V_c, V_{r1}, V_{r2})\right] \tag{5.18}$$

The function concerned is the increment in present value v which depends upon the two intercepts γ_1, γ_2. The total grid search is well suited to computer applications and it has the virtue of being robust. In practice the primary grid suggested by Lane (1988) is 9×9 cells or 100 grid points. The maximum is then overlaid by a finer grid with 6×6 cells or 49 grid points covering the four original cells which surround the maximum point. Finally, this step is repeated around the new maximum. This gives an accuracy of one in $9 \times 3 \times 3$ (1 in 81) which is near 1.2%. it involves calculating a total of about 200 grid point values.

One safeguard is necessary. If the maximum occurs on the boundary of a secondary grid, the grid is relocated around the new point with no change in scale. This is to ensure that the maximum is still located even when it is on a steep ridge running between grid points. In these circumstances, it is possible that it is outside the grid and further away than the dimension of one grid cell. Moving the grid and several steps are possible. It is the way of bringing the maximum back into view.

4.4 Steps Of The Algorithm

The Following are the steps of the algorithm.

Step 1-

Read the input files, (Input files consist of grade increments of the deposit, and tons available in each increment. They also include the costs and prices associated with both minerals).

Step 2-

Calculate reserves available in the push-back "Tpush".

Step 3-

Calculate reserves available in the deposit "Tdep". If "Tdep" is equal to zero then go to step 12. Otherwise, go to next step.

Step 4-

Set $V = NPV$, initial NPV is equal to zero, $NPV= 0$.

Step 5-

Determine the optimum cutoff grades of mineral 1 "OPT1" and mineral 2 "OPT2" using the procedure explained in previous section (grid search technique).

Step 6-

Find the ore tons, waste tons, average grade for mineral 1, average grade for mineral 2 as a function of *"OPT 1"* and *"OPT 2"* for the push-back. Also, find the Q_m, Q_c, Q_{r1}, and Q_{r2}. These will also be the function of *"OPT 1"* and *"OPT 2"*. The limiting capacity can be determined knowing Q_m, Q_c, Q_{r1}, and Q_{r2}.

Step 7-

Compute the annual profits for the life of mine using this equation.

$$P = \left[(S1 - r1) * Q_{r1}\right] + \left[(S2 - r2) * Q_{r2}\right] - \left[c * Q_c\right] - \left[m * Q_m\right] - f \tag{5.19}$$

Step 8-

Find the life of deposit *"life"*. Compute the NPV by using this equation.

$$NPV = \frac{P * \left[(1 + d)^{life} - 1\right]}{d * (1 + d)^{life}} \tag{5.20}$$

Compare this NPV with the previous V (step 4). If the computed NPV is not within some tolerance (say ± 5,000,000) of V, go to step 4. Otherwise, go to next step.

Step 9-

Adjust the grade tonnage curve of the deposit by subtracting ore tons Q_C from the grade distribution intervals above optimum cutoff grades, and the waste tons Q_m-Q_C from the intervals below optimum cutoff grades in proportionate amount such that the shape of the distribution is not changed.

Step 10-

Check, if the current push-back is finished then go to next step, otherwise go to step 2.

Step 11-

Check, if all of the push-backs in the deposit are depleted, then go to step 3, otherwise go to step 2 and start next push-back.

Step 12-

If it is first iteration then knowing the profits obtained in each year, find the net present value year by year by discounting back those profits and go to step 13. If it is second iteration then stop.

Step 13-

Use the net present values obtained in step 12, as initial NPV's for each corresponding year for second iteration. Repeat whole process again from step 1 to step 12.

This second iteration will give the optimum cutoff grade policy for the mine life. Write the *year, push-back, cutoff grade of both minerals,* Q_m, Q_c, Q_{r1}, Q_{r2}, *profit and* NPV as final output.

4.5 Steps For Grid Search Technique

The grid search technique involves complex calculations. In this sections different steps involved will be explained by a manual example.

4.5.1 Data

The economic parameters for manual example are given in Table 4.1, and the grade tonnage distribution of the deposit is given in Table 4.2.

Description	Value
Mining Capacity, tons per year	10,000,000
Milling Capacity, tons per year	5,000,000
Refining Capacity (Copper), tons per year	50,000
Refining Capacity (Gold), ounces per year	150,000
Mining Cost, dollars per ton	2.50
Milling Cost, dollars per ton	5.50
Marketing Cost (Copper), dollars per ton	100.00
Marketing Cost (Gold), dollars per ounce	5.00
Fixed Costs, dollars per ton	3,500,000
Price (Copper), dollars per ton	2100.00
Price (Gold), dollars per ounce	385.00
Recovery (Copper), %	90
Recovery (Gold), %	80
Discount Rate, %	15

Table 4.1: Economic Parameters For Manual Example

Table 4.2: **Grade-Tonnage distribution of Copper and Gold For Manual Example**

Copper Grades (%)		Gold Grades (oz/ton)		Tons (millions)
Lower Limit	**Upper Limit**	**Lower Limit**	**Upper Limit**	
0.0	0.25	0.0	.015	1.5
		.015	.02	1
		.02	.025	0.5
		.025	.03	0.5
		.03	.035	0.5
		.035	.04	1.0
		.04	.045	1.0
		.045	.05	1.0
		0.05	0.055	1.5
0.25	0.35	0.0	.015	1.5
		.015	.02	1
		.02	.025	0.5
		.025	.03	0.5
		.03	.035	0.5
		.035	.04	1.0
		.04	.045	1.0
		.045	.05	1.0
		0.05	0.055	1.5
0.35	0.45	0.0	.015	1.5
		.015	.02	1
		.02	.025	0.5
		.025	.03	0.5
		.03	.035	0.5
		.035	.04	1.0
		.04	.045	1.0
		.045	.05	1.0
		0.05	0.055	1.5

Table 4.2 Continued.

0.45	0.55	0.0	.015	1.5
		.015	.02	1
		.02	.025	0.5
		.025	.03	0.5
		.03	.035	0.5
		.035	.04	1.0
		.04	.045	1.0
		.045	.05	1.0
		0.05	0.055	1.5
0.55	0.65	0.0	.015	1.5
		.015	.02	1
		.02	.025	0.5
		.025	.03	0.5
		.03	.035	0.5
		.035	.04	1.0
		.04	.045	1.0
		.045	.05	1.0
		0.05	0.055	1.5
0.65	0.75	0.0	.015	1.5
		.015	.02	1
		.02	.025	0.5
		.025	.03	0.5
		.03	.035	0.5
		.035	.04	1.0
		.04	.045	1.0
		.045	.05	1.0
		0.05	0.055	1.5
0.75	0.85	0.0	.015	1.5
		.015	.02	1
		.02	.025	0.5
		.025	.03	0.5
		.03	.035	0.5
		.035	.04	1.0
		.04	.045	1.0

Table 4.2 Continued.

		.045	.05	1.0
		0.05	0.055	1.5
0.85	0.95	0.0	.015	1.5
		.015	.02	1
		.02	.025	0.5
		.025	.03	0.5
		.03	.035	0.5
		.035	.04	1.0
		.04	.045	1.0
		.045	.05	1.0
		0.05	0.055	1.5
0.95	2.0	0.0	.015	1.5
		.015	.02	1
		.02	.025	0.5
		.025	.03	0.5
		.03	.035	0.5
		.035	.04	1.0
		.04	.045	1.0
		.045	.05	1.0
		0.05	0.055	1.5

4.5.2 Solution

Following are the necessary steps required in the grid search technique. This will cover only the step 5 given in previous section (steps of the algorithm).

Step 1-

The lower limits of grade categories are used as the cutoff grades. In the given example, we have an initial grid of 9×9 cells. At each grid point which corresponds to lower limits of grade categories of mineral 1 and mineral 2 on x-axis and y-axis respectively, find the tons of ore, tons of waste, and average grades of mineral 1 and mineral 2. The equations 5.5, 5.6, 5.7, and 5.8 will be used for this purpose. The results of this step are given in Table 4.3.

Step 2-

The values V_m, V_c, V_{r1}, and V_{r2} are calculated on each point of first grid by using the ore tons, waste tons, and average grades obtained in the step 1. Equations 5.11, 5.13, 5.15, and 5.17 are used for this step. The results for this step are given in Table 4.4.

Step 3-

The minimum values among V_m, V_c, V_{r1}, and V_{r2} obtained in step 2 are found for each grid point. The results for manual example are given in Table 4.5.

Step 4-

The maximum is found among the minimums in the step 3. The cutoff grades corresponding to this maximum in the grid are the optimums for this initial grid of 9×9 cells. For manual example the maximum occurs at grid point (3,2), and the cutoff grades corresponding to this point are:

Cutoff grade for mineral 1 in first grid = 0.0035

Cutoff grade for mineral 2 in first grid = 0.0150

Step 5-

The grid point (with maximum value) obtained in the step 4 is surrounded by a small 6×6 cells grid. The grades at each of this small grid points are determined and used as the cutoff grades. The results obtained are as follows.

The grades at these points surrounding (0.0035,0.0150) are:

0.0025 0.0028 0.0032 0.0035 0.0038 0.0042 0.0045 (grid points for mineral 1)

0.0025 0.0050 0.0100 0.0150 0.0167 0.0183 0.0200 (grid points for mineral 2)

Step 6-

The equations 5.5, 5.6, 5.7, and 5.8 will be used to determine ore tons, waste tons and average grades for both minerals at each point of the second grid. The results for manual example are given in Table 4.6.

Step 7-

The values V_m, V_c, V_{r1}, and V_{r2} are calculated at each point of second grid by using the ore tons, waste tons, and average grades obtained in the step 6. Equations 5.11, 5.13, 5.15, and 5.17 are used for this step. The results for this step are given in Table 4.7.

Step 8-

The minimum values among V_m, V_c, V_{r1}, and V_{r2} obtained in step 7 are found for each grid point. The results for manual example are given in Table 4.8.

Step 9-

The maximum is found among the minimums in the step 8. The cutoff grades corresponding to this maximum in the grid are the optimums for this second grid of 6×6 cells. For manual example the maximum occurs at grid point (5,3), and the cutoff grades corresponding to this point are:

Cutoff grade for mineral 1 in second grid = 0.0038

Cutoff grade for mineral 2 in second grid = 0.0100

Step 10-

The grid point (with maximum value)obtained in the step 9 is surrounded by another small 6×6 cells grid. The grades at each of this small grid points are determined and used as the cutoff grades next. The results obtained are as follows.

0.0035 0.0036 0.0037 0.0038 0.0039 0.0041 0.0042 (grid points for mineral 1)

0.0050 0.0067 0.0083 0.0100 0.0117 0.0133 0.0150 (grid points for mineral 2)

Step 11-

The equations 5.5, 5.6, 5.7, and 5.8 will be used to determine ore tons, waste tons and average grades for both minerals at each point of the third grid. The results for manual example are given in Table 4.9.

Step 12-

The values V_m, V_c, V_{r1}, and V_{r2} are calculated on each point of third grid by using the ore tons, waste tons, and average grades obtained in the step 11. Equations 5.11, 5.13, 5.15, and 5.17 are used for this step. The results for this step are given in Table 4.10.

Step 13-

The minimum values among V_m, V_c, V_{r1}, and V_{r2} obtained in step 12 are found for each grid point. The results for manual example are given in Table 4.11.

Step 14-

The maximum is found among the minimums in the step 13. The cutoff grades corresponding to this maximum in the grid are the optimums for this third grid of 6×6 cells, and also they are the overall optimum cutoff grades *"OPT1"* and *"OPT2"* for this current period.

For manual example the maximum occurs at grid point (2,5), and the cutoff grades corresponding to this point are:

Optimum Cutoff grade for mineral 1 = 0.0036

Optimum Cutoff grade for mineral 2 = 0.0120

After finding the optimum cutoff grades by using grid search technique, the procedure given in section 2.4 of chapter 2 (solution of manual example) can be followed step by step (step to step) for the rest of analysis which includes the convergence of net present value for this period and then adjustments of grade tonnage curve. The manual example presented in this section is also for a deposit of one push-back. The cutoff grade policy that can be obtained after completion of the analysis for this push-back is given in Table 4.12.

Table 4.3: Ore Tons, Waste Tons, and Average Grades

Grid Points Mineral 1	Grid Points Mineral 2	Ore Tons	Waste Tons	Avg. Grade Mineral 1	Avg. Grade Mineral 2
1	1	76500000.0	0.00000000	0.0064	0.0325
1	2	63000000.0	13500000.0	0.0064	0.0379
1	3	54000000.0	22500000.0	0.0064	0.0413
1	4	49500000.0	27000000.0	0.0064	0.0430
1	5	45000000.0	31500000.0	0.0064	0.0445
1	6	40500000.0	36000000.0	0.0064	0.0458
1	7	31500000.0	45000000.0	0.0064	0.0482
1	8	22500000.0	54000000.0	0.0064	0.0505
1	9	13500000.0	63000000.0	0.0064	0.0525
2	1	68000000.0	8500000.0	0.0071	0.0325
2	2	56000000.0	20500000.0	0.0071	0.0379
2	3	48000000.0	28500000.0	0.0071	0.0413
2	4	44000000.0	32500000.0	0.0071	0.0430
2	5	40000000.0	36500000.0	0.0071	0.0445
2	6	36000000.0	40500000.0	0.0071	0.0458
2	7	28000000.0	48500000.0	0.0071	0.0482
2	8	20000000.0	56500000.0	0.0071	0.0505
2	9	12000000.0	64500000.0	0.0071	0.0525
3	1	59500000.0	17000000.0	0.0077	0.0325
3	2	49000000.0	27500000.0	0.0077	0.0379
3	3	42000000.0	34500000.0	0.0077	0.0413
3	4	38500000.0	38000000.0	0.0077	0.0430
3	5	35000000.0	41500000.0	0.0077	0.0445
3	6	31500000.0	45000000.0	0.0077	0.0458
3	7	24500000.0	52000000.0	0.0077	0.0482
3	8	17500000.0	59000000.0	0.0077	0.0505
3	9	10500000.0	66000000.0	0.0077	0.0525

Table 4.3 Continued.

Grid Points Mineral 1	Grid Points Mineral 2	Ore Tons	Waste Tons	Avg. Grade Mineral 1	Avg. Grade Mineral 2
4	1	51000000.0	25500000.0	0.0083	0.0325
4	2	42000000.0	34500000.0	0.0083	0.0379
4	3	36000000.0	40500000.0	0.0083	0.0413
4	4	33000000.0	43500000.0	0.0083	0.0430
4	5	30000000.0	46500000.0	0.0083	0.0445
4	6	27000000.0	49500000.0	0.0083	0.0458
4	7	21000000.0	55500000.0	0.0083	0.0482
4	8	15000000.0	61500000.0	0.0083	0.0505
4	9	9000000.0	67500000.0	0.0083	0.0525
5	1	42500000.0	34000000.0	0.0089	0.0325
5	2	35000000.0	41500000.0	0.0089	0.0379
5	3	30000000.0	46500000.0	0.0089	0.0413
5	4	27500000.0	49000000.0	0.0089	0.0430
5	5	25000000.0	51500000.0	0.0089	0.0445
5	6	22500000.0	54000000.0	0.0089	0.0458
5	7	17500000.0	59000000.0	0.0089	0.0482
5	8	12500000.0	64000000.0	0.0089	0.0505
5	9	7500000.0	69000000.0	0.0089	0.0525
6	1	34000000.0	42500000.0	0.0097	0.0325
6	2	28000000.0	48500000.0	0.0097	0.0379
6	3	24000000.0	52500000.0	0.0097	0.0413
6	4	22000000.0	54500000.0	0.0097	0.0430
6	5	20000000.0	56500000.0	0.0097	0.0445
6	6	18000000.0	58500000.0	0.0097	0.0458
6	7	14000000.0	62500000.0	0.0097	0.0482
6	8	10000000.0	66500000.0	0.0097	0.0505
6	9	6000000.0	70500000.0	0.0097	0.0525

Table 4.3 Continued.

Grid Points Mineral 1	Grid Points Mineral 2	Ore Tons	Waste Tons	Avg. Grade Mineral 1	Avg. Grade Mineral 2
7	1	25500000.0	51000000.0	0.0106	0.0325
7	2	21000000.0	55500000.0	0.0106	0.0379
7	3	18000000.0	58500000.0	0.0106	0.0413
7	4	16500000.0	60000000.0	0.0106	0.0430
7	5	15000000.0	61500000.0	0.0106	0.0445
7	6	13500000.0	63000000.0	0.0106	0.0458
7	7	10500000.0	66000000.0	0.0106	0.0482
7	8	7500000.0	69000000.0	0.0106	0.0505
7	9	4500000.0	72000000.0	0.0106	0.0525
8	1	17000000.0	59500000.0	0.0119	0.0325
8	2	14000000.0	62500000.0	0.0119	0.0379
8	3	12000000.0	64500000.0	0.0119	0.0413
8	4	11000000.0	65500000.0	0.0119	0.0430
8	5	10000000.0	66500000.0	0.0119	0.0445
8	6	9000000.0	67500000.0	0.0119	0.0458
8	7	7000000.0	69500000.0	0.0119	0.0482
8	8	5000000.0	71500000.0	0.0119	0.0505
8	9	3000000.0	73500000.0	0.0119	0.0525
9	1	8500000.0	68000000.0	0.0148	0.0325
9	2	7000000.0	69500000.0	0.0148	0.0379
9	3	6000000.0	70500000.0	0.0148	0.0413
9	4	5500000.0	71000000.0	0.0148	0.0430
9	5	5000000.0	71500000.0	0.0148	0.0445
9	6	4500000.0	72000000.0	0.0148	0.0458
9	7	3500000.0	73000000.0	0.0148	0.0482
9	8	2500000.0	74000000.0	0.0148	0.0505
9	9	1500000.0	75000000.0	0.0148	0.0525

Table 4.4: Values V_m, V_c, V_{r1}, and V_{r2}

Grid Points Mineral 1	Grid Points Mineral 2	Vm	Vc	Vr1	Vr2	Grid Points Mineral 1	Grid Points Mineral 2	Vm	Vc	Vr1	Vr2
1	1	7.40	1.30	6.40	3.00	5	5	-0.70	1.40	2.20	0.70
1	2	5.90	2.00	6.20	1.90	5	6	-1.40	1.10	1.80	0.40
1	3	4.60	2.10	5.70	1.20	5	7	-2.80	0.50	1.00	-0.30
1	4	3.80	2.00	5.30	0.90	5	8	-4.30	-0.20	0.10	-0.90
1	5	3.00	1.90	4.90	0.60	5	9	-6.00	-1.10	-0.90	-1.60
1	6	2.00	1.70	4.40	0.30	6	1	1.10	1.80	2.50	2.50
1	7	0.01	1.00	3.10	-0.40	6	2	0.01	1.60	2.20	1.60
1	8	-2.30	0.20	1.70	-1.00	6	3	-0.90	1.40	1.90	1.00
1	9	-4.70	-0.70	0.20	-1.60	6	4	-1.40	1.20	1.60	0.70
2	1	6.70	2.00	5.90	3.40	6	5	-1.90	1.00	1.40	0.40
2	2	5.20	2.40	5.60	2.30	6	6	-2.50	0.70	1.10	0.10
2	3	3.90	2.30	5.10	1.60	6	7	-3.70	0.10	0.40	-0.50
2	4	3.10	2.20	4.70	1.20	6	8	-5.00	-0.50	-0.30	-1.10
2	5	2.30	2.00	4.30	0.80	6	9	-6.40	-1.30	-1.10	-1.60
2	6	1.40	1.80	3.80	0.50	7	1	-0.80	1.30	1.50	1.80
2	7	-0.50	1.10	2.70	-0.20	7	2	-1.70	1.00	1.20	1.00
2	8	-2.70	0.20	1.40	-0.90	7	3	-2.40	0.80	0.90	0.50
2	9	-4.90	-0.80	-0.10	-1.50	7	4	-2.80	0.60	0.70	0.20
3	1	5.60	2.20	5.10	3.50	7	5	-3.30	0.40	0.50	0.00
3	2	4.10	2.40	4.80	2.40	7	6	-3.70	0.20	0.30	-0.30
3	3	2.90	2.30	4.30	1.60	7	7	-4.70	-0.30	-0.20	-0.80
3	4	2.20	2.20	4.00	1.30	7	8	-5.70	-0.90	-0.80	-1.30
3	5	1.40	1.90	3.70	0.90	7	9	-6.80	-1.50	-1.40	-1.80
3	6	0.60	1.70	3.20	0.60	8	1	-2.80	0.50	0.30	0.90
3	7	-1.20	1.00	2.20	-0.10	8	2	-3.60	0.30	0.10	0.30
3	8	-3.20	0.10	1.00	-0.80	8	3	-4.10	0.10	-0.10	-0.10
3	9	-5.20	-0.80	-0.30	-1.50	8	4	-4.40	-0.10	-0.20	-0.30
4	1	4.30	2.30	4.30	3.40	8	5	-4.70	-0.20	-0.40	-0.50
4	2	2.90	2.30	4.00	2.30	8	6	-5.10	-0.40	-0.50	-0.70
4	3	1.80	2.10	3.60	1.60	8	7	-5.80	-0.80	-0.90	-1.10
4	4	1.10	2.00	3.30	1.20	8	8	-6.50	-1.30	-1.30	-1.50
4	5	0.40	1.70	2.90	0.90	8	9	-7.30	-1.70	-1.80	-1.90
4	6	-0.30	1.50	2.50	0.50	9	1	-5.10	-0.40	-0.90	-0.20
4	7	-2.00	0.80	1.60	-0.20	9	2	-5.60	-0.60	-1.00	-0.60
4	8	-3.70	0.00	0.60	-0.80	9	3	-5.90	-0.80	-1.10	-0.90
4	9	-5.60	-0.90	-0.60	-1.50	9	4	-6.10	-0.90	-1.20	-1.00
5	1	2.80	2.10	3.50	3.00	9	5	-6.30	-1.00	-1.30	-1.20
5	2	1.60	2.10	3.10	2.00	9	6	-6.50	-1.20	-1.40	-1.30
5	3	0.50	1.80	2.70	1.30	9	7	-6.90	-1.40	-1.60	-1.60
5	4	-0.10	1.60	2.50	1.00	9	8	-7.40	-1.70	-1.80	-1.80
5	5	-0.70	1.40	2.20	0.70	9	9	-7.80	-2.00	-2.10	-2.10

Table 4.5: Minimum Values

Grid Points Mineral 1	Grid Points Mineral 2	Minimum Values	Grid Points Mineral 1	Grid Points Mineral 2	Minimum Values	Grid Points Mineral 1	Grid Points Mineral 2	Minimum Values
1	1	1.34	4	1	2.28	7	1	-0.76
1	2	1.91	4	2	2.27	7	2	-1.69
1	3	1.23	4	3	1.55	7	3	-2.43
1	4	0.90	4	4	1.13	7	4	-2.83
1	5	0.57	4	5	0.43	7	5	-3.26
1	6	0.25	4	6	-0.33	7	6	-3.72
1	7	-0.38	4	7	-1.96	7	7	-4.70
1	8	-2.26	4	8	-3.71	7	8	-5.74
1	9	-4.68	4	9	-5.58	7	9	-6.83
2	1	1.95	5	1	2.14	8	1	-2.85
2	2	2.28	5	2	1.55	8	2	-3.56
2	3	1.55	5	3	0.51	8	3	-4.11
2	4	1.19	5	4	-0.06	8	4	-4.41
2	5	0.84	5	5	-0.68	8	5	-4.73
2	6	0.50	5	6	-1.35	8	6	-5.06
2	7	-0.54	5	7	-2.79	8	7	-5.78
2	8	-2.66	5	8	-4.33	8	8	-6.53
2	9	-4.93	5	9	-5.96	8	9	-7.32
3	1	2.22	6	1	1.13	9	1	-5.13
3	2	2.35	6	2	0.01	9	2	-5.59
3	3	1.62	6	3	-0.89	9	3	-5.93
3	4	1.26	6	4	-1.38	9	4	-6.12
3	5	0.91	6	5	-1.91	9	5	-6.31
3	6	0.55	6	6	-2.48	9	6	-6.51
3	7	-1.21	6	7	-3.70	9	7	-6.94
3	8	-3.15	6	8	-5.00	9	8	-7.38
3	9	-5.24	6	9	-6.38	9	9	-7.84

Table 4.6: Ore Tons, Waste Tons, and Average Grades

Grid Points Mineral 1	Grid Points Mineral 2	Ore Tons	Waste Tons	Avg. Grade Mineral 1	Avg. Grade Mineral 2
1	1	66000000.0	10500000.0	0.0071	0.0334
1	2	64000000.0	12500000.0	0.0071	0.0344
1	3	60000000.0	16500000.0	0.0071	0.0362
1	4	56000000.0	20500000.0	0.0071	0.0379
1	5	53333340.0	23166664.0	0.0071	0.0390
1	6	50666664.0	25833330.0	0.0071	0.0401
1	7	48000000.0	28500000.0	0.0071	0.0413
2	1	63250000.0	13249999.0	0.0073	0.0334
2	2	61333336.0	15166666.0	0.0073	0.0344
2	3	57500000.0	19000000.0	0.0073	0.0362
2	4	53666668.0	22833332.0	0.0073	0.0379
2	5	51111120.0	25388886.0	0.0073	0.0390
2	6	48555556.0	27944440.0	0.0073	0.0401
2	7	46000000.0	30500000.0	0.0073	0.0413
3	1	60500000.0	16000000.0	0.0075	0.0334
3	2	58666668.0	17833332.0	0.0075	0.0344
3	3	55000000.0	21500000.0	0.0075	0.0362
3	4	51333336.0	25166666.0	0.0075	0.0379
3	5	48888896.0	27611110.0	0.0075	0.0390
3	6	46444444.0	30055552.0	0.0075	0.0401
3	7	44000000.0	32500000.0	0.0075	0.0413
4	1	57750000.0	18749998.0	0.0077	0.0334
4	2	56000000.0	20499998.0	0.0077	0.0344
4	3	52500000.0	23999998.0	0.0077	0.0362
4	4	49000000.0	27499998.0	0.0077	0.0379

Table 4.6 Continued.

Grid Points Mineral 1	Grid Points Mineral 2	Ore Tons	Waste Tons	Avg. Grade Mineral 1	Avg. Grade Mineral 2
4	4	49000000.0	27499998.0	0.0077	0.0379
4	5	46666676.0	29833332.0	0.0077	0.0390
4	6	44333336.0	32166662.0	0.0077	0.0401
4	7	42000000.0	34500000.0	0.0077	0.0413
5	1	55000000.0	21500000.0	0.0079	0.0334
5	2	53333336.0	23166666.0	0.0079	0.0344
5	3	50000000.0	26500000.0	0.0079	0.0362
5	4	46666668.0	29833332.0	0.0079	0.0379
5	5	44444452.0	32055552.0	0.0079	0.0390
5	6	42222224.0	34277776.0	0.0079	0.0401
5	7	40000000.0	36500000.0	0.0079	0.0413
6	1	52250000.0	24250000.0	0.0081	0.0334
6	2	50666668.0	25833332.0	0.0081	0.0344
6	3	47500000.0	29000000.0	0.0081	0.0362
6	4	44333336.0	32166666.0	0.0081	0.0379
6	5	42222228.0	34277776.0	0.0081	0.0390
6	6	40111112.0	36388888.0	0.0081	0.0401
6	7	38000000.0	38500000.0	0.0081	0.0413
7	1	49500000.0	27000000.0	0.0083	0.0334
7	2	48000000.0	28500000.0	0.0083	0.0344
7	3	45000000.0	31500000.0	0.0083	0.0362
7	4	42000000.0	34500000.0	0.0083	0.0379
7	5	40000004.0	36500000.0	0.0083	0.0390
7	6	38000000.0	38500000.0	0.0083	0.0401
7	7	36000000.0	40500000.0	0.0083	0.0413

Table 4.7: Values V_m, V_c, V_{r1}, and V_{r2}

Grid Points Mineral 1	Grid Points Mineral 2	Vm	Vc	Vr1	Vr2	Grid Points Mineral 1	Grid Points Mineral 2	Vm	Vc	Vr1	Vr2
1	1	6.50	2.10	5.90	3.20	4	4	4.10	2.40	4.80	2.40
1	2	6.30	2.20	5.80	3.00	4	5	3.70	2.40	4.70	2.10
1	3	5.80	2.30	5.70	2.60	4	6	3.30	2.40	4.50	1.90
1	4	5.20	2.40	5.60	2.30	4	7	2.90	2.30	4.30	1.60
1	5	4.80	2.40	5.40	2.00	5	1	5.00	2.30	4.90	3.30
1	6	4.30	2.30	5.30	1.80	5	2	4.80	2.40	4.80	3.10
1	7	3.90	2.30	5.10	1.60	5	3	4.30	2.40	4.70	2.70
2	1	6.10	2.20	5.60	3.30	5	4	3.70	2.40	4.60	2.30
2	2	5.90	2.30	5.60	3.10	5	5	3.40	2.40	4.40	2.10
2	3	5.40	2.40	5.50	2.70	5	6	2.90	2.30	4.30	1.90
2	4	4.80	2.40	5.30	2.30	5	7	2.50	2.20	4.10	1.60
2	5	4.40	2.40	5.20	2.10	6	1	4.60	2.30	4.60	3.20
2	6	4.00	2.40	5.00	1.80	6	2	4.30	2.40	4.60	3.00
2	7	3.60	2.30	4.80	1.60	6	3	3.90	2.40	4.50	2.70
3	1	5.80	2.20	5.40	3.30	6	4	3.30	2.40	4.30	2.30
3	2	5.60	2.30	5.40	3.10	6	5	3.00	2.30	4.20	2.10
3	3	5.10	2.40	5.30	2.70	6	6	2.60	2.30	4.00	1.80
3	4	4.50	2.40	5.10	2.30	6	7	2.20	2.20	3.80	1.60
3	5	4.10	2.40	4.90	2.10	7	1	4.10	2.30	4.30	3.20
3	6	3.70	2.40	4.80	1.90	7	2	3.90	2.40	4.30	3.00
3	7	3.20	2.30	4.60	1.60	7	3	3.40	2.40	4.20	2.60
4	1	5.40	2.30	5.10	3.30	7	4	2.90	2.30	4.00	2.30
4	2	5.20	2.40	5.10	3.10	7	5	2.60	2.30	3.90	2.00
4	3	4.70	2.40	5.00	2.70	7	6	2.20	2.20	3.70	1.80
4	4	4.10	2.40	4.80	2.40	7	7	1.80	2.10	3.60	1.60

Table 4.8: Minimum Values

Grid Points Mineral 1	Grid Points Mineral 2	Minimum Values	Grid Points Mineral 1	Grid Points Mineral 2	Minimum Values
1	1	2.07	4	4	2.35
1	2	2.17	4	5	2.11
1	3	2.30	4	6	1.86
1	4	2.28	4	7	1.62
1	5	2.03	5	1	2.33
1	6	1.79	5	2	2.38
1	7	1.55	5	3	2.43
2	1	2.17	5	4	2.34
2	2	2.25	5	5	2.10
2	3	2.36	5	6	1.86
2	4	2.32	5	7	1.62
2	5	2.08	6	1	2.34
2	6	1.83	6	2	2.38
2	7	1.59	6	3	2.41
3	1	2.24	6	4	2.31
3	2	2.31	6	5	2.07
3	3	2.40	6	6	1.83
3	4	2.34	6	7	1.59
3	5	2.10	7	1	2.32
3	6	1.86	7	2	2.35
3	7	1.61	7	3	2.37
4	1	2.29	7	4	2.27
4	2	2.36	7	5	2.03
4	3	2.43	7	6	1.79
4	4	2.35	7	7	1.55

Table 4.9: Ore Tons, Waste Tons, and Average Grades

Grid Points Mineral 1	Grid Points Mineral 2	Ore Tons	Waste Tons	Avg. Grade Mineral 1	Avg. Grade Mineral 2
1	1	56000000.0	20499998.0	0.0077	0.0344
1	2	54833332.0	21666668.0	0.0077	0.0350
1	3	53666668.0	22833328.0	0.0077	0.0356
1	4	52500000.0	23999998.0	0.0077	0.0362
1	5	51333328.0	25166668.0	0.0077	0.0367
1	6	50166668.0	26333330.0	0.0077	0.0373
1	7	49000000.0	27499998.0	0.0077	0.0379
2	1	55111112.0	21388886.0	0.0077	0.0344
2	2	53962964.0	22537034.0	0.0077	0.0350
2	3	52814820.0	23685182.0	0.0077	0.0356
2	4	51666668.0	24833330.0	0.0077	0.0362
2	5	50518516.0	25981480.0	0.0077	0.0367
2	6	49370376.0	27129628.0	0.0077	0.0373
2	7	48222224.0	28277776.0	0.0077	0.0379
3	1	54222224.0	22277776.0	0.0078	0.0344
3	2	53092592.0	23407404.0	0.0078	0.0350
3	3	51962968.0	24537036.0	0.0078	0.0356
3	4	50833336.0	25666664.0	0.0078	0.0362
3	5	49703700.0	26796296.0	0.0078	0.0367
3	6	48574076.0	27925924.0	0.0078	0.0373
3	7	47444448.0	29055552.0	0.0078	0.0379
4	1	53333336.0	23166666.0	0.0079	0.0344
4	2	52222220.0	24277776.0	0.0079	0.0350
4	3	51111112.0	25388888.0	0.0079	0.0356
4	4	50000000.0	26500000.0	0.0079	0.0362

Table 4.9 Continued.

Grid Points Mineral 1	Grid Points Mineral 2	Ore Tons	Waste Tons	Avg. Grade Mineral 1	Avg. Grade Mineral 2
4	4	50000000.0	26500000.0	0.0079	0.0362
4	5	48888884.0	27611112.0	0.0079	0.0367
4	6	47777780.0	28722220.0	0.0079	0.0373
4	7	46666668.0	29833332.0	0.0079	0.0379
5	1	52444448.0	24055554.0	0.0079	0.0344
5	2	51351852.0	25148144.0	0.0079	0.0350
5	3	50259264.0	26240740.0	0.0079	0.0356
5	4	49166668.0	27333332.0	0.0079	0.0362
5	5	48074072.0	28425926.0	0.0079	0.0367
5	6	46981484.0	29518516.0	0.0079	0.0373
5	7	45888888.0	30611108.0	0.0079	0.0379
6	1	51555560.0	24944440.0	0.008	0.0344
6	2	50481484.0	26018514.0	0.008	0.0350
6	3	49407412.0	27092588.0	0.008	0.0356
6	4	48333336.0	28166664.0	0.008	0.0362
6	5	47259256.0	29240740.0	0.008	0.0367
6	6	46185188.0	30314812.0	0.008	0.0373
6	7	45111112.0	31388886.0	0.008	0.0379
7	1	50666668.0	25833332.0	0.0081	0.0344
7	2	49611108.0	26888888.0	0.0081	0.0350
7	3	48555556.0	27944444.0	0.0081	0.0356
7	4	47500000.0	29000000.0	0.0081	0.0362
7	5	46444440.0	30055556.0	0.0081	0.0367
7	6	45388888.0	31111108.0	0.0081	0.0373
7	7	44333336.0	32166666.0	0.0081	0.0379

Table 4.10: Values V_m, V_c, V_{r1}, and V_{r2}

Grid Points Mineral 1	Grid Points Mineral 2	Vm	Vc	Vr1	Vr2	Grid Points Mineral 1	Grid Points Mineral 2	Vm	Vc	Vr1	Vr2
1	1	5.20	2.40	5.10	3.10	4	4	4.30	2.40	4.70	2.70
1	2	5.00	2.40	5.10	3.00	4	5	4.10	2.40	4.70	2.60
1	3	4.90	2.40	5.00	2.80	4	6	3.90	2.40	4.60	2.50
1	4	4.70	2.40	5.00	2.70	4	7	3.70	2.40	4.60	2.30
1	5	4.50	2.40	4.90	2.60	5	1	4.60	2.40	4.70	3.10
1	6	4.30	2.40	4.90	2.50	5	2	4.50	2.40	4.70	2.90
1	7	4.10	2.40	4.80	2.40	5	3	4.30	2.40	4.70	2.80
2	1	5.00	2.40	5.00	3.10	5	4	4.20	2.40	4.60	2.70
2	2	4.90	2.40	5.00	3.00	5	5	4.00	2.40	4.60	2.60
2	3	4.70	2.40	5.00	2.80	5	6	3.80	2.40	4.50	2.50
2	4	4.60	2.40	4.90	2.70	5	7	3.60	2.40	4.50	2.30
2	5	4.40	2.40	4.90	2.60	6	1	4.50	2.40	4.70	3.10
2	6	4.20	2.40	4.80	2.50	6	2	4.30	2.40	4.60	2.90
2	7	4.00	2.40	4.70	2.40	6	3	4.20	2.40	4.60	2.80
3	1	4.90	2.40	4.90	3.10	6	4	4.00	2.40	4.60	2.70
3	2	4.80	2.40	4.90	3.00	6	5	3.80	2.40	4.50	2.60
3	3	4.60	2.40	4.90	2.80	6	6	3.70	2.40	4.40	2.40
3	4	4.40	2.40	4.80	2.70	6	7	3.50	2.40	4.40	2.30
3	5	4.30	2.40	4.80	2.60	7	1	4.30	2.40	4.60	3.00
3	6	4.10	2.40	4.70	2.50	7	2	4.20	2.40	4.50	2.90
3	7	3.90	2.40	4.70	2.30	7	3	4.00	2.40	4.50	2.80
4	1	4.80	2.40	4.80	3.10	7	4	3.90	2.40	4.50	2.70
4	2	4.60	2.40	4.80	3.00	7	5	3.70	2.40	4.40	2.60
4	3	4.50	2.40	4.80	2.80	7	6	3.50	2.40	4.40	2.40
4	4	4.30	2.40	4.70	2.70	7	7	3.30	2.40	4.30	2.30

Table 4.11: Minimum Values

Grid Points Mineral 1	Grid Points Mineral 2	Minimum Values	Grid Points Mineral 1	Grid Points Mineral 2	Minimum Values
1	1	2.36	4	4	2.43
1	2	2.39	4	5	2.43
1	3	2.41	4	6	2.42
1	4	2.43	4	7	2.34
1	5	2.43	5	1	2.38
1	6	2.43	5	2	2.40
1	7	2.35	5	3	2.42
2	1	2.36	5	4	2.42
2	2	2.39	5	5	2.42
2	3	2.41	5	6	2.42
2	4	2.43	5	7	2.33
2	5	2.43	6	1	2.38
2	6	2.43	6	2	2.40
2	7	2.35	6	3	2.41
3	1	2.37	6	4	2.42
3	2	2.40	6	5	2.42
3	3	2.42	6	6	2.41
3	4	2.43	6	7	2.32
3	5	2.43	7	1	2.38
3	6	2.43	7	2	2.39
3	7	2.35	7	3	2.40
4	1	2.38	7	4	2.41
4	2	2.40	7	5	2.41
4	3	2.42	7	6	2.40
4	4	2.43	7	7	2.31

Table 4.12: Complete Cutoff Grade Policy For Manual Example

YEAR	PB	COG1 (%)	COG2 (oz/ton)	Qm (Mtons)	Qc (Mtons)	Qr1 (1000's T)	Qr2 (1000's oz.)	PROFIT ($M)	NPV ($M)
1	1	0.361	0.012	7.57	5.00	34.85	146.97	75.63	394.01
2	1	0.35	0.012	7.45	5.00	34.55	146.97	75.33	377.48
3	1	0.328	0.012	7.22	5.00	33.96	146.97	74.71	358.78
4	1	0.306	0.012	7.01	5.00	33.37	146.97	74.07	337.88
5	1	0.294	0.010	6.75	5.00	33.08	144.67	73.26	314.49
6	1	0.272	0.010	6.56	5.00	32.5	144.67	72.58	288.41
7	1	0.256	0.008	6.28	5.00	32.07	142.32	71.51	259.09
8	1	0.225	0.007	6.09	5.00	31.66	141.13	70.72	226.44
9	1	0.194	0.005	5.82	5.00	31.33	137.50	69.37	189.69
10	1	0.167	0.003	5.59	5.00	31.02	134.41	68.14	148.77
11	1	0.125	0.002	5.45	5.00	30.54	133.79	67.28	102.95
12	1	0.062	0.002	4.71	4.44	26.46	118.85	58.78	51.11

4.5 Grid Search Technique For One Mineral Deposit

In order to confirm the results obtained by applying grid search technique for deposits of two minerals, it was also used to find the optimum cutoff grade policy in one mineral case for the same data shown in chapter 2. It was very encouraging that the results were exactly the same as obtained by applying analytical technique discussed in chapter 2. Therefore, on the other hand it also confirms that the results obtained by applying grid search technique in two mineral case are also correct, since overall concept of the application of the technique is same, the only difference is in some routines of the program to generate the optimum cutoff grade policy.

5. DEVELOPMENT OF COMPUTER PROGRAM FOR CUTOFF GRADE OPTIMIZATION OF TWO MINERALS DEPOSIT

As grid search technique involves complex computations. Therefore, a computer program was developed in FORTRAN 77. Although, This program can also be compiled on FORTRAN 90 compiler. This program is included on a diskette given at the end of thesis under name "opti2.f" in appendix C.

The analytical approach introduced by Dagdelen (1993) to determine the balancing cutoff grades in one mineral case made the problem really simple. The programming and computations required are both reduced. Therefore, the optimum cutoff grade policy is easy to establish now by using simple programming skills. However, the complexities involved in the grid search technique, which is used for the determination of optimum cutoff grades in two mineral case make the problem very difficult. The overall structure of the program is same as "OPTI1.FOR", the only difference is the implementation of grid search technique.

5.1 Summary Of Routines

The routines of the program can be divided into three major types. These are optimum cutoff grade or grid search technique routines, the net present value routines, and the routines which analyze the adjustment of grade tonnage curves after the quantities of material are assigned with respect to mine, mill, and refinery1 and refinery2. These quantities are the function of optimum cutoff grades for current period.

The optimum cutoff grade routines use the economic parameters and grade tonnage distribution of the deposit. The economic parameters include price, costs and capacities associated with mine, mill, refinery1, and refinery2, and the metallurgical recoveries. These inputs are used by the grid search technique in the equations of V_m, V_c, V_{r1},

V_{r2} (chapter 4). The optimum cutoff grades are determined by the procedure given in chapter 4.

The net present value convergence routines use the optimum cutoff grades as a main input, because, all the analysis conducted by them is function of optimum cutoff grades. These routines find the life of deposit based on the assumption that whole deposit will be mined by using these optimum cutoff grades. The life of mine is also a function of the limiting capacity during this period. The annual profit for the life of mine is calculated, and then net present value is determined by discounting back those annual profits for the life of mine. If the net present value determined is converged i.e. within some tolerance of the previous net present value used in the analysis, then the operation of the program is handed over to the grade tonnage curve adjustment routines. Usually it takes three to five iterations to converge the net present value.

The grade tonnage curve adjustment routines use the information obtained from the previous two major portions of the program. The push-back life is determined based on the quantities being sent to the mine, mill, and refinery. The tons of ore, waste and final product handled in the period are subtracted from the grade tonnage distribution such that the shape of the distribution is not changed. If the material required for the current period is not available in the push-back, then the next available push-back is incorporated in this period by the program. However, if the push-backs in the deposit are finished then the program ends. The general logic and structure of the program is given in Figure 5.1.

The program is capable of handling any number of increments given in the grade tonnage distribution for both minerals. This choice is given according to the need of the user in the input file. The number of push-backs can also be defined by the user in the input file. The size of arrays can be modified by the user according to the requirement. All of the subroutines are less than a page in length, and easily understanding. This program consists of the 4500 lines and 103 subroutines, it takes less than a minute to execute the program and obtain the final output.

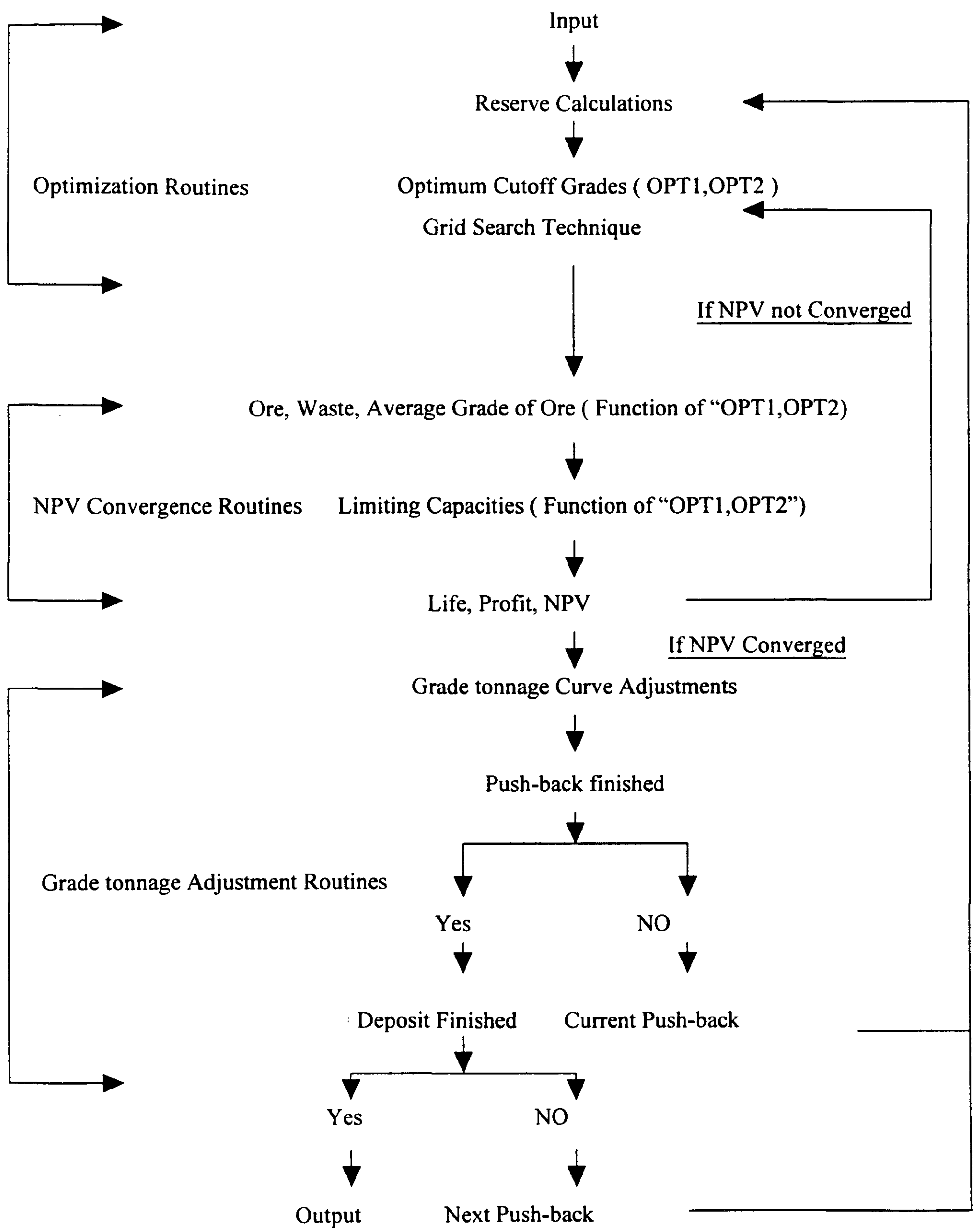

Figure 5.1: Flow Diagram of the Program OPTI2.FOR

5.2 Input

For the example to be demonstrated the input data is shown in Table 5.1 and Table 5.2. This data is assumed for a copper gold deposit. The structure of the input files used by the program is given in the Table 5.3 and Table 5.4. These input files are also given on the diskett as appendix C under names of "aopti2.dat" and "bopti2.dat".

The first line in the Table 5.3 is the capacities associated mine, mill, refinery1, and refinery2 respectively.

The second line has price of mineral 1, price of mineral 2, refinery or marketing cost of mineral 1, refinery or marketing cost of mineral 2, recovery of mineral 1, recovery of mineral 2, mining cost, milling cost, discount rate, and the fixed cost respectively.

In the third line of Table 5.3, user can define the number of increments for grades of mineral 1, the number of increments for grades of mineral 2, and the number of push-backs respectively.

The fourth line is a logical input for the program, this defines whether the grades are in percent or in any other unit. If the grades are given in percent then this input will be ".TRUE.".

The rest of the input file has the lower and upper limits of grade increments with respect to each push-back for mineral 1 and mineral 2. For the demonstration example, there are three push-backs, thirteen increments for mineral 1, and five increments for mineral 2 in the grade distribution. Therefore, the lower and upper grade increments for mineral 1 have three lines, and each line corresponds to the grade distribution of each push-back. The increments for mineral 2 are given with respect to mineral 1. For each increment of mineral 1, there are five increments of mineral 2 in each push-back. Therefore, the grade increments of mineral 2 are given in thirty nine ($13 \times 3 = 39$) lines.

The reserves available in deposit are given with respect to the increments of mineral 2, therefore, they are also given in sixty five lines in Table 5.4.

5.3 Output

The output of this program is divided into two parts. The detailed output of the program consists of a huge file, this includes the year by year analysis done by each sub-routine in the program. This output gives a broader picture of the program. The output which shows the complete cutoff grade policy consists of years in the column 1, push-back in this year in column 2, optimum cutoff grade of mineral 1 in column 3, optimum cutoff grade of mineral 2 in column 4, quantities to be mined Q_m (in million tons) in column 5, quantities to be milled Q_c (in million tons) in column 6, and quantities to be refined for mineral 1 Q_{r1} (in thousand tons) in column 7, and quantities to be refined for mineral 2 Q_{r2} (in thousand tons) in column 8, the profit (in $M) in column 9, and net present value (in $M) in column 10. This output of the demonstration example is shown in Table 5.5.

The results given in Table 5.5, show that during year 1 to 7 when push-back 1 is being mined, the mine and mill are in balance, therefore, the cut-off grades obtained are same for both minerals. And these may be the mine and mill balancing cutoff grades. However, it is obvious that mill is bottleneck throughout the life of mine, therefore, this deposit needs to increase the mill capacity. The cutoff grade is declining for the both minerals with the decreasing net present value. This also supports the creation of stock-piles in the early years of mine life.

Table 5.1: Economic Parameters For Demonstration Example

Description	Value
Mining Capacity, tons per year	20,000,000
Milling Capacity, tons per year	10,000,000
Refining Capacity (Copper), tons per year	100,000
Refining Capacity (Gold), ounces per year	900,000
Mining Cost, dollars per ton	1.48
Milling Cost, dollars per ton	4.45
Marketing Cost (Copper), dollars per ton	100.00
Marketing Cost (Gold), dollars per ounce	5.00
Fixed Costs, dollars per ton	3,500,000
Price (Copper), dollars per ton	2100.00
Price (Gold), dollars per ounce	385.00
Recovery (Copper), %	90
Recovery (Gold), %	80
Discount Rate, %	15

Table 5.2: Grade-Tonnage distribution of Copper and Gold For Demonstration Example

Copper Grades (%)		Gold Grades (oz/ton)		Tons (millions)
Lower Limit	**Upper Limit**	**Lower Limit**	**Upper Limit**	
0.0	0.15	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.15	0.2	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.2	0.25	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.25	0.3	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.3	0.35	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5

Table 5.2 Continued.

0.35	0.4	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.4	0.45	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.45	0.5	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.5	0.55	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.55	0.6	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.6	0.65	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5

Table 5.2 Continued.

0.65	0.7	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.7	4.69	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5

Table 5.3: Input File Structure For OPTI2.FOR

```
20000000.0,1000000.0,100000.0,900000.0
2100.0,385.0,100.,5.0,0.9,0.80,1.5,4.5,0.15,3500000.
13,5,3
.TRUE.
Lower bounds of grade categories for mineral1
0.0,0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7
0.0,0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7
0.0,0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7
Upper bounds of grade categories for mineral1
0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7,4.69
0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7,4.69
0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,0.6,0.65,0.7,4.69
Lower bounds of grade categories for mineral2
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
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0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
```

Table 5.3 Continued.

0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
0.0,0.02,0.03,0.04,0.05
Upper bounds of grade categories for mineral2
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06

Table 5.3 continued.

0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06
0.02,0.03,0.04,0.05,0.06

Table 5.4: Reserves File For OPTI2.FOR

Reserves in each grade increment with respect to mineral 2 (table 5.2)
1.5,1.0,0.5,0.5,6.5
1.5,1.0,0.5,0.5,6.5
1.5,1.0,0.5,0.5,6.5
1.5,1.0,0.5,0.5,6.5
1.5,1.0,0.5,0.5,6.5
1.5,1.0,0.5,0.5,6.5
1.5,1.0,0.5,0.5,6.5
1.5,1.0,0.5,0.5,6.5
1.5,1.0,0.5,0.5,6.5
1.5,1.0,0.5,0.5,6.5
1.5,1.0,0.5,0.5,6.5
1.5,1.0,0.5,0.5,6.5
1.5,1.0,0.5,0.5,6.5
2.0,1.5,1.0,0.5,5.0
2.0,1.5,1.0,0.5,5.0
2.0,1.5,1.0,0.5,5.0
2.0,1.5,1.0,0.5,5.0
2.0,1.5,1.0,0.5,5.0
2.0,1.5,1.0,0.5,5.0
2.0,1.5,1.0,0.5,5.0
2.0,1.5,1.0,0.5,5.0
2.0,1.5,1.0,0.5,5.0
2.0,1.5,1.0,0.5,5.0
2.0,1.5,1.0,0.5,5.0
2.0,1.5,1.0,0.5,5.0
2.0,1.5,1.0,0.5,5.0
2.5,1.5,1.0,0.5,4.5
2.5,1.5,1.0,0.5,4.5
2.5,1.5,1.0,0.5,4.5
2.5,1.5,1.0,0.5,4.5
2.5,1.5,1.0,0.5,4.5
2.5,1.5,1.0,0.5,4.5
2.5,1.5,1.0,0.5,4.5
2.5,1.5,1.0,0.5,4.5
2.5,1.5,1.0,0.5,4.5

Table 5.4 Continued.

2.5,1.5,1.0,0.5,4.5
2.5,1.5,1.0,0.5,4.5
2.5,1.5,1.0,0.5,4.5
2.5,1.5,1.0,0.5,4.5
2.5,1.5,1.0,0.5,4.5

Table 5.5: Optimum Cutoff Grade Policy For Demonstration Example By OPTI2.FOR

YEAR	PB	COG1	COG2	Qm (M tons)	Qc (M tons)	Qr1 (1000's T)	Qr2 (1000's oz.)	PROFIT ($M)	NPV ($M)
1	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1344.49
2	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1326.56
3	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1305.94
4	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1282.23
5	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1254.96
6	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1223.60
7	1	0.339	0.026	10.59	5.32	37.55	219.60	116.85	1187.53
7	2	0.294	0.026	9.32	4.68	31.10	183.34	95.20	1187.53
8	2	0.294	0.026	19.91	10.00	66.46	391.83	203.45	1153.61
9	2	0.283	0.027	19.90	10.00	65.50	396.19	203.20	1123.20
10	2	0.333	0.021	19.91	10.00	70.03	374.37	203.94	1088.49
11	2	0.350	0.018	19.90	10.00	71.66	365.58	203.90	1047.82
12	2	0.328	0.020	19.24	10.00	69.50	370.00	202.23	1001.09
13	2	0.289	0.020	17.62	10.00	65.98	370.00	197.62	949.03
14	2	0.244	0.020	4.20	2.61	16.28	96.70	50.33	893.76
14	3	0.267	0.018	12.89	7.39	47.34	265.62	140.46	893.76
15	3	0.222	0.018	15.98	10.00	60.55	359.60	185.28	837.04
16	3	0.172	0.018	14.59	10.00	56.84	359.60	179.94	777.31
17	3	0.150	0.016	13.45	10.00	55.28	349.95	174.86	713.97
18	3	0.100	0.013	12.65	10.00	54.09	342.13	170.71	646.21
19	3	0.062	0.011	12.00	10.00	53.16	334.25	166.83	572.43
20	3	0.025	0.008	11.31	10.00	52.20	324.31	162.17	491.46
21	3	0.025	0.003	10.57	10.00	52.20	306.20	156.40	403.01
22	3	0.025	0.003	10.57	10.00	52.20	306.20	156.40	307.07
23	3	0.025	0.003	10.57	10.00	52.20	306.20	156.40	196.73
24	3	0.025	0.003	5.43	5.14	26.81	157.26	80.32	69.84

6. OPTIMUM CUTOFF GRADES WITH A STOCKPILE OPTION

6.1 Operational Considerations In Handling Stockpiles

An optimum cutoff grade policy usually indicates a decline in the cutoff grades during the life of mining operation, mainly due to the effect of its declining present value. Because of this declining nature optimizing cutoff grades take a value much higher than the break-even cutoff grade during the initial years. One of the implication of this phenomena is that grades which are marginally economic to treat in the early years are not processed because of higher economic value ores and this marginal material can be treated economically later.

The mineralized material with grades between optimum and break-even cutoff grades is called intermediate grade material. Therefore, depending upon the facilities available the strategy of stockpiling can be considered. The idea has obvious attractions, because it enhances the net present value of operation.

However, the idea has some drawbacks. First the logistics of creating a separate stockpile, or perhaps even several stockpiles if the range of intermediate grade is wide, are never easy. It will depend upon the size of mine site, and nature of adjacent terrain but space is always at a premium. Because there is a need of waste dumps, tailings areas, settling tanks, crushed ore stockpiles, waste storage, maintenance facilities, etc. An additional requirement for stockpiling intermediate grade material, which could amount to a substantial tonnage and which must be kept separate, possibly for many years, can entail redesigning much of the site layout and extending haulage routes.

Several additional costs are incurred. There will be the cost of longer hauls and re-handling costs when the stockpiles are reclaimed. Because Haulage system in open pit mines in routine operation works in the way that a truck after loading ore or waste from the shovel approaches either concentrator for ore or waste dump for waste. Therefore, inclusion of a new possibility i.e. stockpiles for the storage of intermediate grade ore may increase haul distances. However, with the use modern computerized systems the assignment of trucks should not be a problem any more, because, this can be considered as the addition of a new waste dump into the system. Also, there will be a capital cost associated with the setting up of stockpiles and any ancillary equipment.

It is important to emphasize that the sampling requirements will be increased and more comprehensive. Because, the differences between the mineral to be sent to each dumping point is small. Therefore, we need better control over the grade inventory than in the classical system. However, the material coming from blast holes is the best representative of grades to be obtained from the blasting of current bench. This means that we can get very accurate information about grade distribution over the area to be blasted.

Another important consideration to take into account is that the material may deteriorate during the 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 material in particular environment may not be fully understood without some years of experience.

6.2 Description Of The System

The classical Lane's approach to determine the optimum cutoff grades does not consider the stockpile alternative. This means that all material below cutoff grade is sent to the waste dump whereas material above this cutoff grade is sent to the mill.

In proposed system, the stockpile 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 stockpile is to be 45% of the total mining cost. This is composed of 40% corresponding to material handling and 5% corresponding to supervision.

Considering only push-back 1 in the deposit given in chapter 3 (Table 3.5), all material below 0.5% and above 0.23% will be sent to the stockpile. For the second push-back material below 0.53% and above 0.23% will be sent to the stockpile.

Therefore, the stockpiles are generated throughout the life of mine. when the push-backs in the mine are completely depleted, stockpiles are considered as a new push-back. That is, we calculate the optimum cutoff grade, the amount of material to be sent to the mill, and profits to be obtained in the same way as we do for the push-backs in mine.

However, stockpiles can be handled in other ways also. Such as in the example in chapter 3 cutoff grade in year 18 (Table 3.5) is 0.41% and in the stockpile we have material between 0.23% to 0.53%. Therefore, we have the possibility to send material from the stockpile to mill instead of sending material from push-back. But, this needs the comparison to be done between profits expected if material is sent from push-back or stockpile. However, this method may create blending as well as sequencing problems since material is coming from both mine and stockpile to mill.

Another way of handling stockpiles is to analyze of whether or not to send material from the stockpile to the mill is repeated taking into account the profit generated by the material in the stockpile and the profit generated by the material in the push-back. If the profit for the ore in the stockpile is greater than the profit of ore in the push-back, the mill is fed with material exclusively coming from the stockpile. Therefore, the material is sent either from stockpile or push-back, but not from both simultaneously. But, this method has the problem that if stockpile is sending material to the mill, mine will be shut down during those years. Also, there is the possibility that the material available in the stockpile will not be utilized completely although it will be ore.

Therefore, the proposed method selected in this study is the most convenient and practical one as no such problem is associated with it, and it does not require any special arrangements to be done with respect to conducting economically effective operation.

6.3 Steps Of The Modified Algorithm For One Mineral Deposits

Following are the necessary steps to determine optimum cutoff grade policy with stockpiles option in one mineral deposits. The program OPTI1.FOR is executed to determine the lowest and highest cutoff grades. The input files for this algorithm contain these lowest and highest cutoff grades and stockpile handling costs.

Step 1-

Read the input files, which include price, costs, recovery, capacities, grade categories in each push-back, and tonnage associated with each grade category.

Step 2-

Compute the reserves available in push-back "Tpush".

Step 3-

Compute the reserves available in deposit "Tdep". If "Tdep" is equal to zero then go to step 12. Otherwise go to next step.

Step 4-

Set $V = NPV$, initial NPV is equal to zero.

Step 5-

Find the optimum cutoff grade for each pair of stages using criteria given in chapter 2.

Step 6-

Determine the tons of ore T_o, tons of waste T_w, and average grade g_{avg} of ore associated with optimum cutoff grade "*OPT*". Compute the quantities to be mind Q_m, milled Q_c, and refined Q_r. Also find the limiting capacity for this year based on Q_m, Q_c, and Q_r.

Step 7-

Find the life of deposit "*deplife*". Determine the annual profit for life of mine using following expression.

$$P = (S - r) * Qr - c * Qc - m * Qm - f * T. \tag{6.1}$$

Find the net present value *NPV*, by discounting profits at given interest rate *d* for the time *"deplife"*. This relationship can be used.

$$NPV = \frac{P * \left[(1+d)^{deplife} - 1\right]}{d * (1+d)^{deplife}}. \tag{6.2}$$

Compare this *NPV* with the previous *V* (step 4). If the computed *NPV* is not within some tolerance (say ± $500,000) of *V*, go to step 4. Otherwise go to next step.

Step 8-

Create Stockpiles grade increments, and accumulate the reserves available in each increment. This is carried out with respect to lowest cutoff grade and the optimum cutoff grade in each period.

Step 9-

Adjust the grade tonnage curve by subtracting ore tons from intervals above optimum cutoff, and waste tons from intervals below optimum cutoff grade, such that the distribution does not change.

Step 10-

If current push-back is finished, then check if all push-backs are finished and go to next step, otherwise start next push-back from step 2. If the reserves are still available in the current push-back, then go to step 2 and find the remaining reserves.

Step 11-

start the stockpile as a new push-back. The profit equation is

$$P = (S - r) * Qr - c * Qc - ssp * Qm - f * T. \tag{6.3}$$

The stockpile is utilized by following the same procedures of depletion of push-backs in the deposit. If the stockpiles are finished then go to step 3, otherwise go to step 2 to determine the remaining reserves in stockpile.

Step 12-

. If it is first iteration then knowing the profits in each year, find the net present value year by year by discounting back those profits and go to next step. If it is second iteration then stop.

Step 13-

Use the net present values from step 12 as initial NPV's for each corresponding year for second iteration, repeat the whole process again from step 2 to step 12.

The cutoff grades obtained in this iteration will give the optimum cutoff grades policy for the mine life. Write the *Year, Push-back, Cutoff grade,* Q_m, Q_c, Q_r, *Profit, and NPV* as output.

6.4 Steps Of The Modified Algorithm For Two Minerals Deposits

Following are the necessary steps to determine optimum cutoff grade policy with stockpiles option in two minerals deposits. The program OPTI2.FOR is executed to determine the lowest and highest cutoff grades for both minerals. The input files for this algorithm contain these lowest and highest cutoff grades and stockpile handling costs.

Step 1-

Read the input files, (Input files consist of grade increments of the deposit, and tons available in each increment. It also includes the costs and prices associated with both minerals).

Step 2-

Calculate reserves available in the push-back "Tpush".

Step 3-

Calculate reserves available in the deposit "Tdep". If "Tdep" is equal to zero then go to step 12. Otherwise, go to next step.

Step 4-

Set $V = NPV$, initial NPV is equal to zero, $NPV = 0$.

Step 5-

Determine the optimum cutoff grades of mineral 1 *"OPT1"* and mineral 2 *"OPT2"* using the procedure explained in chapter 4 (grid search technique).

Step 6-

Find the ore tons, waste tons, average grade for mineral 1, average grade for mineral 2 as a function of *"OPT 1"* and *"OPT 2"* for the push-back. Also, find the Q_m, Q_c, Q_{r1}, and Q_{r2}. These will also be the function of *"OPT1"* and *"OPT2"*. The limiting capacity can be determined knowing Q_m, Q_c, Q_{r1}, and Q_{r2}.

Step 7-

Compute the annual profits for the life of mine using this equation.

$$P = [(S1 - r1) * Q_{r1}] + [(S2 - r2) * Q_{r2}] - [c * Q_c] - [m * Q_m] - f . \qquad (6.4)$$

Find the life of deposit *"life"*. Compute the NPV by using this equation.

$$NPV = \frac{P * [(1+d)^{life} - 1]}{d * (1+d)^{life}} .$$

Compare this NPV with the previous V (step 4). If the computed NPV is not within some tolerance (say ± 5,000,000) of V, go to step 4. Otherwise, go to next step.

Step 8-

Create Stockpiles grade increments for both minerals, and accumulate the reserves available in each increment. This is carried out with respect to lowest cutoff grades and the optimum cutoff grades of both minerals in each period.

Step 9-

Adjust the grade tonnage curve of the deposit by subtracting ore tons Q_c from the grade distribution intervals above optimum cutoff grades, and the waste tons Q_m-Q_c from the intervals below optimum cutoff grades in proportionate amount such that the shape of the distribution is not changed.

Step 10-

If current push-back is finished, then check if all push-backs are finished and go to next step, otherwise start next push-back from step 2. If the reserves are still available in the current push-back, then go to step 2 and find the remaining reserves.

Step 11-

start the stockpile as a new push-back. The profit equation is

$$P = \left[(S1 - r1) * Q_{r1}\right] + \left[(S2 - r2) * Q_{r2}\right] - \left[c * Q_c\right] - \left[ssp * Q_m\right] - f \,. \tag{6.5}$$

The stockpile is utilized by following the same procedures of depletion of push-backs in the deposit. If the stockpiles are finished then go to step 3, otherwise go to step 2 to determine the remaining reserves in stockpile.

Step 12-

If it is first iteration then knowing the profits obtained in each year, find the net present value year by year by discounting back those profits and go to next step. If it is second iteration then stop.

Step 13-

Use the net present values obtained in step 12, as initial NPV's for each corresponding year for second iteration. Repeat whole process again from step 2 to step 12.

This second iteration will give the optimum cutoff grade policy for the mine life. Write the *year, push-back, cutoff grade of both minerals,* Q_m, Q_c, Q_{r1}, Q_{r2}, *profit and* NPV as final output.

7. DEVELOPMENT OF COMPUTER PROGRAMS FOR CUTOFF GRADE OPTIMIZATION WITH STOCKPILES

As the algorithms for both cases (one and two minerals) have been modified to incorporate stockpiles. Therefore, two separate programs SPOPTI1.FOR and SPOPTI2.FOR are developed in FORTRAN 77, however, the program can also be complied on a FORTRAN 90 compiler. These programs are included on the diskette given at the end of thesis under names "sopti1.f" and "sopti2.f" in appendix C.

7.1 Summary Of Routines For SPOPTI1.FOR

The routines of the program can be divided into five major types. These are optimum cutoff grade routines, the net present value routines, creation of stockpiles, the routines which analyze the adjustment of grade tonnage curves after the quantities of material are assigned with respect to mine, mill, and refinery, and the routines for utilization of stockpiles.

The optimum cutoff grade routines use the economic parameters such as price, costs and capacities associated with mine, mill, and refinery, and the metallurgical recoveries. These economic parameters are involved in calculation of limiting economic cutoff grades. The balancing cutoff grades use the grade tonnage distribution of the deposit. The optimum cutoff grade is determined by using the criteria defined in chapter 2, in a different subroutine.

The net present value convergence routines use the optimum cutoff grade as a main input, because, all the analysis conducted by them is function of optimum cutoff grade. These routines find the life of deposit based on the assumption that whole deposit will be mined by using this optimum cutoff grade. The life of mine is also a function of the limiting capacity during this period. The annual profit for the life of mine is calculated, and then net present value is determined by discounting back those annual profits for the life of mine. If the net present value determined is converged i.e. within some tolerance of the previous net present value used in the analysis, then the operation of the program is handed over to the stockpile creation routines. Usually it takes three to five iterations to converge the net present value.

The routines which create the stockpiles are using the lowest cutoff grade and the optimum cutoff grade for the current period. The grade increments which are sent to the stockpile are defined, and then reserves within each increment are accumulated in each period until the depletion of the push-backs in the deposit.

The grade tonnage curve adjustment routines use the information obtained from the first two major portions of the program. The push-back life is determined based on the quantities being sent to the mine, mill, and refinery. The tons of ore, waste and final product handled in the period are subtracted from the grade tonnage distribution such that the shape of the distribution is not changed. If the material required for the current period is not available in the push-back, then the next available push-back is incorporated in this period by the program. However, if the push-backs in the deposit are finished then the stockpile utilization starts. The general logic and structure of the program is given in Figure 7.1.

The structure of stockpile utilization routines is exactly the same. Because, it is considered as a new push-back. After the depletion of stockpile the program writes down the final output of the program.

The program is capable of handling any number of increments given in the grade tonnage distribution. This choice is given according to the need of the user in the input file. The number of push-backs can also be defined by the user in the input file. The size of arrays can be modified by the user according to the requirement. All of the subroutines are less than a page in length, and easily understanding. This program consists of the 2600 lines and 55 subroutines, it takes less than a minute to execute the program and obtain the final output.

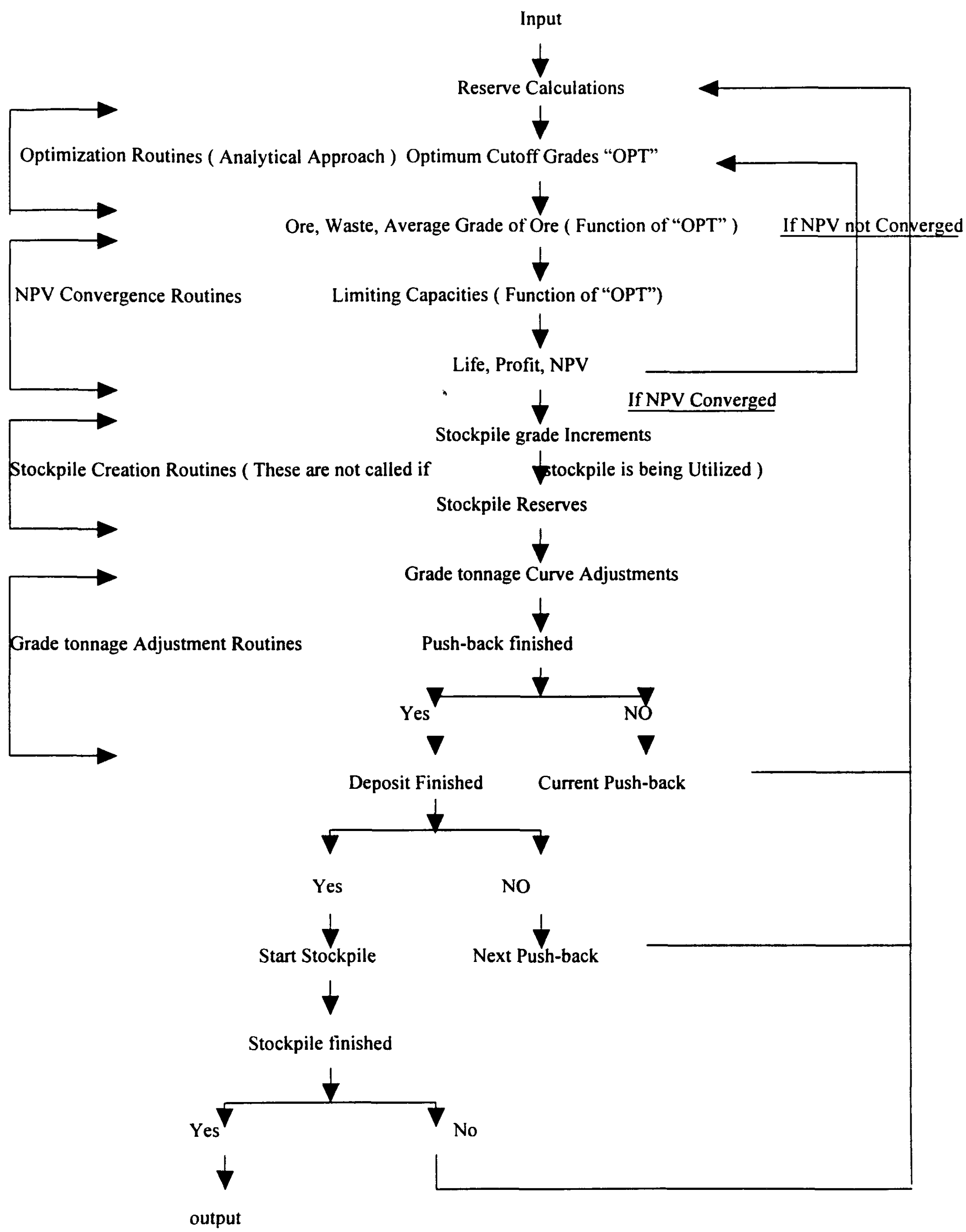

Figure 7.1: Flow Diagram of the SPOPTI1.FOR

7.2 Input For SPOPTI1.FOR

For the example to be demonstrated the input data is shown in Table 7.1 and Table 7.2. The structure of the input files used by the program is exactly the same as given in Table 3.3 and table 3.4. Only The stockpile handling cost, lowest cutoff grade, and highest cutoff grade obtained from OPTI1.FOR are included in the input file. This input file is also included on the diskette under the name "asopti1.dat" as appendix C.

The modification in Table 3.3 and 3.4 for this program is as follows.

The second line has price, refinery or marketing cost, milling cost, mining cost, stockpile handling cost, recovery, discount rate, and the fixed cost respectively.

The third line is added to give lowest and highest cutoff grades respectively.

Rest of the structure is same.

7.3 Output For SPOPTI1.FOR

The output of this program is divided into two parts. The detailed output of the program consists of a huge file, this includes the year by year analysis done by each subroutine in the program. This output gives a broader picture of the program. The output which shows the complete cutoff grade policy consists of years in the column 1, push-back in this year in column 2, optimum cutoff grades in column 3, quantities to be mined Q_m (in million tons) in column 4, quantities to be milled Q_c (in million tons) in column 5, and quantities to be refined Q_r (in thousand tons) in column 6, the profit (in $M) in column 7, and net present value (in $M) in column 8. After the depletion of deposit, the stockpile is started as new push-back, the program shows this with "0" in the second column. This output of the demonstration example is shown in Table 7.3.

The results given in Table 7.3 are clearly showing that the net present value can be further enhanced by the creation of stockpiles. However, in this particular case the difference is not very significant. But, this is very encouraging that the mine life has been increased by twelve years and still the net present value is higher irrespective of the discounting back of cash flows for these years. The stockpile will be feeding the mill for twelve years, these years are shown by push-back "0" in the output of program. The cut-off grade policy for first 32 years is almost same even by including stockpiles. However, the increase in net present value in early years has increased the cutoff grades for some of the years. The milling capacity is limiting the throughput for the mine life. Therefore this capacity is needed to be increased.

Description	**Value**
Mining Capacity, tons per year	20,000,000
Milling Capacity, tons per year	10,000,000
Refining Capacity (Copper), tons per year	90,000
Mining Cost, dollars per ton	0.5
Milling Cost, dollars per ton	0.6
Marketing Cost (Copper), dollars per ton	50.00
Fixed Costs, dollars per ton	4,000,000
Stockpile Handling Cost, dollars per ton	0.225
Price (Copper), dollars per ton	550.00
Recovery (Copper), %	90
Discount Rate, %	15

Table 7.1: ***Economic Parameters For Demonstration Example***

Table 7.2: **Grade Tonnage Distribution Of The Deposit**

Lower limits of grade categories (%)	Upper limits of grade categories (%)	Tons(in millions) in each Push-back					
		1	2	3	4	5	6
0.0	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	0.25	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
0.70	+ 0.70	42.3	37.5	31.6	25.0	17.4	9.0
Last upper grade category for each Push-back		1.56	1.44	1.30	1.16	1.04	0.90

Table 7.3: **Complete Cutoff Grade Policy With Stockpile By SPOPTI1.FOR**

Year	Push-Back	COG (%)	Qm (M tons)	Qc (M tons)	Qr (1000's T)	Profit ($M)	NPV ($M)
1	1	0.50	17.80	10.00	90.00	26.10	150.4
2	1	0.50	17.80	10.00	90.00	26.10	146.9
3	1	0.50	17.80	10.00	90.00	26.10	142.9
4	1	0.50	17.80	10.00	90.00	26.10	138.2
5	1	0.50	17.80	10.00	90.00	26.10	132.9
6	1	0.50	10.80	6.00	54.30	15.70	126.7
6	2	0.53	7.90	4.00	34.10	9.10	126.7
7	2	0.53	20.00	10.00	85.80	22.90	120.8
8	2	0.53	20.00	10.00	85.80	22.90	116.1
9	2	0.53	20.00	10.00	85.80	22.90	110.6
10	2	0.53	20.00	10.00	85.80	22.90	104.3
11	2	0.53	12.10	6.00	51.80	13.80	97.1
11	3	0.47	7.90	4.00	30.20	7.20	97.1
12	3	0.47	20.00	10.00	76.10	18.00	90.6
13	3	0.47	20.00	10.00	76.10	18.00	86.2
14	3	0.47	20.00	10.00	76.10	18.00	80.9
15	3	0.47	20.00	10.00	76.10	18.00	75
16	3	0.45	12.10	6.20	46.70	11.10	68.2
16	4	0.41	7.50	3.80	25.00	5.00	68.2
17	4	0.41	20.00	10.00	66.50	13.20	62.6
18	4	0.41	20.00	10.00	66.50	13.20	58.5
19	4	0.40	19.70	10.00	66.00	13.20	54.3
20	4	0.39	19.10	10.00	65.00	13.00	48.9
21	4	0.37	13.60	7.50	48.00	9.50	43.7
21	5	0.35	5.10	2.50	14.70	2.20	43.7
22	5	0.35	20.00	10.00	57.10	8.60	38.1
23	5	0.34	19.50	10.00	56.60	8.50	35.2
24	5	0.33	19.00	10.00	56.00	8.50	32.6
25	5	0.32	18.50	10.00	55.20	8.40	29.0
26	5	0.30	17.80	10.00	53.90	8.10	25.0
26	6	0.29	0.20	0.30	0.50	0.30	25.0
27	6	0.29	20.00	9.70	47.60	3.80	20.6

Table 7.3 is continued.

Year	Push-Back	COG	Qm (M tons)	Qc (M tons)	Qr (1000's T)	Profit ($M)	NPV ($M)
28	6	0.29	19.90	10.00	47.50	3.80	19.9
29	6	0.29	19.80	10.00	47.40	3.80	19.0
30	6	0.29	19.70	10.00	47.30	3.80	18.1
31	6	0.29	19.60	10.00	47.20	3.80	17.0
32	6	0.28	0.90	1.60	2.10	0.20	15.8
33	0	0.29	10.00	10.00	33.80	4.60	18.0
34	0	0.28	10.00	10.00	33.20	4.30	16.0
35	0	0.27	10.00	10.00	32.50	4.00	14.1
36	0	0.26	10.00	10.00	31.90	3.70	12.2
37	0	0.26	10.00	10.00	31.30	3.40	10.3
38	0	0.25	10.00	10.00	30.80	3.10	8.5
39	0	0.24	10.00	10.00	29.80	2.70	6.6
40	0	0.24	10.00	10.00	28.70	2.10	5.2
41	0	0.23	10.00	10.00	27.80	1.70	3.6
42	0	0.23	10.00	10.00	27.20	1.40	2.4
43	0	0.23	10.00	10.00	27.10	1.30	1.5
44	0	0.23	3.00	3.00	8.20	0.40	0.3

7.4 Summary Of Routines For SPOPTI2.FOR

The routines of the program can be divided into five major types. These are optimum cutoff grade or grid search technique routines, the net present value routines, creation of stockpiles, the routines which analyze the adjustment of grade tonnage curves after the quantities of material are assigned with respect to mine, mill, and refinery, and the routines for utilization of stockpiles.

The optimum cutoff grade routines use the economic parameters and grade tonnage distribution of the deposit. The economic parameters include price, costs and capacities associated with mine, mill, refinery1, and refinery2, and the metallurgical recoveries. These inputs are used by the grid search technique in the equations of V_m, V_c, V_{r1}, V_{r2} (chapter 4). The optimum cutoff grades are determined by the procedure given in chapter 4.

The net present value convergence routines use the optimum cutoff grades as a main input, because, all the analysis conducted by them is function of optimum cutoff grades. These routines find the life of deposit based on the assumption that whole deposit will be mined by using these optimum cutoff grades. The life of mine is also a function of the limiting capacity during this period. The annual profit for the life of mine is calculated, and then net present value is determined by discounting back those annual profits for the life of mine. If the net present value determined is converged i.e. within some tolerance of the previous net present value used in the analysis, then the operation of the program is handed over to the grade tonnage curve adjustment routines. Usually it takes three to five iterations to converge the net present value.

The routines which create the stockpiles are using the lowest cutoff grades and the optimum cutoff grades for the current period for both minerals. The grade increments for both minerals which are sent to the stockpile are defined, and then reserves within each increment are accumulated in each period until the depletion of the push-backs in the deposit.

The grade tonnage curve adjustment routines use the information obtained from the previous two major portions of the program. The push-back life is determined based on the quantities being sent to the mine, mill, and refinery. The tons of ore, waste and final product handled in the period are subtracted from the grade tonnage distribution such that the shape of the distribution is not changed. If the material required for the current period is not available in the push-back, then the next available push-back is incorporated in this period by the program. However, if the push-backs in the deposit are finished then the program ends. The general logic and structure of the program is given in Figure 7.2.

The program is capable of handling any number of increments given in the grade tonnage distribution for both minerals. This choice is given according to the need of the user in the input file. The number of push-backs can also be defined by the user in the input file. The size of arrays can be modified by the user according to the requirement. All of the subroutines are less than a page in length, and easily understanding. This program consists of the 10,000 lines and 197 subroutines, it takes about a minute and half to execute the program and obtain the final output.

5.2 Input For SPOPTI2.FOR

For the example to be demonstrated the input data is shown in Table 7.4 and Table 7.5. This data is assumed for a copper gold deposit. The structure of the input files used by the program is same as given in Table 5.3 and 5.4. However, the lowest and highest cutoff grades for both minerals and the stockpile handling costs are included in the input file. This input file is also included on the diskette as appendix C under the name "asopti2.dat".

The Table 5.3 is modified for this purpose, which is as follows.

The second line has price of mineral 1, price of mineral 2, refinery or marketing cost of mineral 1, refinery or marketing cost of mineral 2, recovery of mineral 1, recovery

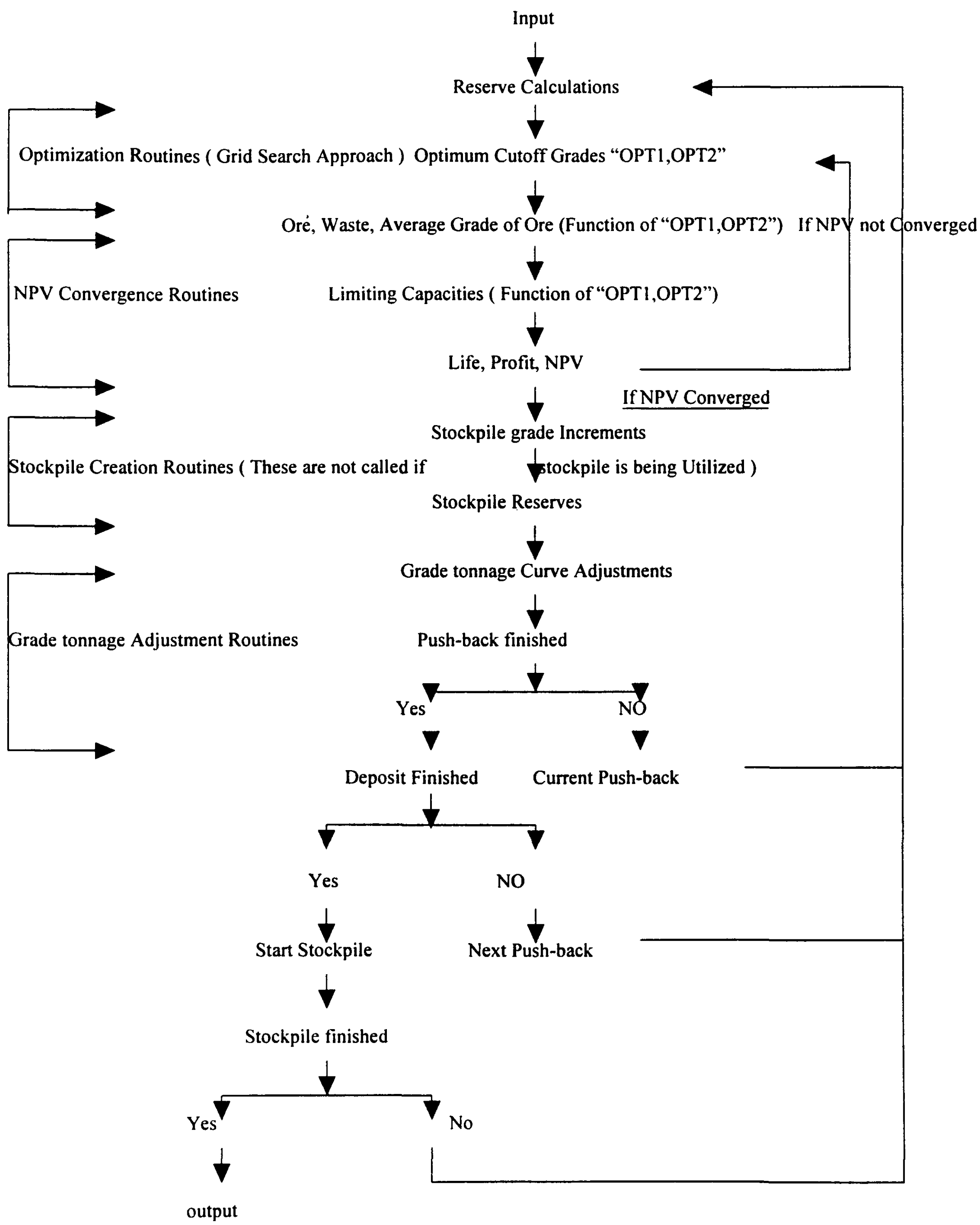

Figure 7.2: Flow Diagram of the SPOPTI2.FOR

of mineral 2, mining cost, milling cost, stockpile handling cost, discount rate, and the fixed cost respectively. The third line consist of lowest cutoff grade for mineral 1, lowest cutoff grade for mineral 2, highest cutoff grade for mineral 1, and highest cutoff grade for mineral 2 respectively.

The rest of the table will be same. The Table 5.4 is not modified for this program.

5.3 Output For SPOPTI2.FOR

The output of this program is divided into two parts. The detailed output of the program consists of a huge file, this includes the year by year analysis done by each subroutine in the program. This output gives a broader picture of the program. The output which shows the complete cutoff grade policy consists of years in the column 1, push-back in this year in column 2, optimum cutoff grade of mineral 1 in column 3, optimum cutoff grade of mineral 2 in column 4, quantities to be mined Q_m (in million tons) in column 5, quantities to be milled Q_c (in million tons) in column 6, and quantities to be refined for mineral 1 Q_{r1} (in thousand tons) in column 7, and quantities to be refined for mineral 2 Q_{r2} (in thousand tons) in column 8, the profit (in $M) in column 9, and net present value (in $M) in column 10. After the push-backs in deposit are depleted, the stockpile utilization starts as a new push-back, this is indicated by "0" in the output. This output of the demonstration example is shown in Table 7.6.

The results given in Table 7.6 are clearly showing that the net present value can be further enhanced by the creation of stockpiles. The difference in net present value obtained in OPTI2.FOR and this program is very significant. This is very encouraging that the mine life has been increased by 5 years and still the net present value is higher irrespective of the discounting back of cash flows for these years. The stockpile will be feeding the mill for 5 years, these years are shown by push-back "0" in the output of program. The cutoff grades for both minerals have been increased in the last years of deposit depletion. The mining and milling capacities are limiting the throughput for the mine life. Therefore these capacities are needed to be increased.

Description	**Value**
Mining Capacity, tons per year	20,000,000
Milling Capacity, tons per year	10,000,000
Refining Capacity (Copper), tons per year	100,000
Refining Capacity (Gold), ounces per year	900,000
Mining Cost, dollars per ton	1.48
Milling Cost, dollars per ton	4.45
Marketing Cost (Copper), dollars per ton	100.00
Marketing Cost (Gold), dollars per ounce	5.00
Fixed Costs, dollars per ton	3,500,000
Stockpile Handling Cost, dollars per ton	0.65
Price (Copper), dollars per ton	2100.00
Price (Gold), dollars per ounce	385.00
Recovery (Copper), %	90
Recovery (Gold), %	80
Discount Rate, %	15

Table 7.4: ***Economic Parameters For Demonstration Example***

Table 7.5: Grade Tonnage Distribution Of The Deposit

Copper Grades (%)		Gold Grades (oz/ton)		Tons (millions)
Lower Limit	Upper Limit	Lower Limit	Upper Limit	
0.0	0.15	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.15	0.2	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.2	0.25	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.25	0.3	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.3	0.35	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5

Table 7.5 Continued.

0.35	0.4	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.4	0.45	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.45	0.5	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.5	0.55	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.55	0.6	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.6	0.65	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5

Table 7.5 Continued.

0.65	0.7	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.7	4.69	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5

Table 7.6: Complete Cutoff Grade Policy With Stockpile By SPOPTI2.FOR

YEAR	PB	COG1	COG2	Qm (Mtons)	Qc (Mtons)	Qr1 (1000's T)	Qr2 (1000's T)	PROFIT ($M)	NPV ($M)
1	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1360.39
2	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1344.85
3	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1326.97
4	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1306.41
5	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1282.77
6	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1255.58
7	1	0.339	0.026	10.59	5.32	37.55	219.60	116.85	1224.31
7	2	0.294	0.026	9.32	4.68	31.10	183.34	95.20	1224.31
8	2	0.294	0.026	19.91	10.00	66.46	391.83	203.45	1195.91
9	2	0.294	0.026	19.91	10.00	66.46	391.83	203.45	1171.84
10	2	0.300	0.024	19.70	10.00	66.95	387.47	203.09	1144.17
11	2	0.333	0.021	19.91	10.00	70.03	374.37	203.94	1112.70
12	2	0.350	0.018	19.90	10.00	71.66	365.58	203.90	1075.66
13	2	0.339	0.020	19.76	10.00	70.56	370.00	203.58	1033.11
14	2	0.300	0.020	1.59	0.88	5.91	32.64	17.55	984.49
14	3	0.322	0.018	17.97	9.12	62.89	327.88	179.19	984.49
15	3	0.289	0.018	18.29	10.00	65.98	359.60	192.67	935.43
16	3	0.250	0.018	16.86	10.00	62.73	359.60	188.31	883.08
17	3	0.211	0.018	15.65	10.00	59.70	359.60	184.08	827.23
18	3	0.183	0.017	14.49	10.00	57.64	353.82	179.51	767.23
19	3	0.150	0.016	13.45	10.00	55.27	349.95	174.86	702.81
20	3	0.117	0.013	12.76	10.00	54.49	342.13	171.34	633.37
21	3	0.087	0.011	12.16	10.00	53.78	334.25	167.84	557.04
22	3	0.050	0.010	8.37	7.13	37.69	235.61	117.77	472.76
23	0	0.422	0.003	10.00	10.00	79.80	109.47	146.19	425.90
24	0	0.372	0.003	10.00	10.00	72.89	109.47	132.37	343.59
25	0	0.311	0.003	10.00	10.00	63.50	109.47	113.61	262.76
26	0	0.278	0.003	10.00	10.00	57.53	109.47	101.67	188.56
27	0	0.222	0.003	10.00	10.00	46.36	109.47	79.33	115.18
28	0	0.172	0.003	10.00	10.00	33.00	109.47	52.61	53.13
29	0	0.035	0.013	5.49	5.49	4.58	81.07	9.77	8.49

8. CAPITAL COSTS AND CASH FLOW ANALYSIS

8.1 Introduction

In order to know whether material under consideration is ore or simply a mineralized rock, both the revenues and costs must be examined. In the studies conducted before for the calculation of cutoff grade policies, only operating costs were used. The Lane's approach is also considering operating costs only. The purpose of this chapter is to include the capital costs incurred after obtaining the optimum cutoff grade policy. Although, this analysis will not be very precise (because, costs will be estimated), but it will serve the purpose of proving that even if capital costs are considered, the net present value can still be maximized.

8.2 Capital and Operating Costs Estimation

The updated O'Hara cost estimator (1988) is used to calculate the capital and operating costs. These costs are according to formulas updated in 1988, therefore, an escalation factor of 1.5 will be applied to change these costs for current applications.

8.2.1 Mine Associated Capital Costs

If mine capacity is M tons per year, and it is assumed that mine is scheduled to work 260 days in a year (O'Hara cost formulas are based on this assumption). Therefore, the tons of material mined per day T can be calculated as:

$$T = \frac{M}{260}. \tag{8.1}$$

8.2.1.1 Drills

The size, hole diameter, and number of drills required depends on the tons of ore and waste drilled off daily. The number of drills N_d should never be less than two. For tonnages up to 25,000 tpd, two drills of appropriate hole diameter should be chosen. Three drills should be adequate for up to 60,000 tpd, and four or more drills will be required for daily tonnages over 60,000.

The cost of drilling equipment is given by:

$$\text{Drilling Equipment costs} = N_d \times \$20{,}000\, d^{1.8}\,. \tag{8.2}$$

where d is the diameter of drill hole.

8.2.1.2 Shovels

The optimum size S expressed in cubic yards of nominal dipper capacity in relation to tons per day of material handled is:

$$S = 0.145 \times T^{0.4}\,. \tag{8.3}$$

The number of shovels "N_s" with dipper size "S" that will be required to load a total of "T" tons per day is:

$$N_s = 0.011 \frac{T^{0.8}}{S}\,. \tag{8.4}$$

In practice, size of shovel chosen will be one with a standard dipper size close to the one calculated by equation 8.3. The calculated number of shovels usually is not a whole number. It should be rounded down. The omitted fractional number expresses the need for either a small sized shovel or a front end loader for supplemental loading service.

The total cost of fleet of shovel, supplemented by auxiliary bulldozers and front end loaders will be:

$$\text{Loading equipment cost} = N_S \times \$510{,}000\, S^{0.8} \tag{8.5}$$

8.2.1.3 Trucks

The optimum truck size t in tons that is well matched with shovels of bucket size S is:

$$t = 9.0S^{1.1}. \tag{8.6}$$

The total number of trucks N_t of t tons capacity required for the open pit truck fleet, plus an allowance for trucks under repair, is approximated as:

$$N_t = 0.25\frac{T^{0.8}}{t}. \tag{8.7}$$

The cost of haulage equipment including the accessory road maintenance equipment is given by:

$$\textit{Haulage equipment cost} = N_t \times \$20{,}000\, t^{0.9} \tag{8.8}$$

8.2.2 Mine Associated Operating Costs

Following are the operating costs associated with mine.

$$\textit{Drilling cost per ton of material} = \$1.9\, t^{-0.3} \tag{8.9}$$

$$\textit{Blasting cost per ton of material} = \$3.17\, t^{-0.3} \tag{8.10}$$

$$\textit{Loading cost per ton of material} = \$2.67\, t^{-0.3} \tag{8.11}$$

$$\textit{Haulage cost per ton of material} = \$18.07\, t^{-0.3} \tag{8.12}$$

$$\textit{general services cost per ton of material} = \$6.65\, t^{-0.3} \tag{8.13}$$

8.2.3 Mill Associated Capital Costs

If mill capacity is C tons per year, and it is assumed that mill is scheduled to work 365 days in a year (O'Hara cost formulas are based on this assumption). Therefore, the tons of ore milled per day T_p can be calculated as:

$$T_p = \frac{C}{365}. \tag{8.14}$$

8.2.3.1 Concentrator Building

The costs of the concentrator building include all costs of constructing the building, plus the cost of internal offices, laboratories, and change rooms.

$$\textit{Cost of building} = \$27{,}000 \times T_p^{0.6}. \tag{8.15}$$

8.2.3.2 Primary Crusher

Open pit mines generally place the primary crusher on the surface outside the pit. The cost of the primary crusher depends on the size and capacity of the gyratory crusher selected for crushing T_p tons of ore daily.

$$\textit{Cost of gyratory crusher} = \$63 \times T_p^{0.9}. \tag{8.16}$$

$$\text{Cost of primary crusher plant} = \$15{,}000 \times T_p^{0.7}. \tag{8.17}$$

8.2.3.3 Grinding Plant

The fine storage bins must have sufficient live capacity to provide mill feed for at least the number of days that the crushing plant is idle per week. The size and cost of grinding mills depend on the tons of ore to be ground daily by each mill. But they also depend upon the hardness of the ore as measured by the work index and the fineness of grind that is required.

$$\text{Cost of grinding and bins} = \$18{,}700 \times T_p^{0.7}. \tag{8.18}$$

This formula is for medium hard ore with a work index of 15, ground to 70% passing 200 mesh.

8.2.3.4 Processing Plant

The capital costs in this section cover the purchase and installation of all equipment required to concentrate or extract valuable minerals from the ground ore.

$$\textit{Process capital costs} = \$13{,}700 \times T_p^{0.6}. \tag{8.19}$$

This capital cost is for simple low grade base metal ores of copper.

8.2.3.5 General Plant Capital Costs

Following are general plant capital costs.

Cost of water supply system = $\$14{,}000 \times T_p^{0.6}$. (8.20)

Cost of substation = $\$580 \times PL^{0.8}$. (8.21)

Cost of surface power distribution = $\$1150 \times PL^{0.8}$. (8.22)

where PL is the peak load expressed in kilowatts per month.

Peak load = $78 \times T_p^{0.6}$. (8.23)

8.2.4 Mill Associated Operating Costs

Following are mill associated operating costs.

Crushing cost per ton of ore = $\$7.9 \times T_p^{-0.4}$. (8.24)

Fine crushing cost per ton of ore = $\$12.6 \times T_p^{-0.4}$. (8.25)

Grinding cost per ton of ore = $\$4.9 \times T_p^{-0.4}$. (8.26)

Processing cost per ton of ore = $\$54 \times T_p^{-0.4}$. (8.27)

Maintenance cost per ton of ore = $\$40.8 \times T_p^{-0.4}$. (8.28)

Power costs per ton of ore = $\$145 \times T_p^{-0.44}$. (8.29)

Power costs include daily power requirements for open pit, crushing plant and concentrator, etc.

However, the labor costs per ton of material for mine and per ton of ore for mill should also be included. The cost per ton of salaried staff is assigned 75% to mine and 25% to mill.

8.3 Cash Flow Analysis

Cash flow analysis involves the tax consideration. In order to find the cash flows in the pre-production and the production period, it is necessary to follow the tax laws in the concerned state. However, in this study the tax laws of Colorado will be used. Following are different steps for the determination of net cash flows.

8.3.1 Depreciation

Depreciation can be defined as a deduction allowed in computing taxable income which reflects exhaustion, wear and tear, and obsolescence of property used in trade or business. There are four different methods of depreciation calculation, such as straight line, sum of the year digits, declining balance, and unit of production.

According to current depreciation system "Modified Accelerated Cost Recovery System (MACRS)", the mine and mill equipment is considered as 7-year property. Cost is recovered over a seven year life using the 200% declining balance method with a switch to the straight line method at a time that maximizes the deductions. Table 8.1, shows the deduction rate calculation for a 7-year property.

In order to find the "Alternative Minimum Taxable Income (AMTI)" with seven year property, a 150% declining balance method and switch to straight line is utilized with 10 year life. Table 8.2, shows the deduction rate calculation for a 7-year property.

The depreciation with respect to mine is used in depletion and production cash flow calculations. The depreciation with respect to mill is used in production cash flows.

Year	Method	Rate	Basis (%)	Deduction (%)	Alt. Life	Alt. St. Line Deduction (%)
1	200% DB	2×1/7×1/2	100	14.29	-	-
2	"	2×1/7	85.71	24.49	6.5	13.19
3	"	2×1/7	61.22	17.49	5.5	11.13
4	"	2×1/7	43.73	12.49	4.5	9.72
5	SLD	1/3.5	31.24	8.93	3.5	8.93
6	"	1/3.5	31.24	8.92	-	-
7	"	1/3.5	31.24	8.93	-	-
8	"	1/3.5×1/2	31.24	4.46	-	-

Table 8.1: Depreciation Rate Calculation

Year	Method	Rate	Basis (%)	Deduction (%)	Alt. Life	Alt. St. Line Deduction (%)
1	150% DB	1.5/10×1/2	100	7.5	-	-
2	"	1.5×1/10	92.50	13.88	9.5	9.74
3	"	1.5×1/10	78.62	11.79	8.5	9.25
4	"	1.5×1/10	66.83	10.02	7.5	8.91
5	SLD	1/6.5	56.81	8.74	6.5	8.74
6	"	1/6.5	56.81	8.74	-	-
7	"	1/6.5	56.81	8.74	-	-
8	"	1/6.5	56.81	8.74	-	-
9	"	1/6.5	56.81	8.74	-	-
10	"	1/6.5	56.81	8.74	-	-
11	"	1/6.5×1/2	56.81	4.37	-	-

Table 8.2: Depreciation Rate Calculation (AMTI)

8.3.2 Depletion

Depletion can be defined as deduction allowed in computing taxable income which reflects exhaustion of the reserves. There are two basic calculation procedures, unit or cost depletion and percentage depletion.

Cost or unit depletion is based on capitalized acquisition, exploration, reserves and annual production. The statutory or percentage depletion is based on statutory percentage of revenue less royalty. The percentage depletion rates are different for different commodities. For copper and gold this percentage rate is 15%. The percentage depletion is the lesser of "statutory percentage of revenue less royalty" and "50% of the revenue less deductions i.e. net after depreciation". The depletion earned is the larger of percentage and cost depletion.

No depletion is actually claimed until exploration expensed in the pre-production period has been recaptured.

The depletion claimed is used in the production cash flow calculations.

8.3.3 Exploration and Development

Exploration expenditures incurred for the purpose of ascertaining the existence, location, extent or quality of any deposit of ore or other mineral can be treated in the following way.

The most common way of treating these expenditures is to expense. when expensed the expenditures are subject to recapture. Also deduction must be reduced by 30%. The 30% reduction amount is amortized on a straight line basis over a 5 year period, beginning in the year the costs were incurred.

The development expenditures are also treated in the same way usually. For the purpose of calculation of alternative minimum taxable income, both exploration and development are amortized on a straight line basis over a 10 year period.

Exploration and development deductions are used in depletion, production cash flows, and alternative minimum taxable income calculations.

8.3.4 Property Tax

These are usually based on two components.

1- Plant, equipment, and facilities determined by county assessor.

2- Value of deposit determined by state agency.

The general procedure in calculating property taxes is, the value of property is set, property is assessed at percentage of fair market value and tax liability is determined by applying mill rate to assessed value. Property tax on ore or mineral is levied on all operations with gross proceeds of $5,000 or more. Appraised value of sales is the greater of 25% of gross proceeds or the net proceeds. Cross proceeds can be defined as value of the ore after extraction less all costs of treatment, reduction, transportation and sale of the ore. Net proceeds are defined as gross proceeds less all costs of extraction of the ore. Assessed value is set at 100% of appraised value.

Property tax associated with mine is used in depletion calculations as a cost, and total property tax (mine & mill) is used in production & pre-production cash flow calculations.

The cash flow analysis also uses the net smelter return and severence tax calculations. These calculations depend upon the existing law and also they are self explanatory. Their exapmles are given in the appendix A (cash flow calculations for case studies). The net smelter return is used to find the revenue to be generated in a year and severence tax is used in depletion and production cash flow calculations.

9. CUTOFF GRADE OPTIMIZATION AND COMPLETE CASH FLOW ANALYSIS

9.1 Case Studies

In this section of the chapter two case studies will be presented. One of the case study will cover all the aspects (optimum cutoff grade policy, cash flow analysis) of one mineral deposits, and the other will present the same analysis for two minerals deposits.

In both case studies, it is assumed that projects will have four years of pre-production. Therefore, production starts in the year 5. The mine and mill equipment will be placed into service in the first year of production.

9.1.1 Complete Cash Flow Analysis For One Mineral Deposit

For one mineral case, following capacities will be considered.

Mining Capacity = 50,000,000 tons per year

Milling Capacity = 30,000,000 tons per year

Refining Capacity = 200,000 tons per year

Following schedule will be observed during the mine life.

Mine Schedule = 260 days per year

Mill Schedule = 365 days per year

By using the O'Hara cost estimator as discussed in section 8.2, the capital and operating costs are calculated.

Tons of material mined per day:

T = 192308 tons per day

Tons of ore processed per day:

T_p = 82192 tons per day

The estimates of costs incurred in the pre-production years in millions of dollars is given in table 9.1. These costs include the property payment, exploration and development expenses, property tax, and the capital costs for mine and mill equipment. The property payment, exploration and development expenses are assumed. The capital costs of mine and mill equipment are calculated by using O'Hara cost estimator. The property tax is also calculated by using cash flow analysis.

The detailed results of costs calculation are given in Table 9.2, 9.3, 9.4, and 9.5.

The operating costs given in table 9.5 and administrative costs (fixed costs) shown in Table 9.4 are used as input for the program OPTI1.FOR. The complete input is shown in Table 9.6, 9.7. The economic parameters in Table 9.6 are different than that of the demonstration example given in chapter 3 to present different scenarios. The output and final cash flows of production period are given in Table 9.8 and 9.9.

For cash flow analysis, the depreciation will start in year 5 (first production year) as the equipment is placed into service in this year. it is also considered that equipment will be replaced in the project year 12 at the 25% of capital equipment costs. The equipment will be placed into service in the year of replacement, and the depreciation will begin in the year of replacement i.e. year 12.

The complete cash flow analysis of the case study is given appendix A.

The cash flow analysis for the break-even cutoff grades is also conducted for this one mineral case for the purpose of comparison. The mine and mill capacities are same, but refinery is unlimited. The capital and operating and other pre-production costs will also be same. The results of this analysis are given in Table 9.10 and 9.11. It can be observed that life of the mine is 21 years as whole which includes both pre-production and production period. Similarly, the equipment will also be replaced in year 19 in addition to year 12, and the depreciation will begin in the year of replacement i.e. year 12 and 19.

It is clear from the Table 9.11, that net present value for break-even cutoff grades is less than that of optimum cutoff grades by 15 millions. The mine life is 3 years more than that of optimum cutoff grades. Also, in year 19 the cash flows are negative, which may contribute in decreasing the net present value. The break-even cutoff grade obtained by the program OPTI1.FOR is actually the milling cutoff grade discussed in chapter one in the section of traditional cutoff grades.

Year	0	1	2	3	4
Property Payment	25	-	-	-	-
Exploration	-	15	15	-	-
Development	-	-	-	-	15
Mine Equipment	-	-	-	50	154
Mill Equipment	-	-	-	92	201
Property Tax	-	-	-	-	9

Table 9.1: Pre-Production Costs

Table 9.2: Mine Associated Capital Costs

Description	Units	Size	Costs (dollars)
"Drills"			
Number of Drills "N_d"	7		
If diameter of holes is " d " in inches		9	
Drilling Equipment Cost			7,307,428
"Shovels"			
Shovel Size in cubic yards		19	
Number of Shovels " Ns"	10		
Loading Equipment Cost			52,621,940
"Trucks"			
Truck Size in tons		227	
Number of Trucks "N_t"	19		
Haulage Equipment Cost			49,033,935
Subtotal			*108,963,303*
Escalation Factor (1.5)			163,444,954
Contingency @ 15%			24,516,743
Engineering @ 10%			16,344,495
Total Mine Capital Costs			*204,306,193*

Table 9.3: Mill Associated Capital Costs

Description	Costs (dollars)
"Concentrator Building"	
Cost of Building	24,002,739
"Primary Crusher"	
Cost of Gyratory Crusher	1,669,883
Cost of Crushing Plant	41,349,583
"Grinding Plant"	
Cost of Grinding plant & Bins	51,549,147
"Processing Plant"	
Cost of Processing	12,179,167
"General Plant Capital Costs"	
Cost of Water Supply System	12,445,865
Overall Power Costs	
Peak Load	69341
Cost of Substation	4,327,343
Cost of Surface Power	8,580,076
Subtotal	*156,103,802*
Escalation Factor (1.5)	234,155,704
Contingency @ 15%	35,123,356
Engineering @ 10%	23,415,570
Total Mill Capital Cost	*292,694,630*

Table 9.4: Labor Costs

Description	Total	Wages/Day	Cost ($)/year
Mine:			
Shovel Operator	30	120	936000
Shovel Oiler	30	90	702000
Truck Drivers	57	90	1333800
Drill Operators	21	120	655200
Drill Helper	21	80	436800
Blasters	20	100	520000
Laborers	30	70	546000
Subtotal			*5129800*
Fringes @ 40%			2051920
Total			*7181720*
Mill:			
Number of Persons in Plant	170		
Plant Operators	170	100	6205000
Other labor	30	80	876000
Subtotal			*7081000*
Fringes @ 40%			2832400
Total			*9913400*
Salaried Staff:			
Mine Superintendent	1		100000
Mill Superintendent	1		100000
Engineers	25		1500000
Surveyors	16		560000
Office Managers	15		450000
Foreman	15		525000
Mechanics	31		775000
Total			*4010000*
Total labor Cost			*21105120*

Table 9.5: Mine and Mill Operating Costs

Description	Cost ($/ton)
Mine:	
Drilling Cost per ton	0.049
Blasting Cost per ton	0.082
Loading Cost per ton	0.069
Haulage Cost per ton	0.470
General Services Cost per ton	0.173
Total	*0.844*
Mill:	
Crushing Cost per ton	0.085
Fine crushing & conveying	0.136
Grinding cost per ton	0.053
Processing Cost per ton	0.584
maintenance Cost per ton	0.441
Power Costs per ton (include both mine & mill)	0.997
Total	*2.297*
Salaried labor Assigned 75% to mine	3007500
Salaried labor Assigned 25% to mill	1002500
Mine Labor Cost per ton	0.20
Mill Labor Cost per ton	0.36
Total mine Operating Cost per ton	*1.05*
Total Mill Operating Cost per ton	*2.66*

Table 9.6: Economic Parameters For OPTI1.FOR

Description	**Value**
Mining Capacity, tons per year	50,000,000
Milling Capacity, tons per year	30,000,000
Refining Capacity (Copper), tons per year	200,000
Mining Cost, dollars per ton	1.05
Milling Cost, dollars per ton	2.66
Marketing Cost (Copper), dollars per ton	100.00
Fixed Costs, dollars per ton	4,000,000
Price (Copper), dollars per ton	2100.00
Recovery (Copper), %	90
Discount Rate, %	15

Table 9.7: **Grade Tonnage Distribution Of Deposit**

Lower limits of grade categories (%)	Upper limits of grade categories (%)	Tons(in millions) in each Push-back					
		1	2	3	4	5	6
0.0	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	0.25	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.	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
0.70	+ 0.70	42.3	37.5	31.6	25.0	17.4	9.0
Last upper grade category for each Push-back		1.56	1.44	1.30	1.16	1.04	0.90

Table 9.8: Output of The Program OPTI1.FOR

YEAR	PB	COG	Qm (MT)	Qc (m) (MT)	Qr (t) (1000's T)	Prof ($M)	NPV ($M)
1	1	0.34	36.11	24.99	200.00	292.10	1474.50
2	1	0.32	35.80	25.36	200.00	291.50	1403.60
3	1	0.30	28.10	20.37	158.27	230.10	1322.70
3	2	0.30	8.32	5.79	41.73	58.60	1322.70
4	2	0.28	39.52	28.23	200.00	279.90	1232.40
5	2	0.26	39.20	28.66	200.00	279.10	1137.30
6	2	0.24	12.96	9.69	66.59	92.60	1028.90
6	3	0.31	30.84	20.01	133.39	178.80	1028.90
7	3	0.31	46.23	30.00	199.97	268.10	911.70
8	3	0.31	22.93	14.88	99.17	132.90	780.40
8	4	0.32	25.21	15.12	91.98	115.50	780.40
9	4	0.32	50.00	30.00	182.45	229.10	649.00
10	4	0.29	24.79	15.47	92.10	115.20	517.20
10	5	0.27	24.22	14.53	76.08	86.40	517.20
11	5	0.26	48.89	30.00	155.16	175.70	393.20
12	5	0.23	26.89	17.70	87.96	98.60	276.50
12	6	0.23	20.51	12.30	53.61	51.50	276.50
13	6	0.20	46.59	30.00	125.69	119.20	167.90
14	6	0.17	32.91	22.64	91.20	85.00	73.90

Table 9.9: Cash Flow Analysis Of Production Period

Year	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Revenues	362.5	362.5	362.5	362.5	362.5	361	361	346	330	305	281	256	227	163
Royalty @5%	18	18	18	18	18	18	18	17	16	15	14	13	11	8
Tons Mined	36	36	36	40	39	44	46	48	50	49	49	48	47	33
Tons Processed	24.9	25.4	26.2	28.2	28.7	29.7	30	30	30	30	30	30	30	22.3
Operating Cost	108	109	112	120	122	129	132	134	136	135	135	134	133	97
Property Tax	24	23	22	20	19	18	17	17	15	13	11	9	7	10
Severence Tax	3	3	3	3	3	3	3	3	3	2	2	2	1	1
Net after Costs	209	210	208	201	201	193	191	174	159	139	119	98	74	47
Explo. & Dev. Deductions	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	29	50	36	26	18	18	18	16	13	9	6	5	5	5
Depreciation - Mill	42	72	51	37	26	26	26	24	18	13	9	7	7	7
Net after Depreciation	136	86	120	137	157	149	147	134	128	117	104	86	62	35
Depletion	52	52	52	52	52	51	51	49	47	43	40	36	32	23
Net after Depletion	84	34	68	85	105	97	95	85	81	74	64	50	29	12
Colorado State Tax @ 5%	4	2	3	4	5	5	5	4	4	4	3	2	1	1
Federal Taxable Income	80	32	65	81	100	93	90	81	77	70	60	47	28	11
Federal Income Tax @ 35%	28	11	23	28	35	32	32	28	27	24	21	17	10	4
Alt. Minimum Taxable Income	142	138	145	147	151	143	142	119	96	81	85	89	66	40
Minimum Tax @ 20%	28	28	29	29	30	29	28	24	19	16	17	18	13	8
Federal Income Tax	28	28	29	29	35	32	32	28	27	24	21	18	13	8
Net Profit	51	5	36	52	65	60	59	53	50	45	39	29	15	3
Explo. & Dev. Deductions	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	29	50	36	26	18	18	18	16	13	9	6	5	5	5
Depreciation - Mill	42	72	51	37	26	26	26	24	18	13	9	7	7	7
Depletion	52	52	52	52	52	51	51	49	47	43	40	36	32	23
Operating Cash Flow	177	180	176	167	161	156	154	142	128	111	94	78	59	38
Capital Expeditures	0	0	0	0	0	0	0	124.3	0	0	0	0	0	0
Net Cash Flow	177	180	176	167	161	156	154	18	128	111	94	78	59	38
Net Present Value	124.6													

Table 9.10: Output Of OPTI1.FOR For Break-even Cutoff Grades

YEAR	PB	COG	Qm (MT)	Qc (MT)	Qr (1000's T)	Profit ($M)	NPV ($M)
1	1	0.15	34.96	30.00	206.22	291.90	1431.80
2	1	0.15	34.96	30.00	206.22	291.90	1354.60
3	1	0.15	30.07	25.81	177.39	251.10	1265.90
3	2	0.15	4.97	4.19	26.39	35.80	1265.90
4	2	0.15	35.58	30.00	188.79	256.40	1168.80
5	2	0.15	35.57	30.00	188.79	256.40	1087.70
6	2	0.15	23.88	20.13	126.71	172.10	994.40
6	3	0.15	11.98	9.87	56.10	72.10	994.40
7	3	0.15	36.43	30.00	170.61	219.20	899.40
8	3	0.15	36.43	30.00	170.61	219.20	815.20
9	3	0.15	15.17	12.49	71.05	91.30	718.30
9	4	0.15	21.88	17.51	88.90	105.90	718.30
10	4	0.15	37.50	30.00	152.34	181.50	628.80
11	4	0.15	37.50	30.00	152.34	181.50	541.60
12	4	0.15	3.11	2.49	12.65	15.10	441.30
12	5	0.15	35.75	27.51	123.64	132.90	441.30
13	5	0.15	38.99	30.00	134.83	144.90	359.60
14	5	0.15	25.26	19.43	87.34	93.90	268.60
14	6	0.15	14.53	10.57	41.09	37.40	268.60
15	6	0.15	41.26	30.00	116.65	106.20	177.60
16	6	0.15	41.26	30.00	116.65	106.20	98.10
17	6	0.15	2.95	2.14	8.33	7.60	6.60

Table 9.11: Cash Flow Analysis For Break-even Cutoff Grades

Year	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Revenues	380.7	380.7	362.5	344.4	344.4	326	308	308	290	272	272	254	236	236	217.5	217.5	18.13
Royalty @5%	19	19	18	17	17	16	15	15	15	14	14	13	12	12	11	11	1
Tons Mined	35	35	35	36	36	36	36	36	37	38	38	39	39	40	41	41	3
Tons Processed	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	2.14
Operating Cost	121	121	121	121	121	121	122	122	123	123	123	125	125	126	127	127	13
Property Tax	23	23	21	19	18	16	14	15	13	11	10	9	8	8	8	7	2
Severence Tax	3	3	3	3	3	3	2	2	2	2	2	2	2	2	1	1	0
Net after Costs	214	215	200	185	186	170	155	153	138	122	123	106	90	89	71	71	2
Explo. & Dev. Deductions	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	29	50	36	26	18	18	18	16	13	9	6	5	5	5	10	13	9
Depreciation - Mill	42	72	51	37	26	26	26	24	18	13	9	7	7	7	14	18	13
Net after Depreciation	141	92	112	121	142	126	111	113	107	100	108	94	78	77	47	40	-20
Depletion	54	54	52	49	49	46	44	44	41	39	39	36	34	34	31	31	2.1
Net after Depletion	87	37	61	72	92	80	67	69	65	62	69	57	44	43	16	9	-22
Colorado State Tax @ 5%	4	2	3	4	5	4	3	3	3	3	3	3	2	2	1	0	0
Federal Taxable Income	82	35	58	68	88	76	63	66	62	59	66	55	42	41	15	8	0
Federal Income Tax @ 35%	29	12	20	24	31	27	22	23	22	21	23	19	15	14	5	3	0
Alt. Minimum Taxable Income	144	140	134	128	132	118	104	95	72	61	85	93	78	77	49.8	41.4	-23
Minimum Tax @ 20%	29	28	27	26	26	24	21	19	14	12	17	19	16	15	10	8	0
Federal Income Tax	29	28	27	26	31	27	22	23	22	21	23	19	16	15	10	8	0
Net Profit	54	7	31	43	57	49	41	43	40	38	43	35	26	26	5	0	0
Explo. & Dev. Deductions	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	29	50	36	26	18	18	18	16	13	9	6	5	5	5	10	13	9
Depreciation - Mill	42	72	51	37	26	26	26	24	18	13	9	7	7	7	14	18	13
Depletion	54	54	52	49	49	46	44	44	41	39	39	36	34	34	31	31	2.1
Operating Cash Flow	181	186	170	156	150	140	129	127	113	99	96	84	72	71	60	62	24
Capital Expeditures	0	0	0	0	0	0	0	124.3	0	0	0	0	0	0	124.3	0	0
Net Cash Flow	181	186	170	156	150	140	129	2	113	99	96	84	72	71	-64	62	24
Net Present Value	109.1																

9.1.2 Complete Cash Flow Analysis For Two Minerals Deposit

For two minerals case, following capacities will be considered.

Mining Capacity = 30,000,000 tons per year

Milling Capacity = 15,000,000 tons per year

Refining Capacity (Copper) = unlimited tons per year

Refining Capacity (Gold) = 900,000 tons per year

Following schedule will be observed during the mine life.

Mine Schedule = 260 days per year

Mill Schedule = 365 days per year

By using the O'Hara cost estimator as discussed in section 8.2, the capital and operating costs are calculated.

Tons of material mined per day:

$T = 115385$ tons per day

Tons of ore processed per day:

$T_p = 41096$ tons per day

The estimates of costs incurred in the pre-production years in millions of dollars is given in table 9.12. These costs include the property payment, exploration and development expenses, property tax, and the capital costs for mine and mill equipment. The property payment, exploration and development expenses are assumed. The capital costs of mine and mill equipment are calculated by using O'Hara cost estimator. The property tax is also calculated by using cash flow analysis.

The detailed results of costs calculation are given in Table 9.13, 9.14, 9.15, and 9.16.

The operating costs given in Table 9.16 and administrative costs (fixed costs) shown in Table 9.15 are used as input for the program OPTI2.FOR. The complete input is shown in Table 9.17, 9.18. The economic parameters given in Table 9.17 are different from those given in demonstration in chapter 5 to present different scenarios example in The output and final cash flows of production period are given in Table 9.19 and 9.20.

For cash flow analysis, the depreciation will start in year 5 (first production year) as the equipment is placed into service in this year. it is also considered that equipment will be replaced in the project year 12 and 19 at the 25% of capital equipment costs. The equipment will be placed into service in the year of replacement, and the depreciation will begin in the same year i.e. year 12 and 19.

The complete cash flow analysis is given in appendix A.

Year	0	1	2	3	4
Property Payment	35	-	-	-	-
Exploration	-	20	20	-	-
Development	-	-	-	-	20
Mine Equipment	-	-	-	50	90.6
Mill Equipment	-	-	-	50	160.6
Property Tax	-	-	-	-	6

Table 9.12: Pre-Production Cost

Table 9.13: Mine Associated Capital Costs

Description	Units	Size	Cost (dollars)
Drills			
Number Of Drills "Nd"	5		
Diameter of holes " d " in inches		9	
Drilling Equipment Cost in dollars			5,219,592
Shovels			
Shovel Size in cubic yards		15	
Number of Shovels " Ns"	8		
Loading Equipment Cost in dollars			36,428,036
Trucks			
Truck Size in tons		182	
Number of Trucks "Nt"	15		
Haulage Equipment Cost in dollars			33,325,685
Subtotal			*74,973,313*
Escalation Factor (1.5)			112,459,969
Contingency @ 15%			16,868,995
Engineering @ 10%			11,245,997
Total Mine Capital Costs			*140,574,961*

Table 9.14: Mill Associated Capital Costs

Description	Costs (dollars)
Concentrator Building	
Cost of Building	15,835,902
Primary Crusher Plant	
Cost of Gyratory Crusher	894,868
Cost of Primary Crushing Plant	25,453,654
Grinding Plant	
Cost of Grinding plant & Bins	31,732,222
Processing Plant	
Cost of Processing	20,920,829
General Plant Capital Costs	
Cost of Water Supply System	8,211,208
Overall Power Costs	
Peak Load	45748
Cost of Substation	3,102,608
Cost of Surface Power	6,151,723
Subtotal	*112,303,014*
Escalation Factor (1.5)	168,454,521
Contingency @ 15%	25,268,178
Engineering @ 10%	16,845,452
Total Mill Capital Cost	*210,568,152*

Table 9.15: Labor Costs

Description	Total	Wages/Day	Cost ($)/year
Mine:			
Shovel Operator	24	120	748800
Shovel Oiler	24	90	561600
Truck Drivers	45	90	1053000
Drill Operators	15	120	468000
Drill Helper	15	80	312000
Blasters	15	100	390000
Laborers	25	70	455000
Subtotal			3988400
Fringes @ 40%			1595360
Total			*5583760*
Mill:			
Number of Persons in Plant	138		
Plant Operators	138	100	5037000
Other labor	25	80	730000
Subtotal			5767000
Fringes @ 40%			2306800
Total			*8073800*
Salaried Staff:			
Mine Superintendent	1		100000
Mill Superintendent	1		100000
Engineers	20		1200000
Surveyors	13		455000
Office Managers	15		450000
Foreman	13		455000
Mechanics	30		750000
Total			*3510000*
Total labor Cost			*17167560*

Table 9.16: Mine and Mill Operating Costs

Description	Costs ($/ton)
Mine:	
Drilling Cost per ton	0.058
Blasting Cost per ton	0.096
Loading Cost per ton	0.081
Haulage Cost per ton	0.547
General Services Cost per ton	0.201
Total	*0.983*
Mill:	
Crushing Cost per ton	0.113
Fine crushing & conveying	0.180
Grinding cost per ton	0.070
Processing Cost per ton	0.771
maintenance Cost per ton	0.582
Power Costs per ton	1.353
(include both mine & mill)	
Total	*3.068*
Salaried labor Assigned 75% to mine	2632500
Salaried labor Assigned 25% to mill	877500
Mine Labor Cost per ton	0.27
Mill Labor Cost per ton	0.60
Total mine Operating Cost per ton	*1.26*
Total Mill Operating Cost per ton	*3.67*

Table 9.17: Economic Parameters For OPTI2.FOR

Description	Value
Mining Capacity, tons per year	30,000,000
Milling Capacity, tons per year	15,000,000
Refining Capacity (Copper), tons per year	Unlimited
Refining Capacity (Gold), ounces per year	900,000
Mining Cost, dollars per ton	1.26
Milling Cost, dollars per ton	3.71
Marketing Cost (Copper), dollars per ton	100.00
Marketing Cost (Gold), dollars per ounce	5.00
Fixed Costs, dollars per ton	3,500,000
Price (Copper), dollars per ton	2100.00
Price (Gold), dollars per ounce	385.00
Recovery (Copper), %	90
Recovery (Gold), %	80
Discount Rate, %	15

Table 9.18: Grade Tonnage Distribution Of Deposit

Copper Grades (%)		Gold Grades (oz/ton)		Tons (millions)
Lower Limit	Upper Limit	Lower Limit	Upper Limit	
0.0	0.15	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.15	0.2	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.2	0.25	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.25	0.3	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.3	0.35	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5

Table 9.18 Continued.

0.35	0.4	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.4	0.45	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.45	0.5	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.5	0.55	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.55	0.6	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.6	0.65	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5

Table 9.18 Continued.

0.65	0.7	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5
0.7	4.69	0.0	.02	1.5
		.02	.03	1
		.03	.04	0.5
		.04	.05	0.5
		.05	.06	6.5

Table 9.19: Output Of The Program OPTI2.FOR

YEAR	PB	COG1	COG2	Qm (M tons)	Qc (M tons)	Qr1 (1000's T)	Qr2 (1000's oz.)	PROFIT ($M)	NPV ($M)
1	1	0.294	0.033	29.19	15.00	99.69	641.82	347.35	1950.49
2	1	0.294	0.032	28.97	15.00	99.69	639.95	346.91	1895.72
3	1	0.294	0.030	28.54	15.00	99.69	636.00	345.95	1833.16
4	1	0.294	0.028	27.72	15.00	99.69	627.67	343.82	1762.18
5	1	0.289	0.026	15.60	8.79	57.99	362.78	199.53	1682.68
5	2	0.294	0.024	12.08	6.21	41.27	240.61	134.26	1682.68
6	2	0.294	0.022	27.92	15.00	99.69	568.12	320.94	1601.29
7	2	0.294	0.020	26.75	15.00	99.69	555.00	317.42	1520.55
8	2	0.244	0.020	24.11	15.00	93.43	555.00	308.23	1431.21
9	2	0.206	0.018	21.93	15.00	88.92	548.37	299.45	1337.66
10	2	0.156	0.018	17.21	12.86	71.56	469.98	249.33	1238.87
10	3	0.167	0.018	3.10	2.14	12.10	77.10	41.15	1238.87
11	3	0.133	0.016	19.99	15.00	82.33	524.92	279.79	1134.22
12	3	0.083	0.013	18.80	15.00	80.51	513.20	273.20	1024.56
13	3	0.050	0.010	17.59	15.00	79.26	495.43	265.46	905.05
14	3	0.025	0.005	16.21	15.00	78.30	468.40	255.01	775.34
15	3	0.025	0.003	15.86	15.00	78.30	459.30	252.00	636.63
16	3	0.025	0.003	15.86	15.00	78.30	459.30	252.00	480.13
17	3	0.025	0.003	15.86	15.00	78.30	459.30	252.00	300.15
18	3	0.025	0.003	6.74	6.38	33.29	195.29	107.15	93.17

Table 9.20: Cash Flow Analysis Of Production Period

Year	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Revenues	1211	1211	1211	1204.6	1143.6	1104	1091	1079	1057	1038	1006	969.5	941.5	906.3	897	897	897	322.3
Royalty @5%	61	61	61	60	57	55	55	54	53	52	50	48	47	45	45	45	45	16
Tons Mined	30	30	30	29	28	28	26	24	21	20	20	18	17	16	16	16	16	6
Tons Processed	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	5.37
Operating Cost	97	97	97	95	95	95	92	89	86	84	84	82	81	79	79	79	79	31
Property Tax	74	73	72	71	67	64	63	63	61	59	57	54	52	50	51	51	50	19
Severence Tax	13	13	13	13	12	12	11	11	11	11	11	10	10	9	9	9	9	3
Net after Costs	968	968	969	965	913	879	870	862	846	832	804	774	751	722	713	713	713	254
Explo. & Dev. Deductions	3.6	2.4	1.2	1.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	20	34	25	18	13	13	13	11	9	6	4	3	3	3	7	9	6	4
Depreciation - Mill	30	52	37	26	19	19	19	17	13	9	7	5	5	5	10	13	9	7
Net after Depreciation	914	880	906	920	881	847	838	834	824	817	793	766	743	714	696	691	698	243
Depletion	173	173	173	172	163	157	155	154	151	148	143	138	134	129	128	128	128	46
Net after Depletion	741	707	733	748	718	689	683	680	674	669	650	628	609	585	568	563	570	197
Colorado State Tax @ 5%	37	35	37	37	36	34	34	34	34	33	32	31	30	29	28.4	28	29	10
Federal Taxable Income	704	672	697	711	682	655	649	646	640	635	617	597	579	556	539	535	542	187
Federal Income Tax @ 35%	247	235	244	249	239	229	227	226	224	222	216	209	203	194	189	187	190	65
Alt. Minimum Taxable Income	863	878	884	887	841	808	802	789	768	757	748	735	713	685	669	665	667	231
Minimum Tax @ 20%	173	176	177	177	168	162	160	158	154	151	150	147	143	137	134	133	133	46
Federal Income Tax	247	235	244	249	239	229	227	226	224	222	216	209	203	194	189	187	190	65
Net Profit	458	437	453	462	443	426	422	420	416	413	401	388	376	361	351	348	352	121
Explo. & Dev. Deductions	3.6	2.4	1.2	1.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	20	34	25	18	13	13	13	11	9	6	4	3	3	3	7	9	6	4
Depreciation - Mill	30	52	37	26	19	19	19	17	13	9	7	5	5	5	10	13	9	7
Depletion	173	173	173	172	163	157	155	154	151	148	143	138	134	129	128	128	128	46
Operating Cash Flow	684	698	689	679	638	615	609	602	589	576	556	534	518	498	495	498	495	178
Capital Expeditures	0	0	0	0	0	0	0	87.8	0	0	0	0	0	0	87.8	0	0	0
Net Cash Flow	684	698	689	679	638	615	609	514	589	576	556	534	518	498	408	498	495	178
Net Present Value	1882																	

9.2 Determination of Optimum Mine, Mill and Refinery Capacities

The cash flow analysis presented in the previous section for two case studies is performed on the same deposits for different mining, milling and refining capacities. The results obtained for each analysis conducted are different, because of the change in capacities. These results are given in Table 9.21 and 9.22 for one and two mineral cases. These results are depicting very obviously that as we increase the capacities, the capital costs increase but the operating costs are subject to decrease. Also, there is an increase in the net present value with an increase in the capacities.

In Table 9.21, the net present value for mine and mill capacities of 35 and 20 millions respectively has a significant difference from the prior two cases. This greater difference arises from the increase in refining capacity. The increase in refining capacity increases the tons of product produced and hence the revenues. Similarly, with the increase in all of three capacities, the life of deposit decreased, and it can be observed in the production cash flow table for this case that equipment is replaced only twice in the mine life rather than three times in the previous two cases. Therefore, this factor also has the greater impact in increasing the net present value. The analysis conducted for both one and two minerals cases in this regard can be interpreted in this way by using the tables given in this chapter, and in the appendix A.

The capital and operating costs given in both Table 9.21 and 9.22 are obtained by using O'Hara cost estimator. The net present values are obtained by discounting back the pre-production and production cash flows obtained in each case at a discount rate of 15%. The outputs of the program OPTI1.FOR and cash flow analysis for each of the case in Table 9.21 are given in appendix B. The outputs of the program OPTI2.FOR and cash flow analysis for each of the case in Table 9.22 are given in appendix B. The case studies given in the previous section of the chapter are also one of the cases given in Table 9.21 and 9.22.

Mine Capacity (MT)	Mill capacity (MT)	Refining Capacity (1000's T)	Capital Cost (MT)	Mine Operating Cost ($/ton)	Mill Operating Cost ($/ton)	Net Present value ($M)
20	10	90	250	1.5	4.5	-6
30	15	100	327	1.25	3.65	14
35	20	200	383	1.19	3.19	93
35	30	200	451	1.19	2.66	94
50	30	200	497	1.05	2.66	125
60	30	250	524	0.97	2.66	158

Table 9.21: Cash Flow Analysis For One Mineral Case

Mine Capacity (MT)	Mill capacity (MT)	Refinery1 Capacity (1000's T)	Refinery2 Capacity (1000's oz)	Capital Cost ($M)	Mine Operating Cost ($/ton)	Mill Operating Cost ($/ton)	NPV ($M)
20	10	100	900	268	1.5	4.5	1328
30	15	unlimited	900	351	1.3	3.5	1882
40	25	unlimited	900	463	1.15	2.9	2704
60	40	unlimited	1000	624	0.99	2.34	2670

Table 9.22: Cash Flow Analysis For Two Mineral Case

10. CONCLUSIONS & RECOMMENDATIONS

10.1 Conclusions

The primary objective of a mining operation is to maximize the net present value. The cutoff grade policy has a very significant effect on this most important economic parameter. Therefore, the technique to find this policy should be capable of maximizing this function. It is quite clear from the study that declining cutoff grades policy has the feature of maximizing net present value.

The important conclusion of the study is that decisions about cutoff grades, which are the decisions of major economic significance, cannot be taken by a simple economic formula which equates marginal revenue to marginal cost. In fact, the optimum cutoff grade is influenced by the economics of the present value, the capacities of several stages in the mining operation, and the grade distribution of the deposit. These three influences can interact in a complex way with the result that cutoff grade changes, sometimes widely, during the life of the operation.

Four computer programs have been developed in this study. They are not expensive with respect to computer memory storage, and they are fast in the execution time. However, the programs developed for two minerals case are slower than those of one mineral case. This is because of the complex and repetitive calculations involved in the two mineral case. However, all of these programs provide the opportunity of analyzing a large number of alternatives.

The case studies in chapter 5, are giving promising results. The detailed cash flow analysis is helpful in proving further that by using the declining cutoff grade policies, it is possible to maximize the net present value even by incorporating the capital costs incurred as the initial investment.

It has been realized that the stockpiles should always be considered in open pit mine planning, specially in the two mineral deposits. Because, the interaction of one mineral on the other is so significant that the provision of stockpiles will help in maximizing the net present value by saving the major portion of ore going to the waste dumps. However, the contribution of the stockpile to the net present value is dependent upon the particular case. It depends specially upon the spread between the highest and the lowest cutoff grades in the project cutoff grade policy. If the spread is significant then stockpile will be the potential component to be considered in the project.

The handling of stockpiles, as a separate or new push-back after the depletion of reserves provide an easy operation. Because, this does not require blending of material from the mine and stockpile. Therefore, it also reduces the re-handling cost of stockpile.

In addition to the economic reasons for using a stockpile, 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 of a larger slope angle by taking into account that if any thing occurs in the mine, we have mineral in the stock to feed the mill. Also we can reduce the number of main access roads, taking into account the prior considerations.

Although, this study is specific to the open pit mining operations. But, its application to the underground mining is also possible. Because, the underground mining can be divided into three major stages. For example, the development can included in mining, because, it is the process of creating an access to the mineralized body. The stoping, tramming and hoisting can be considered as treatment stage because these operations involve the handling of ore mostly. The marketing stage is same as that of the open pit mining operation.

10.2 Recommendations

This study is confined to the two mineral deposits. Therefore, most interesting point of the future research is to develop an algorithm for more than two minerals in the deposit.

The grid search technique applied in this study is although robust for the computer application but it is crude. Therefore, the introduction to of a simple and more reliable technique as in one mineral case will be a greater contribution to industry for cutoff grade optimization.

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Appendix A
Cash Flow Analysis of Case Studies
(Chapter 9)

CASH FLOW ANALYSIS FOR CASE STUDIES

ONE MINERAL CASE

Depreciation Calculations:

Initial Investments:
Assumption: MACRS System, Equipment placed into service in year 5.

Table 1: Mine Equipment

Project Year	Deprec. Year	Basis ($M)	MACRS %/100	MACRS Deductions ($M)	AMTI %/100	AMTI Deduction ($M)
5	1	204.3	0.1429	**29**	0.075	**15**
6	2	204.3	0.2449	**50**	0.1388	**28**
7	3	204.3	0.1749	**36**	0.1179	**24**
8	4	204.3	0.1249	**26**	0.1002	**20**
9	5	204.3	0.0893	**18**	0.0874	**18**
10	6	204.3	0.0892	**18**	0.0874	**18**
11	7	204.3	0.0893	**18**	0.0874	**18**
12	8	204.3	0.0446	**9**	0.0874	**18**
13	9	204.3			0.0874	**18**
14	10	204.3			0.0874	**18**
15	11	204.3			0.0437	**9**

TABLE 2: Mill Equipment

Project Year	Depre. Year	Basis ($M)	MACRS %/100	MACRS Deductions ($M)	AMTI %/100	AMTI Deduction ($M)
5	1	292.7	0.143	**42**	0.075	**22**
6	2	292.7	0.245	**72**	0.139	**41**
7	3	292.7	0.175	**51**	0.118	**35**
8	4	292.7	0.125	**37**	0.1	**29**
9	5	292.7	0.089	**26**	0.087	**26**
10	6	292.7	0.089	**26**	0.087	**26**
11	7	292.7	0.089	**26**	0.087	**26**
12	8	292.7	0.045	**13**	0.087	**26**
13	9	292.7			0.087	**26**
14	10	292.7			0.087	**26**
15	11	292.7			0.044	**13**

Replacements:

25% of the Capital costs will be incurred in year 12 for equipment replacement. The equipment will be placed into service in the same year.

Replacement Expenditures:

Mine	.25 * 204.3	= 51.08
Mill	.25 * 292.7	= 73.18
Total		124.25

Table 3: Mine equipment:

Project Year	Deprec. Year	Basis ($M)	MACRS %/100	MACRS Deductions ($M)	AMTI %/100	AMTI Deduction ($M)
5	1	51.08	0.1429	**7**	0.075	**4**
6	2	51.08	0.2449	**13**	0.1388	**7**
7	3	51.08	0.1749	**9**	0.1179	**6**
8	4	51.08	0.1249	**6**	0.1002	**5**
9	5	51.08	0.0893	**5**	0.0874	**4**
10	6	51.08	0.0892	**5**	0.0874	**4**
11	7	51.08	0.0893	**5**	0.0874	**4**
12	8	51.08	0.0446	**2**	0.0874	**4**
13	9	51.08			0.0874	**4**
14	10	51.08			0.0874	**4**
15	11	51.08			0.0437	**2**

Table 4:Mill Equipment

Project Year	Deprec. Year	Basis ($M)	MACRS %/100	MACRS Deductions ($M)	AMTI %/100	AMTI Deduction ($M)
5	1	73.18	0.1429	**10**	0.075	**5**
6	2	73.18	0.2449	**18**	0.1388	**10**
7	3	73.18	0.1749	**13**	0.1179	**9**
8	4	73.18	0.1249	**9**	0.1002	**7**
9	5	73.18	0.0893	**7**	0.0874	**6**
10	6	73.18	0.0892	**7**	0.0874	**6**
11	7	73.18	0.0893	**7**	0.0874	**6**
12	8	73.18	0.0446	**3**	0.0874	**6**
13	9	73.18			0.0874	**6**
14	10	73.18			0.0874	**6**
15	11	73.18			0.0437	**3**

Table 5: Depreciation Deduction Summary - Mine ($1,000,000)

Project Year	Mine equipment	Replacements Year 12	Total
5	29		**29**
6	50		**50**
7	36		**36**
8	26		**26**
9	18		**18**
10	18		**18**
11	18		**18**
12	9	7	**16**
13		13	**13**
14		9	**9**
15		6	**6**
16		5	**5**
17		5	**5**
18		5	**5**

Table 6: AMTI Depreciation Deduction Summary - Mine ($1,000,000)

Project Year	Mine equipment	Replacements Year 12	Total
5	15		**15**
6	28		**28**
7	24		**24**
8	20		**20**
9	18		**18**
10	18		**18**
11	18		**18**
12	18	4	**22**
13	18	7	**25**
14	18	6	**24**
15	9	5	**14**
16		4	**4**
17		4	**4**
18		4	**4**

Table 7: Depreciation Deduction Summary - Mill ($1,000,000)

Project Year	Mine equipment	Replacements Year 12	Total
5	42		**42**
6	72		**72**
7	51		**51**
8	37		**37**
9	26		**26**
10	26		**26**
11	26		**26**
12	13	10	**24**
13		18	**18**
14		13	**13**
15		9	**9**
16		7	**7**
17		7	**7**
18		7	**7**

Table 8: AMTI Depreciation Deduction Summary - Mill ($1,000,000)

Project Year	Mine equipment	Replacements Year 12	Total
5	22		**22**
6	41		**41**
7	35		**35**
8	29		**29**
9	26		**26**
10	26		**26**
11	26		**26**
12	26	5	**31**
13	26	10	**36**
14	26	9	**34**
15	13	7	**20**
16		6	**6**
17		6	**6**
18		6	**6**

Exploration & Develpoment Tax Calculations

Table 9: Exploration & Development Tax Savings - Pre-Production ($1,000,000)

Year	1	2	3	4	5	6	7	8
Exploration Expenditure	15	15						
Allowable Expense Deduction @ 70%	10.5	10.5						
30% Reduction Amount	4.5	4.5						
Year 1								
30% Reduction Deduction Rate	0.20	0.20	0.20	0.20	0.20			
30% Reduction Deduction	0.9	0.9	0.9	0.9	0.9			
Year 2								
30% Reduction Deduction Rate		0.20	0.20	0.20	0.20	0.20		
30% Reduction Deduction		0.9	0.9	0.9	0.9	0.9		
Total Exploration Deduction	11.4	12.3	1.8	1.8	1.8	0.9		
Exploration Tax Savings @ 35%	4.0	4.3	0.6	0.6	0.6	0.3		
Development Expenditures				15				
Allowable Expense Deduction @ 70%				10.5				
30% Reduction Amount				4.5				
Year 4								
30% Reduction Deduction Rate				0.20	0.20	0.20	0.20	0.20
30% Reduction Deduction				0.9	0.9	0.9	0.9	0.9
Total Development Deduction				11.4	0.9	0.9	0.9	0.9
Development Tax Savings @ 35%				4.0	0.3	0.3	0.3	0.3
Exploration & Development Deduct. Carried to Production Cash Flows					2.7	1.8	0.9	0.9

Table 10 : Exploration & Development Tax Savings - AMTI ($1,000,000

Year	1	2	3	4	5	6	7	8	9	10	11	12	13
Exploration Expenditures													
Year 1	15												
Straight Line Rate	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10			
Deduction	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5			
Year 2		15											
Straight Line Rate		0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10		
Deduction		1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5		
Development Expenditures													
Year 4				15									
Straight Line Rate				0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Deduction				1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Total AMTI Explo. & Dev.	**1.5**	**3**	**3**	**4.5**	**4.5**	**4.5**	**4.5**	**4.5**	**4.5**	**4.5**	**3**	**1.5**	**1.5**

Property Tax Calculations:

Book Value of Mine & Mill Equipment:
Initial Investments:
Assumption: Straight Line Depreciation

Table 11- Mine equipment - 10 Year Life

Project Year	Deprec. Year	Basis ($M)	Rate	Deduction ($M)	Book value ($M)
4					**204.3**
5	1	204.3	0.10	20.43	**183.87**
6	2	204.3	0.10	20.43	**163.44**
7	3	204.3	0.10	20.43	**143.01**
8	4	204.3	0.10	20.43	**122.58**
9	5	204.3	0.10	20.43	**102.15**
10	6	204.3	0.10	20.43	**81.72**
11	7	204.3	0.10	20.43	**61.29**
12	8	204.3	0.10	20.43	**40.86**
13	9	204.3	0.10	20.43	**20.43**
14	10	204.3	0.10	20.43	**0**

Table 12- Mill Equipment - 10 Year Life

Project Year	Deprec. Year	Basis ($M)	Rate	Deduction ($M)	Book value ($M)
4					**292.7**
5	1	292.7	0.10	29.27	**263.43**
6	2	292.7	0.10	29.27	**234.16**
7	3	292.7	0.10	29.27	**204.89**
8	4	292.7	0.10	29.27	**175.62**
9	5	292.7	0.10	29.27	**146.35**
10	6	292.7	0.10	29.27	**117.08**
11	7	292.7	0.10	29.27	**87.81**
12	8	292.7	0.10	29.27	**58.54**
13	9	292.7	0.10	29.27	**29.27**
14	10	292.7	0.10	29.27	**0**

Replacements:

Table 13: Mine Equipment - 10 Year life

Project Year	Deprec. Year	Basis ($M)	Rate	Deduction ($M)	Book value ($M)
4					**51.08**
5	1	51.08	0.10	5.108	**45.972**
6	2	51.08	0.10	5.108	**40.864**
7	3	51.08	0.10	5.108	**35.756**
8	4	51.08	0.10	5.108	**30.648**
9	5	51.08	0.10	5.108	**25.54**
10	6	51.08	0.10	5.108	**20.432**
11	7	51.08	0.10	5.108	**15.324**
12	8	51.08	0.10	5.108	**10.216**
13	9	51.08	0.10	5.108	**5.108**
14	10	51.08	0.10	5.108	**0**

Table 14: Mill Equipment - 10 Year Life

Project Year	Deprec. Year	Basis ($M)	Rate	Deduction ($M)	Book value ($M)
4					**73.18**
5	1	73.18	0.10	7.318	**65.862**
6	2	73.18	0.10	7.318	**58.544**
7	3	73.18	0.10	7.318	**51.226**
8	4	73.18	0.10	7.318	**43.908**
9	5	73.18	0.10	7.318	**36.59**
10	6	73.18	0.10	7.318	**29.272**
11	7	73.18	0.10	7.318	**21.954**
12	8	73.18	0.10	7.318	**14.636**
13	9	73.18	0.10	7.318	**7.318**
14	10	73.18	0.10	7.318	**0**

Table 15: Book Value Calculation Summary - Mine ($1,000,000)

Project. year	Mine Equipment	Replacements year 12	Total
4	204		**204**
5	184		**184**
6	163		**163**
7	143		**143**
8	123		**123**
9	102		**102**
10	82		**82**
11	61		**61**
12	41	51	**92**
13	20	46	**66**
14	0	41	**41**
15		36	**36**
16		31	**31**
17		26	**26**
18		20	**20**

Table 16: Book Value Calculation Summary - Mine ($1,000,000)

Project. year	Mill Equipment	Replacements year 12	Total
4	293		**293**
5	263		**263**
6	234		**234**
7	205		**205**
8	176		**176**
9	146		**146**
10	117		**117**
11	88		**88**
12	59	73	**132**
13	29	66	**95**
14	0	59	**59**
15		51	**51**
16		44	**44**
17		37	**37**
18		29	**29**

Assessed Value Calculations:

Operating Cost Breakdown

Mining ($/ton)	1.05
Milling ($/ton)	2.66
Administration ($/ton)	0.4
Total	4.11

Net Smelter Return Calculations:

Payments:	
	646.8
Deductions:	
Smelter Charge	70
Price Adjustment	33
Net Smelter Return	543.8

Table 17: Assessed Value Of Concentrate Sales ($1,000,000)

Year	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Tons of Product	0.20	0.2	0.2	0.2	0.2	0.199	0.199	0.191	0.182	0.168	0.155	0.14	0.13	0.09
Tons of Concentrate	0.67	0.67	0.67	0.67	0.67	0.66	0.66	0.64	0.61	0.56	0.52	0.47	0.42	0.30
Gross Value of Product	363	363	363	363	363	361	361	346	330	305	281	256	227	163
Tons Processed	24.9	25.4	26.2	28.2	28.7	29.7	30	30	30	30	30	30	30	22.3
Less: Processing	66.23	67.56	69.69	75.01	76.34	79.00	79.80	79.80	79.80	79.80	79.80	79.80	79.80	59.32
General Proc. Cost														
Prorate Administration	7.14	7.28	7.51	8.09	8.23	8.52	8.60	8.60	8.60	8.60	8.60	8.60	8.60	6.40
Gross Proceeds	289	288	285	279	278	273	272	258	242	216	193	167	138	97
Less: Mining	26.15	26.67	27.51	29.61	30.14	31.19	31.50	31.50	31.50	31.50	31.50	31.50	31.50	23.42
General Mining. Cost														
Prorate Administration	2.82	2.88	2.97	3.19	3.25	3.36	3.40	3.40	3.40	3.40	3.40	3.40	3.40	2.52
Net Proceeds	260	258	255	247	245	239	237	223	207	181	158	132	103	71
25% of Gross Proceeds	72	72	71	70	69	68	68	64	60	54	48	42	35	24
Larger of Net or 25% Gross	260	258	255	247	245	239	237	223	207	181	158	132	103	71
Appraised Value	260	258	255	247	245	239	237	223	207	181	158	132	103	71
Percentage	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Assessed Value	**260**	**258**	**255**	**247**	**245**	**239**	**237**	**223**	**207**	**181**	**158**	**132**	**103**	**71**

Table 18: Property Tax ($1,000,000)

Year	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Mine:															
Book Value	204	184	163	143	123	102	82	61	92	66	41	36	31	26	20
Assessed Value @30%	61	55	49	43	37	31	25	18	28	20	12	11	9	8	4
Assessed Value of Rock Sales	0	260	258	255	247	245	239	237	223	207	181	158	132	103	71
Total Assessed Value	61	315	307	298	284	275	263	256	251	226	194	168	142	111	156
Property Tax @60 mils	4	19	18	18	17	17	16	15	15	14	12	10	8	7	9
Mill:															
Book Value	293	263	234	205	176	146	117	88	132	95	59	51	44	37	29
Assessed Value @30%	88	79	70	62	53	44	35	26	40	29	18	15	13	11	4
Property Tax @60 mils	5	5	4	4	3	3	2	2	2	2	1	1	1	1	0
Total Property Tax	9	24	23	22	20	19	18	17	17	15	13	11	9	7	10

Table 19: Severence Tax Calculation ($1,000,000)

Year	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Gross Value of Concentrate	362.5	362.5	362.5	362.5	362.5	360.7	361	346	330	305	281	255.6	226.6	163.1
Less: Processing	66	68	70	75	76	79	80	80	80	80	80	80	80	59
General Proc. Cost														
Prorate Administration	7	7	8	8	8	9	9	9	9	9	9	9	9	6
Gross Proceeds	289	288	285	279	278	273	272	258	242	216	193	167	138	97
less Ist 11,000,000	11	11	.11	11	11	11	11	11	11	11	11	11	11	12
taxable proceeds	278	277	274	268	267	262	261	247	231	205	182	156	127	85
Tax @ 2.25%	6	6	6	6	6	6	6	6	5	5	4	4	3	2
Ad valorem Tax credit														
Credit Limit @ 50%	3	3	3	3	3	3	3	3	3	2	2	2	1	1
Ad valorem Tax	24	23	22	20	19	18	17	17	15	13	11	9	7	10
Severence Tax	3	3	3	3	3	3	3	3	3	2	2	2	1	1

Table 20: Depletion Calculations ($1,000,000)

Year	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Revenue	362.5	362.5	362.5	362.5	362.5	361	361	346	330	305	281	256	227	163
Royalty @5%	18	18	18	18	18	18	18	17	16	15	14	13	11	8
Net after Royalty	344	344	344	344	344	343	343	329	313	289	267	243	215	155
Tons Mined	36	36	36	40	39	44	46	48	50	49	49	48	47	33
Operating Costs	38	38	38	41	41	46	49	51	53	52	51	50	49	34
Property Tax	19	18	18	17	17	16	15	15	14	12	10	8	7	9
Severence Tax	3	3	3	3	3	3	3	3	3	2	2	2	1	1
Net after Costs	284	285	285	283	284	278	276	261	245	224	203	183	158	111
Explo. & Dev. Deduc.	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0	0	0
Depreciation- Mine	29	50	36	26	18	18	18	16	13	9	6	5	5	5
Net after Depreciation (NAD)	253	233	248	256	266	260	258	245	232	215	197	178	153	106
State Tax @.0256 NAD	6	6	6	7	7	7	7	6	6	6	5	5	4	3
Net after State Tax	246	228	242	249	259	253	251	238	226	209	192	173	149	103
Depletion Basis	25	0	0	0	0	0	0	0	0	0	0	0	0	0
Reserves	600	564	528	492	452	413	369	323	275	225	176	127	79	33
Unit Depletion	0.04	0.00	0	0	0	0	0	0	0	0	0	0	0	0
Production	36	36	36	40	39	44	46	48	50	49	49	48	47	33
Cost Depletion	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Net after State Tax * 50%	123	114	121	125	129	127	126	119	113	105	96	87	75	51
Net after Royalty * 15%	52	52	52	52	52	51	51	49	47	43	40	36	32	23
Percentage Depletion	52	52	52	52	52	51	51	49	47	43	40	36	32	23
Initial recapture Balance	21													
Depletion Earned	52	52	52	52	52	51	51	49	47	43	40	36	32	23
Depletion Recaptured	21	0	0	0	0	0	0	0	0	0	0	0	0	0
Recapture Balance	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depletion Claimed	**52**	**52**	**52**	**52**	**52**	**51**	**51**	**49**	**47**	**43**	**40**	**36**	**32**	**23**
Initial balance = .7 * 30 = 21														

Table 21: Production Cash Flows ($1,000,000)

Year	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Revenues	362.5	362.5	362.5	362.5	362.5	361	361	346	330	305	281	256	227	163
Royalty @5%	18	18	18	18	18	18	18	17	16	15	14	13	11	8
Tons Mined	36	36	36	40	39	44	46	48	50	49	49	48	47	33
Tons Processed	24.9	25.4	26.2	28.2	28.7	29.7	30	30	30	30	30	30	30	22.3
Operating Cost	108	109	112	120	122	129	132	134	136	135	135	134	133	97
Property Tax	24	23	22	20	19	18	17	17	15	13	11	9	7	10
Severence Tax	3	3	3	3	3	3	3	3	3	2	2	2	1	1
Net after Costs	209	210	208	201	201	193	191	174	159	139	119	98	74	47
Explo. & Dev. Deductions	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	29	50	36	26	18	18	18	16	13	9	6	5	5	5
Depreciation - Mill	42	72	51	37	26	26	26	24	18	13	9	7	7	7
Net after Depreciation	136	86	120	137	157	149	147	134	128	117	104	86	62	35
Depletion	52	52	52	52	52	51	51	49	47	43	40	36	32	23
Net after Depletion	84	34	68	85	105	97	95	85	81	74	64	50	29	12
Colorado State Tax @ 5%	4	2	3	4	5	5	5	4	4	4	3	2	1	1
Federal Taxable Income	80	32	65	81	100	93	90	81	77	70	60	47	28	11
Federal Income Tax @ 35%	28	11	23	28	35	32	32	28	27	24	21	17	10	4
Alt. Minimum Taxable Income	142	138	145	147	151	143	142	119	96	81	85	89	66	40
Minimum Tax @ 20%	28	28	29	29	30	29	28	24	19	16	17	18	13	8
Federal Income Tax	28	28	29	29	35	32	32	28	27	24	21	18	13	8
Net Profit	51	5	36	52	65	60	59	53	50	45	39	29	15	3
Explo. & Dev. Deductions	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	29	50	36	26	18	18	18	16	13	9	6	5	5	5
Depreciation - Mill	42	72	51	37	26	26	26	24	18	13	9	7	7	7
Depletion	52	52	52	52	52	51	51	49	47	43	40	36	32	23
Operating Cash Flow	177	180	176	167	161	156	154	142	128	111	94	78	59	38
Capital Expeditures	0	0	0	0	0	0	0	124.3	0	0	0	0	0	0
Net Cash Flow	177	180	176	167	161	156	154	18	128	111	94	78	59	38
Net Present Value	124.6													

Table 22: Alternative Minimum Taxable Income Calculation ($1,000,000)

Year	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Revenues	362.5	362.5	362.5	362.5	362.5	361	361	346	330	305	281	256	227	163
Royalty @ 5%	18	18	18	18	18	18	18	17	16	15	14	13	11	8
Tons Mined	36	36	36	40	39	44	46	48	50	49	49	48	47	33
Tons Processed	24.9	25.4	26.2	28.2	28.7	29.7	30	30	30	30	30	30	30	22.3
Operating Cost	105	106	108	117	118	125	129	131	133	132	132	130	129	94
Property Tax	24	23	22	20	19	18	17	17	15	13	11	9	7	10
Severence Tax	3	3	3	3	3	3	3	3	3	2	2	2	1	1
Colorado State Tax @ 5%	4	2	3	4	5	5	5	4	4	4	3	2	1	1
Net after Costs	209	211	208	200	199	192	189	174	159	139	119	99	76	50
Explo. & Dev. Deductions	4.5	4.5	4.5	4.5	4.5	4.5	3	1.5	1.5	0	0	0	0	0
Depreciation - Mine	15	28	24	20	18	18	18	22	25	24	14	4	4	4
Depreciation - Mill	22	41	35	29	26	26	26	31	36	34	20	6	6	6
Net after Depreciation	167	138	145	147	151	143	142	119	96	81	85	89	66	40
Depletion Claimed	52	52	52	52	52	51	51	49	47	43	40	36	32	23
Adjusted Basis	25	0	0	0	0	0	0	0	0	0	0	0	0	0
Allowable Depletion	25	0	0	0	0	0	0	0	0	0	0	0	0	0
Alternatine Min. Tax. Income	142	138	145	147	151	143	142	119	96	81	85	89	66	40

Table 23: Pre-Production Cash Flows ($1,000,000)

Year	0	1	2	3	4
Property Payment	25	0	0	0	0
Explor. & Feas. Study	0	15	15	0	0
Preproduction Development	0	0	0	0	15
Mine Equipment	0	0	0	50	154.3
Mill Equipment	0	0	0	92	200.7
Property Tax	0	0	0	0	9
Total Capital Expenditures	-25	-15	-15	-142	-379
Tax Savings					
Explor. & Feas. Study	0	4.0	4.3	0.6	0.6
Preproduction Development	0	0	0	0	4
Property Tax	0	0	0	0	3.15
Total cash Generated	0	3.99	4.305	0.63	7.78
Net Cash Flow	-25	-11	-10.7	-141	-371

Table 24: Net Present Value Calculation ($1,000,000)

Year	Cash Flow	Discounted Cas Flow
0	-25	-25
1	-11	-10
2	-11	-8
3	-141	-93
4	-371	-212
5	177	88
6	180	78
7	176	66
8	167	55
9	161	46
10	156	39
11	154	33
12	17.6	3
13	128	21
14	111	16
15	94.4	12
16	78	8
17	59	5
18	38.4	3
NPV		**125**

TWO MINERALS CASE

Depreciation Calculations:

Initial Investments:
Assumption: MACRS SYSTEM, Equipment placed into service in year 5.

Table 1- Mine Equipment

Project Year	Deprec. Year	Basis ($M)	MACRS %/100	MACRS Deductions ($M)	AMTI %/100	AMTI Deduction ($M)
5	1	140.6	0.1429	**20**	0.075	**11**
6	2	140.6	0.2449	**34**	0.1388	**20**
7	3	140.6	0.1749	**25**	0.1179	**17**
8	4	140.6	0.1249	**18**	0.1002	**14**
9	5	140.6	0.0893	**13**	0.0874	**12**
10	6	140.6	0.0892	**13**	0.0874	**12**
11	7	140.6	0.0893	**13**	0.0874	**12**
12	8	140.6	0.0446	**6**	0.0874	**12**
13	9	140.6			0.0874	**12**
14	10	140.6			0.0874	**12**
15	11	140.6			0.0437	**6**

Table 2: Mill Equipment

Project Year	Deprec. Year	Basis ($M)	MACRS %/100	MACRS Deductions ($M)	AMTI %/100	AMTI Deduction ($M)
5	1	210.6	0.1429	**30**	0.075	**16**
6	2	210.6	0.2449	**52**	0.1388	**29**
7	3	210.6	0.1749	**37**	0.1179	**25**
8	4	210.6	0.1249	**26**	0.1002	**21**
9	5	210.6	0.0893	**19**	0.0874	**18**
10	6	210.6	0.0892	**19**	0.0874	**18**
11	7	210.6	0.0893	**19**	0.0874	**18**
12	8	210.6	0.0446	**9**	0.0874	**18**
13	9	210.6			0.0874	**18**
14	10	210.6			0.0874	**18**
15	11	210.6			0.0437	**9**

Replacements:

Replacement Expenditures:

Mine .25 * 140.6 = 35.15
Mill .25 * 210.6 = 52.65

Total **87.8**

Table 3: Mine Equipment

Project Year	Deprec. Year	Basis ($M)	MACRS %/100	MACRS Deductions ($M)	AMTI %/100	AMTI Deduction ($M)
5	1	35.15	0.1429	**5**	0.075	**3**
6	2	35.15	0.2449	**9**	0.1388	**5**
7	3	35.15	0.1749	**6**	0.1179	**4**
8	4	35.15	0.1249	**4**	0.1002	**4**
9	5	35.15	0.0893	**3**	0.0874	**3**
10	6	35.15	0.0892	**3**	0.0874	**3**
11	7	35.15	0.0893	**3**	0.0874	**3**
12	8	35.15	0.0446	**2**	0.0874	**3**
13	9	35.15			0.0874	**3**
14	10	35.15			0.0874	**3**
15	11	35.15			0.0437	**2**

Table 4: Mill Equipment

Project Year	Deprec. Year	Basis ($M)	MACRS %/100	MACRS Deductions ($M)	AMTI %/100	AMTI Deduction ($M)
5	1	52.65	0.1429	**8**	0.075	**4**
6	2	52.65	0.2449	**13**	0.1388	**7**
7	3	52.65	0.1749	**9**	0.1179	**6**
8	4	52.65	0.1249	**7**	0.1002	**5**
9	5	52.65	0.0893	**5**	0.0874	**5**
10	6	52.65	0.0892	**5**	0.0874	**5**
11	7	52.65	0.0893	**5**	0.0874	**5**
12	8	52.65	0.0446	**2**	0.0874	**5**
13	9	52.65			0.0874	**5**
14	10	52.65			0.0874	**5**
15	11	52.65			0.0437	**2**

Table 5: Depreciation Summary - Mine ($1,000,000)

Project year	Mine equipment	Replacement Year 12	Replacement Year 19	Total
5	20			**20**
6	34			**34**
7	25			**25**
8	18			**18**
9	13			**13**
10	13			**13**
11	13			**13**
12	6	5		**11**
13		9		**9**
14		6		**6**
15		4		**4**
16		3		**3**
17		3		**3**
18		3		**3**
19		2	5	**7**
20			9	**9**
21			6	**6**
22			4	**4**

Table 6: AMTI - Depreciation Summary - Mine ($1,000,000)

Project year	Mine equipment	Replacement Year 12	Replacement Year 19	Total
5	11			**11**
6	20			**20**
7	17			**17**
8	14			**14**
9	12			**12**
10	12			**12**
11	12			**12**
12	12	3		**15**
13	12	5		**17**
14	12	4		**16**
15	6	4		**10**
16		3		**3**
17		3		**3**
18		3		**3**
19		3	3	**6**
20		3	5	**8**
21		3	4	**7**
22		2	4	**5**

Table 7: Depreciation Summary - Mill ($1,000,000)

Project year	Mine equipment	Replacement Year 12	Replacement Year 19	Total
5	30			**30**
6	52			**52**
7	37			**37**
8	26			**26**
9	19			**19**
10	19			**19**
11	19			**19**
12	9	8		**17**
13		13		**13**
14		9		**9**
15		7		**7**
16		5		**5**
17		5		**5**
18		5		**5**
19		2	8	**10**
20			13	**13**
21			9	**9**
22			7	**7**

Table 8: AMTI- Depreciation Summary - Mill ($1,000,000)

Project year	Mine equipment	Replacement Year 12	Replacement Year 19	Total
5	16			**16**
6	29			**29**
7	25			**25**
8	21			**21**
9	18			**18**
10	18			**18**
11	18			**18**
12	18	4		**22**
13	18	7		**26**
14	18	6		**25**
15	9	5		**14**
16		5		**5**
17		5		**5**
18		5		**5**
19		5	4	**9**
20		5	7	**12**
21		5	6	**11**
22		2	5	**8**

Exploration & Development Tax calculations:

Table 9:Exploration & development Tax Savings - Pre-Production ($1,000,000)

Year	1	2	3	4	5	6	7	8
Exploration Expenditure	20	20						
Allowable Expense Deduction @ 70%	14	14						
30% Reduction Amount	6	6						
Year 1								
30% Reduction Deduction Rate	0.20	0.20	0.20	0.20	0.20			
30% Reduction Deduction	1.2	1.2	1.2	1.2	1.2			
Year 2								
30% Reduction Deduction Rate		0.20	0.20	0.20	0.20	0.20		
30% Reduction Deduction		1.2	1.2	1.2	1.2	1.2		
Total Exploration Deduction	15.2	16.4	2.4	2.4	2.4	1.2		
Exploration Tax Savings @ 35%	5.3	5.7	0.8	0.8	0.8	0.4		
Development Expenditures				20				
Allowable Expense Deduction @ 70%				14				
30% Reduction Amount				6				
Year 4								
30% Reduction Deduction Rate				0.20	0.20	0.20	0.20	0.20
30% Reduction Deduction				1.2	1.2	1.2	1.2	1.2
Total Development Deduction				15.2	1.2	1.2	1.2	1.2
Development Tax Savings @ 35%				5.3				
Exploration & Development Deductions Carried to Production Cash Flows					**3.6**	**2.4**	**1.2**	**1.2**

Table 10: Exploration & Development Tax Savings - AMTI ($1,000,000)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13
Exploration Expenditures													
Year 1	20												
Straight Line Rate	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10			
Deduction	2	2	2	2	2	2	2	2	2	2			
Year 2		20											
Straight Line Rate		0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10		
Deduction		2	2	2	2	2	2	2	2	2	2		
Development Expenditures													
Year 4				20									
Straight Line Rate				0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Deduction				2	2	2	2	2	2	2	2	2	2
Total AMTI Explo. & Dev.	**2**	**4**	**4**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**4**	**2**	**2**

Property Tax Calculations:

Book Value of Mine & Mill Equipment:
Initial Investments:
Assumption - Straight Line Depreciation

Table 11: Mine Equipment - 10 Year Life

Project Year	Deprec. Year	Basis ($M)	Rate	Deduction ($M)	Book value ($M)
4					**140.6**
5	1	140.6	0.10	14.06	**126.54**
6	2	140.6	0.10	14.06	**112.48**
7	3	140.6	0.10	14.06	**98.42**
8	4	140.6	0.10	14.06	**84.36**
9	5	140.6	0.10	14.06	**70.3**
10	6	140.6	0.10	14.06	**56.24**
11	7	140.6	0.10	14.06	**42.18**
12	8	140.6	0.10	14.06	**28.12**
13	9	140.6	0.10	14.06	**14.06**
14	10	140.6	0.10	14.06	**0**

Table 12: Mill Equipment - 10 Year Life

Project Year	Deprec. Year	Basis ($M)	Rate	Deduction ($M)	Book value ($M)
4					**210.6**
5	1	210.6	0.10	21.06	**189.54**
6	2	210.6	0.10	21.06	**168.48**
7	3	210.6	0.10	21.06	**147.42**
8	4	210.6	0.10	21.06	**126.36**
9	5	210.6	0.10	21.06	**105.3**
10	6	210.6	0.10	21.06	**84.24**
11	7	210.6	0.10	21.06	**63.18**
12	8	210.6	0.10	21.06	**42.12**
13	9	210.6	0.10	21.06	**21.06**
14	10	210.6	0.10	21.06	**0**

Replacements:

Table 13: Mine Equipment - 10 Year Life

Project Year	Deprec. Year	Basis ($M)	Rate	Deduction ($M)	Book value ($M)
4					**35.15**
5	1	35.15	0.10	3.515	**31.635**
6	2	35.15	0.10	3.515	**28.12**
7	3	35.15	0.10	3.515	**24.605**
8	4	35.15	0.10	3.515	**21.09**
9	5	35.15	0.10	3.515	**17.575**
10	6	35.15	0.10	3.515	**14.06**
11	7	35.15	0.10	3.515	**10.545**
12	8	35.15	0.10	3.515	**7.03**
13	9	35.15	0.10	3.515	**3.515**
14	10	35.15	0.10	3.515	**0**

Table 14: Mill Equipment - 10 Year Life

Project Year	Deprec. Year	Basis ($M)	Rate	Deduction ($M)	Book value ($M)
4					**52.65**
5	1	52.65	0.10	5.265	**47.385**
6	2	52.65	0.10	5.265	**42.12**
7	3	52.65	0.10	5.265	**36.855**
8	4	52.65	0.10	5.265	**31.59**
9	5	52.65	0.10	5.265	**26.325**
10	6	52.65	0.10	5.265	**21.06**
11	7	52.65	0.10	5.265	**15.795**
12	8	52.65	0.10	5.265	**10.53**
13	9	52.65	0.10	5.265	**5.265**
14	10	52.65	0.10	5.265	**0**

Table 15: Book Value Calculation Summary - Mine ($1,000,000)

Project Year	Mine Equipment	Replacement Year 12	Replacement Year 19	Total
4	141			**141**
5	127			**127**
6	112			**112**
7	98			**98**
8	84			**84**
9	70			**70**
10	56			**56**
11	42			**42**
12	28	35		**63**
13	14	32		**46**
14	0	28		**28**
15		25		**25**
16		21		**21**
17		18		**18**
18		14		**14**
19		11	35	**46**
20		7	32	**39**
21		4	28	**32**
22		0	25	**25**

Table 16: Book Value Calculation Summary - Mill ($1,000,000)

Project Year	Mine Equipment	Replacement Year 12	Replacement Year 19	Total
4	211			**211**
5	190			**190**
6	168			**168**
7	147			**147**
8	126			**126**
9	105			**105**
10	84			**84**
11	63			**63**
12	42	53		**95**
13	21	47		**68**
14	0	42		**42**
15		37		**37**
16		32		**32**
17		26		**26**
18		21		**21**
19		16	53	**68**
20		11	47	**58**
21		5	42	**47**
22		0	37	**37**

Assessed Value Calculation:

Table 17: Net Smelter Return

Year	5	6	7	8	9	10	11	12	13
Tons of Product1	0.106	0.106	0.106	0.103	0.103	0.103	0.097	0.092	0.087
Ounces of Product2	0.619	0.619	0.619	0.619	0.58	0.555	0.555	0.555	0.548
Tons of Product2	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05
Concentrate Grade of Product2	6E+00	6E+00	6E+00	6E+00	6E+00	5E+00	6E+00	6E+00	6E+00
Payments:									
Product1 (Copper)	646.8	646.8	646.8	646.8	646.8	646.8	646.8	646.8	646.8
Product2 (Gold)	2093.67	2093.67	2093.67	2155.07	2018.38	1930.76	2051.08	2163.34	2259.45
Deductions:									
Smelter Charge	70	70	70	70	70	70	70	70	70
Price Adjustments	33	33	33	33	33	33	33	33	33
Net Smelter Return	2637.47	2637.47	2637.47	2698.87	2562.18	2474.56	2594.88	2707.14	2803.25

Table 17 Cintinued.

Year	14	15	16	17	18	19	20	21	22
Tons of Product1	0.082	0.081	0.081	0.079	0.078	0.078	0.078	0.078	0.028
Ounces of Product2	0.543	0.524	0.501	0.486	0.465	0.459	0.459	0.459	0.165
Tons of Product2	2E-05	2E-05	2E-05	2E-05	1E-05	1E-05	1E-05	1E-05	5E-06
Concentrate Grade of Product2	7E+00	6E+00	6E+00	6E+00	6E+00	6E+00	6E+00	6E+00	6E+00
Payments:									
Product1 (Copper)	646.8	646.8	646.8	646.8	646.8	646.8	646.8	646.8	646.8
Product2 (Gold)	2376.09	2320.92	2218.42	2206.4	2137.68	2109.91	2109.91	2109.91	2112.88
Deductions:									
Smelter Charge	70	70	70	70	70	70	70	70	70
Price Adjustments	33	33	33	33	33	33	33	33	33
Net Smelter Return	2919.89	2864.72	2762.22	2750.2	2681.48	2653.71	2653.71	2653.71	2656.68

Table 18: Assessed Value of Concentrate sales ($1,000,000)

Operating Cost Breakdown	
Mining ($/ton)	1.26
Milling ($/ton)	3.71
Administration ($/ton)	0.35
Total	5.15

Year	5	6	7	8	9	10	11	12	13
Tons of Product1	0.106	0.106	0.106	0.103	0.103	0.103	0.097	0.092	0.087
ounces of Product2	0.619	0.619	0.619	0.619	0.58	0.555	0.555	0.555	0.548
Tons of Product2	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05
Concentrate Grade of Product2	6E+00	6E+00	6E+00	6E+00	6E+00	5E+00	6E+00	6E+00	6E+00
Tons of Concentrate	5E-01	5E-01	5E-01	4E-01	4E-01	4E-01	4E-01	4E-01	4E-01
Net Smelter Return	3E+03	3E+03	3E+03	3E+03	3E+03	2E+03	3E+03	3E+03	3E+03
Tons Processed	15	15	15	15	15	15	15	15	15
Gross Value of Concentrate	1211.48	1211.48	1211.48	1204.6	1143.59	1104.48	1090.71	1079.24	1056.83
Less: Processing	55.65	55.65	55.65	55.65	55.65	55.65	55.65	55.65	55.65
General Proc. Cost									
Prorate Administration	3.919	3.919	3.919	3.919	3.919	3.919	3.919	3.919	3.919
Gross Proceeds	1152	1152	1152	1145	1084	1045	1031	1020	997
Less: Mining	18.90	18.90	18.90	18.90	18.90	18.90	18.90	18.90	18.90
General Mining. Cost									
Prorate Administration	1.331	1.331	1.331	1.331	1.331	1.331	1.331	1.331	1.331
Net Proceeds	1131.7	1131.7	1131.7	1124.8	1063.8	1024.7	1010.9	999.4	977.0
25% of Gross Proceeds	288.0	288.0	288.0	286.3	271.0	261.2	257.8	254.9	249.3
Larger of Net or 25% Gross	1131.7	1131.7	1131.7	1124.8	1063.8	1024.7	1010.9	999.4	977.0
Appraised Value	1131.7	1131.7	1131.7	1124.8	1063.8	1024.7	1010.9	999.4	977.0
Percentage	100	100	100	100	100	100	100	100	100
Assessed Value	1132	1132	1132	1125	1064	1025	1011	999	977

Table 18 continued

Year	14	15	16	17	18	19	20	21	22
Tons of Product1	0.082	0.081	0.081	0.079	0.078	0.078	0.078	0.078	0.028
ounces of Product2	0.543	0.524	0.501	0.486	0.465	0.459	0.459	0.459	0.165
Tons of Product2	2E-05	2E-05	2E-05	2E-05	1E-05	1E-05	1E-05	1E-05	5E-06
Concentrate Grade of Product2	7E+00	6E+00	6E+00	6E+00	6E+00	6E+00	6E+00	6E+00	6E+00
Tons of Concentrate	4E-01	4E-01	4E-01	3E-01	3E-01	3E-01	3E-01	3E-01	1E-01
Net Smelter Return	3E+03	3E+03	3E+03	3E+03	3E+03	3E+03	3E+03	3E+03	3E+03
Tons Processed	15	15	15	15	15	15	15	15	5.37
Gross Value of Concentrate	1037.53	1005.52	969.538	941.485	906.34	896.954	896.954	896.954	322.344
Less: Processing	55.65	55.65	55.65	55.65	55.65	55.65	55.65	55.65	19.92
General Proc. Cost									
Prorate Administration	3.919	3.919	3.919	3.919	3.919	3.919	3.919	3.919	1.403
Gross Proceeds	978	946	910	882	847	837	837	837	301
Less: Mining	18.90	18.90	18.90	18.90	18.90	18.90	18.90	18.90	6.77
General Mining. Cost									
Prorate Administration	1.331	1.331	1.331	1.331	1.331	1.331	1.331	1.331	0.476
Net Proceeds	957.7	925.7	889.7	861.7	826.5	817.2	817.2	817.2	293.8
25% of Gross Proceeds	244.5	236.5	227.5	220.5	211.7	209.3	209.3	209.3	75.3
Larger of Net or 25% Gross	957.7	925.7	889.7	861.7	826.5	817.2	817.2	817.2	293.8
Appraised Value	957.7	925.7	889.7	861.7	826.5	817.2	817.2	817.2	293.8
Percentage	100	100	100	100	100	100	100	100	100
Assessed Value	958	926	890	862	827	817	817	817	294

Table 19: Property Tax - ($1,000,000)

Year	4	5	6	7	8	9	10	11	12
Mine:									
Book Value	141	127	112	98	84	70	56	42	63
Assessed Value @ 30%	42	38	34	29	25	21	17	13	19
Assessed Value of Rock Sales	0	1132	1132	1132	1125	1064	1025	1011	999
Total Assessed Value	42	1170	1165	1161	1150	1085	1041	1024	1018
Property Tax @ 60 mils	3	70	70	70	69	65	62	61	61
Mill:									
Book Value	211	190	168	147	126	105	84	63	95
Assessed Value @ 30%	63	57	50	44	38	32	25	19	29
Property Tax @ 60 mils	4	3	3	3	2	2	2	1	2
Total Property Tax	6	74	73	72	71	67	64	63	63

Table 19 continued.

Year	13	14	15	16	17	18	19	20	21	22
Mine:										
Book Value	46	28	25	21	18	14	46	39	32	25
Assessed Value @ 30%	14	8	8	6	5	4	14	12	10	8
Assessed Value of Rock Sales	977	958	926	890	862	827	817	817	817	294
Total Assessed Value	991	966	933	896	867	831	831	829	827	301
Property Tax @ 60 mils	59	58	56	54	52	50	50	50	50	18
Mill:										
Book Value	68	42	37	32	26	21	68	58	47	37
Assessed Value @ 30%	20	13	11	10	8	6	20	17	14	11
Property Tax @ 60 mils	1	1	1	1	0	0	1	1	1	1
Total Property Tax	61	59	57	54	52	50	51	51	50	19

Table 20 : Severence Tax - ($1,000,000)

Year	5	6	7	8	9	10	11	12	13
Gross Value of Concentrate	1211	1211	1211	1205	1144	1104	1091	1079	1057
Less: Processing	56	56	56	56	56	56	56	56	56
General Proc. Cost									
Prorate Administration	4	4	4	4	4	4	4	4	4
Gross Proceeds	1152	1152	1152	1145	1084	1045	1031	1020	997
less Ist 11,000,000	11	11	11	11	11	11	11	11	11
taxable proceeds	1141	1141	1141	1134	1073	1034	1020	1009	986
Tax @ 2.25%	26	26	26	26	24	23	23	23	22
Ad valorem Tax credit									
Credit Limit @ 50%	13	13	13	13	12	12	11	11	11
Ad valorem Tax	74	73	72	71	67	64	63	63	61
Severence Tax	13	13	13	13	12	12	11	11	11

Table 20 continued.

Year	14	15	16	17	18	19	20	21	22
Gross Value of Concentrate	1038	1006	970	941	906	897	897	897	322
Less: Processing	56	56	56	56	56	56	56	56	20
General Proc. Cost									
Prorate Administration	4	4	4	4	4	4	4	4	1
Gross Proceeds	978	946	910	882	847	837	837	837	301
less Ist 11,000,000	11	11	11	11	11	11	11	11	11
taxable proceeds	967	935	899	871	836	826	826	826	290
Tax @ 2.25%	22	21	20	20	19	19	19	19	7
Ad valorem Tax credit									
Credit Limit @ 50%	11	11	10	10	9	9	9	9	3
Ad valorem Tax	59	57	54	52	50	51	51	50	19
Severence Tax	11	11	10	10	9	9	9	9	3

Table 21 : Depletion Calculation - ($1,000,000)

Year	5	6	7	8	9	10	11	12	13
Revenue	1211	1211	1211	1205	1144	1104	1091	1079	1057
Royalty @ 5%	61	61	61	60	57	55	55	54	53
Net after Royalty	1151	1151	1151	1144	1086	1049	1036	1025	1004
Tons Mined	30	30	30	29	28	28	26	24	21
Operating Costs	38	38	38	36	35	36	33	30	27
Property Tax	70	70	70	69	65	62	61	61	59
Severence Tax	13	13	13	13	12	12	11	11	11
Net after Costs	1030	1031	1031	1026	974	939	931	923	907
Explo. & Dev. Deduc.	3.6	2.4	1.2	1.2	0	0	0	0	0
Depreciation- Mine	20	34	25	18	13	13	13	11	9
Net after Depreciation (NAD)	1007	994	1005	1007	961	926	918	912	898
State Tax @ .0256 NAD	26	25	26	26	25	24	23	23	23
Net after State Tax	981	969	979	981	936	903	894	889	875
Depletion Basis	35	0	0	0	0	0	0	0	0
Reserves	390	360	330	300	272	244	215	189	166
Unit Depletion	0.09	0.00	0	0	0	0	0	0	0
Production	30	30	30	29	28	28	26	24	21
Cost Depletion	3	0	0	0	0	0	0	0	0
Net after State Tax * 50%	490	484	489	491	468	451	447	444	437
Net after Royalty * 15%	173	173	173	172	163	157	155	154	151
Percentage Depletion	173	173	173	172	163	157	155	154	151
Initial recapture Balance	28								
Depletion Earned	173	173	173	172	163	157	155	154	151
Depletion Recaptured	28	0	0	0	0	0	0	0	0
Recapture Balance	0	0	0	0	0	0	0	0	0
Depletion Claimed	**173**	**173**	**173**	**172**	**163**	**157**	**155**	**154**	**151**
Initial balance = .7 * 40 = 28									

Table 21 continued.

Year	14	15	16	17	18	19	20	21	22
Revenue	1038	1006	969.5	941.5	906.3	897	897	897	322.3
Royalty @ 5%	52	50	48	47	45	45	45	45	16
Net after Royalty	986	955	921	894	861	852	852	852	306
Tons Mined	20	20	18	17	16	16	16	16	6
Operating Costs	25	25	23	22	20	20	20	20	7
Property Tax	58	56	54	52	50	50	50	50	18
Severence Tax	11	11	10	10	9	9	9	9	3
Net after Costs	892	864	834	811	782	773	773	773	278
Explo. & Dev. Deduc.	0	0	0	0	0	0	0	0	0
Depreciation- Mine	6	4	3	3	3	7	9	6	4
Net after Depreciation (NAD)	886	860	831	808	779	766	764	767	274
State Tax @ .0256 NAD	23	22	21	21	20	20	20	20	7
Net after State Tax	863	838	810	787	759	746	745	748	267
Depletion Basis	0	0	0	0	0	0	0	0	0
Reserves	144	125	105	87	69	53	37	22	6
Unit Depletion	0	0	0	0	0	0	0	0	0
Production	20	20	18	17	16	16	16	16	6
Cost Depletion	0	0	0	0	0	0	0	0	0
Net after State Tax * 50%	431	419	405	394	379	373	372	374	133
Net after Royalty * 15%	148	143	138	134	129	128	128	128	46
Percentage Depletion	148	143	138	134	129	128	128	128	46
Initial recapture Balance									
Depletion Earned	148	143	138	134	129	128	128	128	46
Depletion Recaptured	0	0	0	0	0	0	0	0	0
Recapture Balance	0	0	0	0	0	0	0	0	0
Depletion Claimed	**148**	**143**	**138**	**134**	**129**	**128**	**128**	**128**	**46**

Table 22: Production Cash Flows - ($1,000,000)

Year	5	6	7	8	9	10	11	12	13
Revenues	1211	1211	1211	1204.6	1143.6	1104	1091	1079	1057
Royalty @ 5%	61	61	61	60	57	55	55	54	53
Tons Mined	30	30	30	29	28	28	26	24	21
Tons Processed	15	15	15	15	15	15	15	15	15
Operating Cost	97	97	97	95	95	95	92	89	86
Property Tax	74	73	72	71	67	64	63	63	61
Severence Tax	13	13	13	13	12	12	11	11	11
Net after Costs	968	968	969	965	913	879	870	862	846
Explo. & Dev. Deductions	3.6	2.4	1.2	1.2	0	0	0	0	0
Depreciation - Mine	20	34	25	18	13	13	13	11	9
Depreciation - Mill	30	52	37	26	19	19	19	17	13
Net after Depreciation	914	880	906	920	881	847	838	834	824
Depletion	173	173	173	172	163	157	155	154	151
Net after Depletion	741	707	733	748	718	689	683	680	674
Colorado State Tax @ 5%	37	35	37	37	36	34	34	34	34
Federal Taxable Income	704	672	697	711	682	655	649	646	640
Federal Income Tax @ 35%	247	235	244	249	239	229	227	226	224
Alt. Minimum Taxable Income	863	878	884	887	841	808	802	789	768
Minimum Tax @ 20%	173	176	177	177	168	162	160	158	154
Federal Income Tax	247	235	244	249	239	229	227	226	224
Net Profit	458	437	453	462	443	426	422	420	416
Explo. & Dev. Deductions	3.6	2.4	1.2	1.2	0	0	0	0	0
Depreciation - Mine	20	34	25	18	13	13	13	11	9
Depreciation - Mill	30	52	37	26	19	19	19	17	13
Depletion	173	173	173	172	163	157	155	154	151
Operating Cash Flow	684	698	689	679	638	615	609	602	589
Capital Expeditures	0	0	0	0	0	0	0	87.8	0
Net Cash Flow	684	698	689	679	638	615	609	514	589
Net Present Value	1882								

Table 22 Continued

Year	14	15	16	17	18	19	20	21	22
Revenues	1038	1006	969.5	941.5	906.3	897	897	897	322.3
Royalty @ 5%	52	50	48	47	45	45	45	45	16
Tons Mined	20	20	18	17	16	16	16	16	6
Tons Processed	15	15	15	15	15	15	15	15	5.37
Operating Cost	84	84	82	81	79	79	79	79	31
Property Tax	59	57	54	52	50	51	51	50	19
Severence Tax	11	11	10	10	9	9	9	9	3
Net after Costs	832	804	774	751	722	713	713	713	254
Explo. & Dev. Deductions	0	0	0	0	0	0	0	0	0
Depreciation - Mine	6	4	3	3	3	7	9	6	4
Depreciation - Mill	9	7	5	5	5	10	13	9	7
Net after Depreciation	817	793	766	743	714	696	691	698	243
Depletion	148	143	138	134	129	128	128	128	46
Net after Depletion	669	650	628	609	585	568	563	570	197
Colorado State Tax @ 5%	33	32	31	30	29	28.4	28	29	10
Federal Taxable Income	635	617	597	579	556	539	535	542	187
Federal Income Tax @ 35%	222	216	209	203	194	189	187	190	65
Alt. Minimum Taxable Income	757	748	735	713	685	669	665	667	231
Minimum Tax @ 20%	151	150	147	143	137	134	133	133	46
Federal Income Tax	222	216	209	203	194	189	187	190	65
Net Profit	413	401	388	376	361	351	348	352	121
Explo. & Dev. Deductions	0	0	0	0	0	0	0	0	0
Depreciation - Mine	6	4	3	3	3	7	9	6	4
Depreciation - Mill	9	7	5	5	5	10	13	9	7
Depletion	148	143	138	134	129	128	128	128	46
Operating Cash Flow	576	556	534	518	498	495	498	495	178
Capital Expeditures	0	0	0	0	0	87.8	0	0	0
Net Cash Flow	576	556	534	518	498	408	498	495	178
Net Present Value									

Table 23: Alternative Minimum Taxable Income Calculation - ($1,000,000)

Year	5	6	7	8	9	10	11	12	13
Revenues	1211	1211	1211	1204.6	1143.6	1104	1091	1079	1057
Royalty @ 5%	61	61	61	60	57	55	55	54	53
Tons Mined	30	30	30	29	28	28	26	24	21
Tons Processed	15	15	15	15	15	15	15	15	15
Operating Cost	97	97	97	95	95	95	92	89	86
Property Tax	74	73	72	71	67	64	63	63	61
Severence Tax	13	13	13	13	12	12	11	11	11
Colorado State Tax @ 5%	37	35.37	37	37	36	34	34	34	34
Net after Costs	931	933	932	928	877	844	836	828	813
Explo. & Dev. Deductions	6	6	6	6	6	6	4	2	2
Depreciation - Mine	11	20	17	14	12	12	12	15	17
Depreciation - Mill	16	29	25	21	18	18	18	22	26
Net after Depreciation	898	878	884	887	841	808	802	789	768
Depletion Claimed	173	173	173	172	163	157	155	154	151
Adjusted Basis	35	0	0	0	0	0	0	0	0
Allowable Depletion	35	0	0	0	0	0	0	0	0
Alternatine Min. Tax. Income	863	878	884	887	841	808	802	789	768

Table 23 Continued.

Year	14	15	16	17	18	19	20	21	22
Revenues	1038	1006	969.5	941.5	906.3	897	897	897	322.3
Royalty @ 5%	52	50	48	47	45	45	45	45	16
Tons Mined	20	20	18	17	16	16	16	16	6
Tons Processed	15	15	15	15	15	15	15	15	5.37
Operating Cost	84	84	82	81	79	79	79	79	31
Property Tax	59	57	54	52	50	51	51	50	19
Severence Tax	11	11	10	10	9	9	9	9	3
Colorado State Tax @ 5%	33	32	31	30	29	28	28	29	10
Net after Costs	798	772	743	721	693	684	685	685	244
Explo. & Dev. Deductions	0	0	0	0	0	0	0	0	0
Depreciation - Mine	16	10	3	3	3	6	8	7	5
Depreciation - Mill	25	14	5	5	5	9	12	11	8
Net after Depreciation	757	748	735	713	685	669	665	667	231
Depletion Claimed	148	143	138	134	129	128	128	128	46
Adjusted Basis	0	0	0	0	0	0	0	0	0
Allowable Depletion	0	0	0	0	0	0	0	0	0
Alternatine Min. Tax. Income	757	748	735	713	685	669	665	667	231

Table 24: Pre-Production Cash Flows - ($1,000,000)

Year	0	1	2	3	4
Property Payment	35	0	0	0	0
Explor. & Feas. Study	0	20	20	0	0
Preproduction Development	0	0	0	0	20
Mine Equipment	0	0	0	50	90.6
Mill Equipment	0	0	0	50	160.6
Property Tax	0	0	0	0	6
Total Capital Expenditures	**-35**	**-20**	**-20**	**-100**	**-277**
Tax Savings					
Explor. & Feas. Study	0	5.3	5.7	0.8	0.8
Preproduction Development	0	0	0	0	5.3
Property Tax	0	0	0	0	2.1
Total cash Generated	**0**	**5.32**	**5.74**	**0.84**	**8.24**
Net Cash Flow	**-35**	**-14.7**	**-14.3**	**-99.2**	**-269**

Table 25: Net Present Value - ($1,000,000)

Year	Cash Flow	Discounted Cash Flow
0	-35	-35
1	-14.7	-13
2	-14.3	-11
3	-99.2	-65
4	-269	-154
5	684	340
6	698	302
7	689	259
8	679	222
9	638	181
10	615	152
11	609	131
12	514	96
13	589	96
14	576	81
15	556	68
16	534	57
17	518	48
18	498	40
19	408	29
20	498	30
21	495	26
22	178	8
NPV		**1882**

Appendix B
Optimum Cutoff Grade Policies and Cash Flow Analysis of Different Alternatives
(Chapter 9, Table 9.21, 9.22)

Table 1: Optimum Cutoff Grade Policy One Mineral Case
(Mine & Mill Cap. 20, 10 Respectively)

YEAR	PUSHBACK	COG	Qm (MT)	Qc (MT)	Qr (1000,s T)	Prof ($M)	NPV ($M)
1	1	0.52	18.10	9.87	90.00	105.00	606.70
2	1	0.51	17.94	9.95	90.00	104.80	592.70
3	1	0.50	17.85	10.00	90.00	104.70	576.80
4	1	0.50	17.85	10.00	90.00	104.70	558.60
5	1	0.50	17.85	10.00	90.00	104.70	537.70
6	1	0.50	10.42	5.84	52.54	61.10	513.60
6	2	0.53	8.32	4.16	35.72	38.80	513.60
7	2	0.53	20.00	10.00	85.82	93.10	490.70
8	2	0.53	20.00	10.00	85.82	93.10	471.20
9	2	0.53	20.00	10.00	85.82	93.10	448.80
10	2	0.53	20.00	10.00	85.82	93.10	422.90
11	2	0.53	11.68	5.84	50.10	54.40	393.20
11	3	0.47	8.32	4.16	31.68	30.70	393.20
12	3	0.47	20.00	10.00	76.10	73.70	367.20
13	3	0.47	20.00	10.00	76.10	73.70	348.50
14	3	0.47	20.00	10.00	76.10	73.70	327.10
15	3	0.47	20.00	10.00	76.10	73.70	302.50
16	3	0.47	11.68	5.84	44.42	43.00	274.20
16	4	0.41	8.32	4.16	27.66	22.60	274.20
17	4	0.41	20.00	10.00	66.46	54.40	249.60
18	4	0.41	20.00	10.00	66.46	54.40	232.70
19	4	0.41	20.00	10.00	66.46	54.40	213.20
20	4	0.41	20.00	10.00	66.46	54.40	190.70
21	4	0.40	11.68	5.97	39.27	32.10	164.90
21	5	0.35	8.07	4.03	23.08	14.50	164.90
22	5	0.35	20.00	10.00	57.23	36.00	143.10
23	5	0.35	20.00	10.00	57.23	36.00	128.60
24	5	0.35	20.00	10.00	57.23	36.00	111.90
25	5	0.34	19.50	10.00	56.58	35.40	92.70
26	5	0.32	12.44	6.68	36.97	22.90	71.20
26	6	0.29	6.65	3.32	15.83	5.60	71.20
27	6	0.29	20.00	10.00	47.62	16.70	53.40
28	6	0.29	20.00	10.00	47.62	16.70	44.70
29	6	0.29	20.00	10.00	47.62	16.70	34.70
30	6	0.29	19.64	10.00	47.23	16.50	23.10
31	6	0.28	13.71	7.19	33.51	11.60	10.10

Table 2: Cash Flow Analysis Of Production Period One Mineral Case
(Mine and Mill Cap. of 20 & 10 Millions Respectively)

Year	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Revenues	163.1	163.1	163.1	163.1	163.1	160	156	156	156	156	148	138	138	138	138	131
Royalty @ 5%	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7
Tons Mined	18.1	18	17.8	17.8	17.8	18.8	20	20	20	20	20	20	20	20	20	20
Tons Processed	9.9	9.9	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Operating Cost	75	75	75	75	75	77	79	79	79	79	79	79	79	79	79	79
Property Tax	10	10	9	9	8	8	7	8	7	6	6	5	5	5	6	5
Severence Tax	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Net after Costs	69	69	70	70	70	66	61	61	61	62	55	47	47	47	46	40
Explo. & Dev. Deductions	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	15	26	18	13	9	9	9	8	6	5	3	2	2	2	5	6
Depreciation - Mill	20	35	25	18	13	13	13	12	9	6	4	3	3	3	7	9
Net after Depreciation	31	6	26	38	48	44	39	41	46	51	48	42	42	42	34	25
Depletion	23	23	23	23	23	23	22	22	22	22	21	20	20	20	20	19
Net after Depletion	8	-17	2	15	25	22	17	18	24	29	27	22	22	22	14	6
Colorado State Tax @ 5%	0	0	0.1	1	1	1	1	1	1	1	1	1	1	1	0.7	0.3
Federal Taxable Income	7	0	2	14	24	21	16	18	23	27	26	21	21	21	13	6
Federal Income Tax @ 35%	3	0	1	5	8	7	6	6	8	10	9	7	7	7	5	2
Alt. Minimum Taxable Income	26	32	40	44	47	43	40	36	32	36	41	44	45	45	39	29
Minimum Tax @ 20%	5	6	8	9	9	9	8	7	6	7	8	9	9	9	8	6
Federal Income Tax	5	0	8	9	9	9	8	7	8	10	9	9	9	9	8	6
Net Profit	2	0	-6	5	14	12	8	10	15	18	17	12	12	12	6	0
Explo. & Dev. Deductions	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	15	26	18	13	9	9	9	8	6	5	3	2	2	2	5	6
Depreciation - Mill	20	35	25	18	13	13	13	12	9	6	4	3	3	3	7	9
Depletion	23	23	23	23	23	23	22	22	22	22	21	20	20	20	20	19
Operating Cash Flow	63	86	61	60	60	57	53	52	52	51	45	37	37	37	37	33
Capital Expeditures	0	0	0	0	0	0	0	62.1	0	0	0	0	0	0	62.1	0
Net Cash Flow	**63**	**86**	**61**	**60**	**60**	**57**	**53**	**-10**	**52**	**51**	**45**	**37**	**37**	**37**	**-25**	**33**
Net Present Value	**-6**															

Table 2 Continued

Year	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Revenues	121	121	121	121	113	104	104	104	103	96	79	86	86	86	60
Royalty @5%	6	6	6	6	6	5	5	5	5	5	4	4	4	4	3
Tons Mined	20	20	20	20	19.8	20	20	20	19.6	19.2	20	20	20	19.6	13.5
Tons Processed	10	10	10	10	10	10	10	10	10	10	10	10	10	10	7.1
Operating Cost	79	79	79	79	78	79	79	79	78	77	79	79	79	78	56
Property Tax	4	4	4	4	3	4	4	3	3	3	2	2	2	2	1
Severence Tax	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Net after Costs	31	31	31	31	25	16	16	16	16	11	-5	1	1	2	0
Explo. & Dev. Deductions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	5	3	2	2	2	5	6	5	3	2	2	2	1	0	0
Depreciation - Mill	6	4	3	3	3	7	9	6	4	3	3	3	2	0	0
Net after Depreciation	20	24	26	26	20	4	1	5	9	6	-10	-4	-2	2	0
Depletion	17	17	17	17	16	15	15	15	15	14	11	12	12	12	9
Net after Depletion	3	7	9	9	4	-11	-14	-10	-6	-8	-21	-16	-14	-10	-9
Colorado State Tax @ 5%	0.1	0.3	0.5	0.5	0.2	0	0	0	0	0	0	0	0	0	0
Federal Taxable Income	3	7	9	9	4	0	0	0	0	0	0	0	0	0	0
Federal Income Tax @ 35%	1	2	3	3	1	0	0	0	0	0	0	0	0	0	0
Alt. Minimum Taxable Income	23	26	30	30	24	9	6	8	11	9	0	0	0	1	0
Minimum Tax @ 20%	5	5	6	6	5	2	1	2	2	2	0	0	0	0	0
Federal Income Tax	5	5	6	6	5	0	0	0	0	0	0	0	0	0	0
Net Profit	-2	1	3	3	-1	0	0	0	0	0	0	0	0	0	0
Explo. & Dev. Deductions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	5	3	2	2	2	5	6	5	3	2	2	2	1	0	0
Depreciation - Mill	6	4	3	3	3	7	9	6	4	3	3	3	2	0	0
Depletion	17	17	17	17	16	15	15	15	15	14	11	12	12	12	9
Operating Cash Flow	26	26	25	25	20	27	30	26	22	19	16	17	15	12	9
Capital Expeditures	0	0	0	0	0	62.1	0	0	0	0	0	0	0	0	0
Net Cash Flow	**26**	**26**	**25**	**25**	**20**	**-35**	**30**	**26**	**22**	**19**	**16**	**17**	**15**	**12**	**9**

Table 3: Optimum Cutoff Grade Policy One Mineral Case
(Mine & Mill Cap. 30, 15 Respectively)

YEAR	PB	COG	Qm (MT)	Qc (MT)	Qr (1000's T)	Prof ($M)	NPV ($M)
1	1	0.51	19.97	11.04	100.00	131.30	785.10
2	1	0.50	19.79	11.13	100.00	131.10	771.60
3	1	0.49	19.61	11.24	100.00	131.00	756.20
4	1	0.47	19.41	11.36	100.00	130.80	738.70
5	1	0.45	19.22	11.49	100.00	130.60	718.70
6	1	0.44	2.00	1.22	10.53	13.70	696.00
6	2	0.44	19.42	11.13	89.47	110.90	696.00
7	2	0.42	21.48	12.58	100.00	123.70	675.70
8	2	0.41	21.26	12.72	100.00	123.50	653.30
9	2	0.39	21.03	12.89	100.00	123.20	627.90
10	2	0.37	16.82	10.56	80.85	99.30	598.90
10	3	0.37	4.63	2.72	19.15	21.90	598.90
11	3	0.36	23.91	14.38	100.00	114.10	567.50
12	3	0.34	23.66	14.56	100.00	113.80	538.50
13	3	0.33	23.42	14.75	100.00	113.40	505.40
14	3	0.31	23.18	14.95	100.00	113.00	467.90
15	3	0.31	1.20	0.78	5.20	5.90	425.10
15	4	0.41	28.44	14.22	94.50	98.20	425.10
16	4	0.41	30.00	15.00	99.68	103.60	384.70
17	4	0.39	28.86	15.00	97.95	101.60	338.80
18	4	0.36	12.70	7.01	44.47	45.90	288.10
18	5	0.35	15.99	7.99	45.75	40.50	288.10
19	5	0.34	29.23	15.00	84.84	74.90	245.00
20	5	0.32	27.66	15.00	82.66	72.50	206.80
21	5	0.29	26.06	15.00	80.25	69.70	165.30
22	5	0.27	1.07	0.64	3.38	2.90	120.50
22	6	0.27	26.97	14.36	66.42	43.40	120.50
23	6	0.25	26.93	15.00	67.91	43.90	92.30
24	6	0.24	25.63	15.00	66.22	42.20	62.20
25	6	0.22	20.47	12.59	54.13	33.80	29.40

Table 4: Cash Flow Analysis Of Production Period One Mineral Case
(Mine and Mill Cap. of 30 & 15 Millions Respectively)

Year	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Revenues	181.3	181.3	181.3	181.3	181.3	181	181	181	181	181	181	181	181	181
Royalty @ 5%	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Tons Mined	20	20	20	19	19	21	22	21	21	22	24	24	23	23
Tons Processed	11	11	11.2	11.4	11.4	12.3	12.6	12.7	12.8	13.2	14.4	14.5	14.7	14.9
Operating Cost	69	68	69	69	69	75	76	76	76	79	86	86	86	87
Property Tax	13	12	11	11	10	9	9	10	9	8	7	7	7	8
Severence Tax	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Net after Costs	90	90	90	91	91	86	86	85	86	84	78	78	78	77
Explo. & Dev. Deductions	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	20	34	25	18	13	13	13	11	9	6	4	3	3	3
Depreciation - Mill	27	46	33	23	17	17	17	15	11	8	6	4	4	4
Net after Depreciation	40	8	32	49	61	56	56	59	66	70	68	71	71	70
Depletion	26	26	26	26	26	26	26	26	26	26	26	26	26	26
Net after Depletion	14	-17	6	23	36	30	30	33	40	45	42	45	45	44
Colorado State Tax @ 5%	1	0	0.3	1	2	2	1	2	2	2	2	2	2	2
Federal Taxable Income	13	0	5	22	34	29	28	31	38	42	40	43	42	42
Federal Income Tax @ 35%	5	0	2	8	12	10	10	11	13	15	14	15	15	15
Alt. Minimum Taxable Income	15	9	31	47	58	53	54	59	65	71	69	72	71	70
Minimum Tax @ 20%	3	2	6	9	12	11	11	12	13	14	14	14	14	14
Federal Income Tax	5	0	6	9	12	11	11	12	13	15	14	15	15	15
Net Profit	9	0	-1	12	22	18	18	20	25	28	26	28	28	27
Explo. & Dev. Deductions	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	20	34	25	18	13	13	13	11	9	6	4	3	3	3
Depreciation - Mill	27	46	33	23	17	17	17	15	11	8	6	4	4	4
Depletion	26	26	26	26	26	26	26	26	26	26	26	26	26	26
Operating Cash Flow	84	108	84	80	78	74	73	71	70	67	62	61	60	60
Capital Expeditures	0	0	0	0	0	0	0	81.7	0	0	0	0	0	0
Net Cash Flow	**84**	**108**	**84**	**80**	**78**	**74**	**73**	**-10**	**70**	**67**	**62**	**61**	**60**	**60**
Net Present Value	14													

Table 4 Continued.

Year	19	20	21	22	23	24	25	26	27	28	29
Revenues	179	179	178	163	154	150	145	125	123	120	94
Royalty @ 5%	9	9	9	8	8	8	7	6	6	6	5
Tons Mined	30	30	29	29	29	28	26	28	27	26	20
Tons Processed	14.9	15	15	14.9	15	15	15	14.9	15	15	11.9
Operating Cost	95	96	94	94	95	93	91	93	92	90	71
Property Tax	8	8	7	6	5	5	5	5	4	4	3
Severence Tax	1	1	1	1	1	1	1	1	1	1	0
Net after Costs	66	66	66	54	45	44	41	20	20	19	15
Explo. & Dev. Deductions	0	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	7	9	6	4	3	3	3	7	9	6	4
Depreciation - Mill	9	11	8	6	4	4	4	9	11	8	6
Net after Depreciation	50	46	52	44	38	37	34	4	0	5	5
Depletion	26	26	25	23	22	21	21	18	18	17	13
Net after Depletion	25	20	27	21	16	16	14	-14	-17	-12	-9
Colorado State Tax @ 5%	1.2	1	1	1	0.8	0.8	1	0	0	0	0
Federal Taxable Income	23	19	25	20	15	15	13	0	0	0	0
Federal Income Tax @ 35%	8	7	9	7	5	5	5	0	0	0	0
Alt. Minimum Taxable Income	52	48	54	46	40	39	37	7	3	8	8
Minimum Tax @ 20%	10	10	11	9	8	8	7	1	1	2	2
Federal Income Tax	10	10	11	9	8	8	7	0	0	0	0
Net Profit	13	10	15	11	7	7	6	0	0	0	0
Explo. & Dev. Deductions	0	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	7	9	6	4	3	3	3	7	9	6	4
Depreciation - Mill	9	11	8	6	4	4	4	9	11	8	6
Depletion	26	26	25	23	22	21	21	18	18	17	13
Operating Cash Flow	55	55	54	44	36	35	33	34	38	31	23
Capital Expeditures	81.7	0	0	0	0	0	0	81.7	0	0	0
Net Cash Flow	**-27**	**55**	**54**	**44**	**36**	**35**	**33**	**-48**	**38**	**31**	**23**

Table 5: Optimum Cutoff Grade Policy One Mineral Case
(Mine & Mill Cap. 35, 20 Respectively)

YEAR	PB	COG	Qm (MT)	Qc (MT)	Qr (1000's T)	Prof ($M)	NPV ($M)
1	1	0.49	35.00	20.00	178.23	247.50	1191.80
2	1	0.49	35.00	20.00	178.23	247.50	1123.00
3	1	0.49	30.00	17.14	152.77	212.20	1044.00
3	2	0.44	5.00	2.86	23.01	30.40	1044.00
4	2	0.44	35.00	20.00	161.04	213.10	958.00
5	2	0.44	35.00	20.00	161.04	213.10	888.60
6	2	0.44	25.00	14.29	115.03	152.20	808.70
6	3	0.39	10.00	5.71	40.81	50.50	808.70
7	3	0.39	35.00	20.00	142.84	176.70	727.30
8	3	0.39	35.00	20.00	142.84	176.70	659.70
9	3	0.39	20.00	11.43	81.62	101.00	581.90
9	4	0.34	15.00	8.57	53.47	60.20	581.90
10	4	0.34	35.00	20.00	124.75	140.60	508.00
11	4	0.34	35.00	20.00	124.75	140.60	443.60
12	4	0.34	15.00	8.59	53.53	60.30	369.60
12	5	0.29	19.96	11.41	61.25	60.40	369.60
13	5	0.29	35.00	20.00	107.4	105.90	304.30
14	5	0.29	34.63	20.00	106.83	105.10	244.10
15	5	0.26	10.40	6.39	33.04	32.20	175.60
15	6	0.24	23.81	13.61	60.82	47.50	175.60
16	6	0.24	34.35	20.00	88.53	68.90	122.30
17	6	0.22	32.53	20.00	86.01	66.00	71.70
18	6	0.19	9.30	6.06	25.22	19.00	16.50

Table 6: Cash Flow Analysis Of Production Period One Mineral Case
(Mine and Mill Cap. of 35 & 20 Millions Respectively)

Year	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Revenues	322.7	322.7	320.8	291.8	291.8	283	259	259	245	227	227	208	194	194	170	161	156	45
Royalty @ 5%	16	16	16	15	15	14	13	13	12	11	11	10	10	10	9	8	8	2
Tons Mined	35	35	35	35	35	35	35	35	35	35	35	35	35	35	34	34	33	9
Tons Processed	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	6
Operating Cost	110	110	110	110	110	110	110	110	110	110	110	109	110	109	109	109	107	34
Property Tax	20	19	18	16	15	14	12	13	11	9	9	8	7	10	7	6	5	2
Severence Tax	3	3	3	2	2	2	2	2	2	2	2	1	1	1	1	1	1	0
Net after Costs	174	175	174	149	150	143	123	122	110	95	95	79	67	64	46	38	35	7
Explo. & Dev. Deductions	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	23	39	28	20	14	14	14	13	10	7	5	4	4	4	7	10	7	5
Depreciation - Mill	32	55	39	28	20	20	20	18	14	10	7	5	5	5	11	14	10	7
Net after Depreciation	117	79	106	101	116	109	89	91	86	78	83	70	58	55	28	14	18	-5
Depletion	46	46	46	42	42	40	37	37	35	32	32	30	28	28	24	23	22	6
Net after Depletion	71	33	61	59	75	69	52	54	51	46	51	41	30	28	3	-9	-4	-12
Colorado State Tax @ 5%	4	2	3	3	4	3	3	3	3	2	3	2	2	1	0.2	0	0	0
Federal Taxable Income	67	32	58	56	71	65	49	51	48	43	48	39	29	26	3	0	0	0
Federal Income Tax @ 35%	24	11	20	20	25	23	17	18	17	15	17	14	10	9	1	0	0	0
Alt. Minimum Taxable Income	116	119	125	106	111	104	86	80	63	51	70	72	60	58	34	19	19	0
Minimum Tax @ 20%	23	24	25	21	22	21	17	16	13	10	14	14	12	12	7	4	4	0
Federal Income Tax	24	24	25	21	25	23	17	18	17	15	17	14	12	12	7	0	4	0
Net Profit	44	8	33	35	46	42	32	33	32	28	31	24	16	15	-4	0	-4	0
Explo. & Dev. Deductions	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	23	39	28	20	14	14	14	13	10	7	5	4	4	4	7	10	7	5
Depreciation - Mill	32	55	39	28	20	20	20	18	14	10	7	5	5	5	11	14	10	7
Depletion	46	46	46	42	42	40	37	37	35	32	32	30	28	28	24	23	22	6
Operating Cash Flow	147	150	146	125	122	117	103	101	90	77	76	63	53	51	39	47	36	18
Capital Expeditures	0	0	0	0	0	0	0	95.75	0	0	0	0	0	0	95.75	0	0	0
Net Cash Flow	147	150	146	125	122	117	103	5	90	77	76	63	53	51	-57	47	36	18
Net Present Value	93																	

Table 7: Optimum Cutoff Grade Policy One Mineral Case
(Mine & Mill Cap. 35, 30 Respectively)

YEAR	PB	COG	Qm (MT)	Qc (m) (MT)	Qr (1000's T)	Prof ($M)	NPV ($M)
1	1	0.26	34.99	26.52	200.00	284.60	1376.60
2	1	0.26	34.99	26.52	200.00	284.60	1298.50
3	1	0.26	30.02	22.75	171.57	244.10	1208.70
3	2	0.26	4.97	3.64	25.39	34.70	1208.70
4	2	0.26	35.00	25.76	178.95	244.50	1111.20
5	2	0.24	35.00	26.18	179.88	245.20	1033.40
6	2	0.23	25.03	19.03	129.29	175.90	943.10
6	3	0.23	9.97	7.32	45.19	58.10	943.10
7	3	0.22	35.00	26.11	159.47	204.60	850.60
8	3	0.21	35.00	26.45	160.11	205.00	773.60
9	3	0.2	20.03	15.33	91.98	117.50	684.70
9	4	0.2	14.97	10.99	59.28	70.10	684.70
10	4	0.19	35.00	26.04	139.19	164.20	599.80
11	4	0.19	35.00	26.34	139.69	164.40	525.50
12	4	0.18	15.03	11.44	60.19	70.70	439.90
12	5	0.18	19.97	14.49	67.79	71.40	439.90
13	5	0.17	35.00	25.69	119.25	125.30	363.80
14	5	0.17	35.00	25.95	119.65	125.40	293.10
15	5	0.16	10.03	7.51	34.39	35.90	211.70
15	6	0.16	24.97	17.58	69.80	60.80	211.70
16	6	0.16	35.00	24.88	98.18	85.30	146.70
17	6	0.15	35.00	25.11	98.49	85.30	83.40
18	6	0.15	5.03	3.64	14.19	12.30	10.70

Table 8: Cash Flow Analysis Of Production Period One Mineral Case
(Mine and Mill Cap. of 35 & 30 Millions Respectively)

Year	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Revenues	362.5	362.5	357.1	324.5	324.5	314	286	286	272	250	250	228	214	214	185	174	176	25
Royalty @ 5%	18	18	18	16	16	16	14	14	14	13	13	11	11	11	9	9	9	1
Tons Mined	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	5
Tons Processed	26.5	26.5	26.3	25.6	25.6	25.5	25.3	25.6	25.4	25.2	25.4	24.9	24.7	25	23.9	23.7	23.9	3.5
Operating Cost	125	125	124	122	122	122	121	122	122	121	122	120	120	120	117	117	117	20
Property Tax	22	21	20	17	17	15	13	14	12	10	9	8	7	10	7	6	6	2
Severence Tax	3	3	3	3	3	2	2	2	2	2	2	2	1	1	1	1	1	0
Net after Costs	195	195	192	166	167	158	136	134	123	105	105	87	75	72	50	42	43	2
Explo. & Dev. Deductions	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	23	39	28	20	14	14	14	13	10	7	5	4	4	4	7	10	7	5
Depreciation - Mill	42	72	51	37	26	26	26	24	18	13	9	7	7	7	14	18	13	9
Net after Depreciation	127	83	112	108	127	118	96	97	95	85	91	76	64	61	29	14	23	-12
Depletion	52	52	51	46	46	45	41	41	39	36	36	33	30	30	26	25	25	4
Net after Depletion	75	31	61	62	81	74	55	56	56	49	55	44	34	31	3	-11	-2	-16
Colorado State Tax @ 5%	4	2	3	3	4	4	3	3	3	2	3	2	2	2	0.1	0	0	0
Federal Taxable Income	71	29	58	59	77	70	52	53	53	47	52	42	32	29	3	0	0	0
Federal Income Tax @ 35%	25	10	20	21	27	24	18	19	19	16	18	15	11	10	1	0	0	0
Alt. Minimum Taxable Income	131	130	134	117	121	113	93	85	66	53	74	79	68	65	35	19	23	0
Minimum Tax @ 20%	26	26	27	23	24	23	19	17	13	11	15	16	14	13	7	4	5	0
Federal Income Tax	26	26	27	23	27	24	19	19	19	16	18	16	14	13	7	0	5	0
Net Profit	45	3	31	35	50	45	34	35	34	30	34	26	18	16	-4	0	-5	0
Explo. & Dev. Deductions	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	23	39	28	20	14	14	14	13	10	7	5	4	4	4	7	10	7	5
Depreciation - Mill	42	72	51	37	26	26	26	24	18	13	9	7	7	7	14	18	13	9
Depletion	52	52	51	46	46	45	41	41	39	36	36	33	30	30	26	25	25	4
Operating Cash Flow	165	168	162	140	136	130	114	112	101	86	84	69	60	58	43	53	40	18
Capital Expeditures	0	0	0	0	0	0	0	112.8	0	0	0	0	0	0	112.8	0	0	0
Net Cash Flow	**165**	**168**	**162**	**140**	**136**	**130**	**114**	**0**	**101**	**86**	**84**	**69**	**60**	**58**	**-70**	**53**	**40**	**18**
Net Present Value	94																	

Table 9: Optimum Cutoff Grade Policy One Mineral Case
(Mine & Mill Cap. 60, 30 Respectively)

YEAR	PB	COG	Qm (MT)	Qc (MT)	Qr (1000,s T)	Prof ($M)	NPV ($M)
1	1	0.39	46.37	30.00	249.98	371.20	1619.40
2	1	0.39	46.37	30.00	249.98	371.20	1491.10
3	1	0.39	7.27	4.70	39.18	58.20	1343.60
3	2	0.49	47.46	25.30	210.79	304.90	1343.60
4	2	0.48	52.54	28.13	233.88	338.20	1182.10
4	3	0.47	3.75	1.87	14.25	19.60	1182.10
5	3	0.43	56.23	30.00	221.6	304.80	1001.60
6	3	0.39	40.02	23.05	163.96	224.70	846.90
6	4	0.39	13.25	6.95	45.19	58.10	846.90
7	4	0.34	52.47	30.00	187.07	239.50	691.20
8	4	0.30	34.28	21.13	126.67	161.00	555.40
8	5	0.30	15.80	8.87	48.05	56.00	555.40
9	5	0.26	49.30	30.00	155.88	180.10	421.60
10	5	0.23	34.90	22.82	113.87	130.10	304.70
10	6	0.23	12.08	7.18	31.43	31.10	304.70
11	6	0.20	46.84	30.00	126.09	122.90	189.20
12	6	0.17	41.08	28.18	113.70	108.80	94.70

Table 10: Cash Flow Analysis Of Production Period One Mineral Case
(Mine and Mill Cap. of 60 & 30 Millions Respectively)

Year	5	6	7	8	9	10	11	12	13	14	15	16
Revenues	453.2	453.2	451.4	449.5	400.6	379	339	317	283	263	228	201
Royalty @ 5%	23	23	23	22	20	19	17	16	14	13	11	10
Tons Mined	46	46	55	56	56	53	53	50	49	47	47	40
Tons Processed	30	30	30	30	30	30	30	30	30	30	30	27.6
Operating Cost	129	129	137	138	138	136	135	132	132	130	129	117
Property Tax	28	27	26	25	21	19	16	16	13	10	8	7
Severence Tax	4	4	4	4	3	3	3	2	2	2	1	1
Net after Costs	269	270	262	259	217	202	169	150	122	108	78	66
Explo. & Dev. Deductions	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0
Depreciation - Mine	33	57	41	29	21	21	21	19	14	10	7	5
Depreciation - Mill	42	72	51	37	26	26	26	24	18	13	9	7
Net after Depreciation	192	139	169	192	170	155	122	107	90	85	62	54
Depletion	65	65	64	64	57	54	48	45	40	37	33	29
Net after Depletion	127	75	104	128	113	101	73	62	50	47	29	26
Colorado State Tax @ 5%	6	4	5	6	6	5	4	3	2	2	1	1
Federal Taxable Income	120	71	99	122	108	96	70	59	47	45	28	25
Federal Income Tax @ 35%	42	25	35	43	38	34	24	21	17	16	10	9
Alt. Minimum Taxable Income	194	189	190	196	161	146	116	90	54	44	41	54
Minimum Tax @ 20%	39	38	38	39	32	29	23	18	11	9	8	11
Federal Income Tax	42	38	38	43	38	34	24	21	17	16	10	11
Net Profit	78	33	61	79	70	62	45	38	31	29	18	14
Explo. & Dev. Deductions	2.7	1.8	0.9	0.9	0	0	0	0	0	0	0	0
Depreciation - Mine	33	57	41	29	21	21	21	19	14	10	7	5
Depreciation - Mill	42	72	51	37	26	26	26	24	18	13	9	7
Depletion	65	65	64	64	57	54	48	45	40	37	33	29
Operating Cash Flow	221	229	218	210	174	163	141	127	103	90	67	54
Capital Expeditures	0	0	0	0	0	0	0	131.1	0	0	0	0
Net Cash Flow	**221**	**229**	**218**	**210**	**174**	**163**	**141**	**-4**	**103**	**90**	**67**	**54**
Net Present Value	**158.2**											

Table 11: Optimum Cutoff Grade Policy Two Minerals Case (Mine & Mill Cap. 20, 10 Respectively)

YEAR	PB	COG1	COG2	Qm (Mtons)	Qc (Mtons)	Qr1 (1000's T)	Qr2 (1000's oz.)	PROFIT ($M)	NPV ($M)
1	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1344.49
2	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1326.56
3	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1305.94
4	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1282.23
5	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1254.96
6	1	0.339	0.026	19.90	10.00	70.56	412.71	219.60	1223.60
7	1	0.339	0.026	10.59	5.32	37.55	219.60	116.85	1187.53
7	2	0.294	0.026	9.32	4.68	31.10	183.34	95.20	1187.53
8	2	0.294	0.026	19.91	10.00	66.46	391.83	203.45	1153.61
9	2	0.283	0.027	19.90	10.00	65.50	396.19	203.20	1123.20
10	2	0.333	0.021	19.91	10.00	70.03	374.37	203.94	1088.49
11	2	0.350	0.018	19.90	10.00	71.66	365.58	203.90	1047.82
12	2	0.328	0.020	19.24	10.00	69.50	370.00	202.23	1001.09
13	2	0.289	0.020	17.62	10.00	65.98	370.00	197.62	949.03
14	2	0.244	0.020	4.20	2.61	16.28	96.70	50.33	893.76
14	3	0.267	0.018	12.89	7.39	47.34	265.62	140.46	893.76
15	3	0.222	0.018	15.98	10.00	60.55	359.60	185.28	837.04
16	3	0.172	0.018	14.59	10.00	56.84	359.60	179.94	777.31
17	3	0.150	0.016	13.45	10.00	55.28	349.95	174.86	713.97
18	3	0.100	0.013	12.65	10.00	54.09	342.13	170.71	646.21
19	3	0.062	0.011	12.00	10.00	53.16	334.25	166.83	572.43
20	3	0.025	0.008	11.31	10.00	52.20	324.31	162.17	491.46
21	3	0.025	0.003	10.57	10.00	52.20	306.20	156.40	403.01
22	3	0.025	0.003	10.57	10.00	52.20	306.20	156.40	307.07
23	3	0.025	0.003	10.57	10.00	52.20	306.20	156.40	196.73
24	3	0.025	0.003	5.43	5.14	26.81	157.26	80.32	69.84

Table 12: Cash Flow Analysis Of Production Period Two Mineral Case
(Mine and Mill Cap. of 20 & 10 Millions Respectively)

Year	5	6	7	8	9	10	11	12	13	14	15	16
Revenues	809	808.97	809	809	809	809	789	765	771	746	738	739
Royalty @ 5%	40	40	40	40	40	40	39	38	39	37	37	37
Tons Mined	20	20	20	20	20	20	20	20	20	20	20	19
Tons Processed	10	10	10	10	10	10	10	10	10	10	10	10
Operating Cost	78	78	78	78	78	78	78	78	78	78	78	77
Property Tax	49	49	48	48	47	47	45	44	44	42	41	41
Severence Tax	8.441	8.4414	8.441	8.441	8.441	8.441	8.214	7.943	8.013	7.729	7.64	7.659
Net after Costs	633	633	634	634	635	635	618	596	602	580	574	576
Explo. & Dev. Deductions	3.6	2.4	1.2	1.2	0	0	0	0	0	0	0	0
Depreciation - Mine	15	26	18	13	9	9	9	8	6	5	3	2
Depreciation - Mill	23	40	29	20	15	15	15	13	10	7	5	4
Net after Depreciation	591	565	585	600	611	611	594	575	586	568	566	570
Depletion	115	115	115	115	115	115	112	109	110	106	105	105
Net after Depletion	476	449	470	485	495	496	481	466	476	462	460	465
Colorado State Tax @ 5%	24	22	24	24	25	25	24	23	24	23	23	23
Federal Taxable Income	452	427	447	460	471	471	457	443	453	439	437	442
Federal Income Tax @ 35%	158	149	156	161	165	165	160	155	158	154	153	155
Alt. Minimum Taxable Income	548	567	575	577	581	581	567	543	543	526	533	547
Minimum Tax @ 20%	110	113	115	115	116	116	113	109	109	105	107	109
Federal Income Tax	158	149	156	161	165	165	160	155	158	154	153	155
Net Profit	294	278	290	299	306	306	297	288	294	285	284	287
Explo. & Dev. Deductions	3.6	2.4	1.2	1.2	0	0	0	0	0	0	0	0
Depreciation - Mine	15	26	18	13	9	9	9	8	6	5	3	2
Depreciation - Mill	23	40	29	20	15	15	15	13	10	7	5	4
Depletion	115	115	115	115	115	115	112	109	110	106	105	105
Operating Cash Flow	451	461	454	449	445	445	434	418	420	404	397	398
Capital Expeditures	0	0	0	0	0	0	0	67.03	0	0	0	0
Net Cash Flow	451	461	454	449	445	445	434	351	420	404	397	398
Net Present Value	1328											

Table 12 Continued.

Year	17	18	19	20	21	22	23	24	25	26	27	28
Revenues	730	713	703	694	674	659	644	626	598	598	598	308
Royalty @ 5%	37	36	35	35	34	33	32	31	30	30	30	15
Tons Mined	18	17	16	15	13	13	12	11	11	11	11	5
Tons Processed	10	10	10	10	10	10	10	10	10	10	10	5.14
Operating Cost	75	74	72	70	69	67	67	65	64	64	64	35
Property Tax	41	39	40	39	38	37	36	34	33	34	33	18
Severence Tax	7.556	7.363	7.251	7.147	6.92	6.753	6.587	6.385	6.068	6.068	6.068	3.061
Net after Costs	571	557	548	543	527	515	503	489	465	464	464	237
Explo. & Dev. Deductions	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	2	2	5	6	5	3	2	2	2	5	6	5
Depreciation - Mill	4	4	8	10	7	5	4	4	4	8	10	7
Net after Depreciation	565	551	535	527	515	507	497	483	459	451	448	225
Depletion	104	102	100	99	96	94	92	89	85	85	85	44
Net after Depletion	461	449	435	428	419	413	405	393	374	366	363	181
Colorado State Tax @ 5%	23	22	21.8	21	21	21	20.3	19.7	19	18	18	9
Federal Taxable Income	438	426	413	406	398	393	385	374	355	348	345	172
Federal Income Tax @ 35%	153	149	145	142	139	137	135	131	124	122	121	60
Alt. Minimum Taxable Income	542	528	516	506	493	484	477	463	440	435	431	215
Minimum Tax @ 20%	108	106	103	101	99	97	95	93	88	87	86	43
Federal Income Tax	153	149	145	142	139	137	135	131	124	122	121	60
Net Profit	284	277	269	264	259	255	250	243	231	226	224	112
Explo. & Dev. Deductions	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation - Mine	2	2	5	6	5	3	2	2	2	5	6	5
Depreciation - Mill	4	4	8	10	7	5	4	4	4	8	10	7
Depletion	104	102	100	99	96	94	92	89	85	85	85	44
Operating Cash Flow	394	385	382	379	367	357	348	338	322	324	325	168
Capital Expeditures	0	0	67.03	0	0	0	0	0	0	67.03	0	0
Net Cash Flow	394	385	315	379	367	357	348	338	322	257	325	168
Net Present Value												

Table 13: Optimum Cutoff Grade Policy Two Minerals Case (Mine & Mill Cap. 40, 25 Respectively)

YEAR	PB	COG1	COG2	Qm (Mtons)	Qc (Mtons)	Qr1 (1000's T)	Qr2 (1000's oz.)	PROFIT ($M)	NPV ($M)
1	1	0.328	0.004	39.64	25.00	173.72	900.00	567.36	2845.58
2	1	0.311	0.004	38.13	25.00	169.85	900.00	561.36	2705.06
3	1	0.256	0.004	33.85	25.00	157.93	900.00	542.44	2549.46
4	1	0.200	0.004	18.38	15.10	88.89	543.67	317.03	2389.44
4	2	0.200	0.016	13.85	9.90	58.27	354.36	204.98	2389.44
5	2	0.144	0.016	31.97	25.00	137.86	895.03	502.57	2225.85
6	2	0.150	0.013	31.25	25.00	138.19	879.49	498.14	2057.16
7	2	0.050	0.011	28.87	25.00	132.10	863.61	482.67	1867.59
8	2	0.025	0.008	24.06	21.77	113.64	734.41	412.06	1665.05
8	3	0.033	0.007	3.58	3.23	16.92	102.78	58.90	1665.05
9	3	0.025	0.003	26.43	25.00	130.49	765.51	444.99	1443.84
10	3	0.025	0.003	26.43	25.00	130.49	765.51	444.99	1215.43
11	3	0.025	0.003	26.43	25.00	130.49	765.51	444.99	952.76
12	3	0.025	0.003	26.43	25.00	130.49	765.51	444.99	650.68
13	3	0.025	0.003	20.71	19.60	102.28	600.02	348.79	303.30

Table 14: Cash Flow Analysis Of Production Period Two Mineral Case
(Mine and Mill Cap. of 40 & 25 Millions Respectively)

Year	5	6	7	8	9	10	11	12	13	14	15	16	17
Revenues	1805	1803	1783	1757	1726	1680	1642	1613	1479	1501	1506	1506	1182
Royalty @ 5%	90	90	89	88	86	84	82	81	74	75	75	75	59
Tons Mined	40	38	34	32	32	31	29	28	26	26	26	26	21
Tons Processed	25	25	25	25	25	25	25	25	25	25	25	25	19.6
Operating Cost	122	120	115	114	113	112	110	108	107	107	107	107	85
Property Tax	109	108	106	104	101	97	94	94	85	85	85	85	67
Severence Tax	19	19	19	19	18	18	17	17	16	16	16	16	12
Net after Costs	1464	1465	1454	1434	1407	1368	1338	1313	1198	1218	1223	1223	959
Explo. & Dev. Deductions	3.6	2.4	1.2	1.2	0	0	0	0	0	0	0	0	0
Depreciation - Mine	25	42	30	22	15	15	22	18	8	5	4	4	4
Depreciation - Mill	41	71	51	36	26	26	26	23	18	13	9	6	6
Net after Depreciation	1394	1350	1371	1374	1366	1327	1290	1272	1172	1200	1210	1213	949
Depletion	257	257	254	250	246	239	234	230	211	214	215	215	168
Net after Depletion	1137	1093	1117	1124	1120	1088	1056	1042	961	986	995	998	781
Colorado State Tax @ 5%	57	55	56	56	56	54	53	52	48	49	50	50	39
Federal Taxable Income	1081	1038	1061	1068	1064	1033	1004	990	913	937	945	948	742
Federal Income Tax @ 35%	378	363	371	374	372	362	351	347	320	328	331	332	260
Alt. Minimum Taxable Income	1331	1340	1338	1325	1305	1268	1242	1210	1092	1115	1141	1163	910
Minimum Tax @ 20%	266	268	268	265	261	254	248	242	218	223	228	233	182
Federal Income Tax	378	363	371	374	372	362	351	347	320	328	331	332	260
Net Profit	702	675	690	694	692	672	652	644	594	609	614	616	482
Explo. & Dev. Deductions	3.6	2.4	1.2	1.2	0	0	0	0	0	0	0	0	0
Depreciation - Mine	25	42	30	22	15	15	22	18	8	5	4	4	4
Depreciation - Mill	41	71	51	36	26	26	26	23	18	13	9	6	6
Depletion	257	257	254	250	246	239	234	230	211	214	215	215	168
Operating Cash Flow	1029	1047	1026	1004	979	952	934	914	830	841	842	841	660
Capital Expeditures	0	0	0	0	0	0	0	115.9	0	0	0	0	0
Net Cash Flow	**1029**	**1047**	**1026**	**1004**	**979**	**952**	**934**	**799**	**830**	**841**	**842**	**841**	**660**
Net Present Value	**2704**												

Table 15: Optimum Cutoff Grade Policy Two Minerals Case (Mine & Mill Cap. 60, 40 Respectively)

YEAR	PB	COG1	COG2	Qm (Mtons)	Qc (Mtons)	Qr1 (1000's T)	Qr2 (1000's oz.)	PROFIT ($M)	NPV ($M)
1	1	0.389	0.003	46.33	25.10	190.22	900.00	613.85	3035.94
2	1	0.344	0.003	41.25	25.10	178.45	900.00	595.34	2877.48
3	1	0.294	0.003	36.72	25.10	166.78	900.00	576.49	2713.77
4	1	0.244	0.003	5.69	4.32	26.89	154.82	96.18	2544.35
4	2	0.233	0.003	30.09	23.12	141.98	745.18	479.92	2544.35
5	2	0.183	0.003	33.14	27.92	160.97	900.00	561.79	2349.89
6	2	0.117	0.003	30.73	27.92	152.15	900.00	546.55	2140.59
7	2	0.062	0.003	29.84	27.92	148.43	900.00	539.98	1915.13
8	2	0.025	0.003	6.20	5.92	30.91	190.83	113.48	1662.42
8	3	0.025	0.003	24.48	23.16	120.89	709.17	429.68	1662.42
9	3	0.025	0.003	31.07	29.39	153.42	900.00	545.30	1368.62
10	3	0.025	0.003	31.07	29.39	153.42	900.00	545.30	1028.61
11	3	0.025	0.003	31.07	29.39	153.42	900.00	545.30	637.60
12	3	0.025	0.003	12.31	11.65	60.81	356.70	216.12	187.93

Table 16: Cash Flow Analysis Of Production Period Two Mineral Case
(Mine and Mill Cap. of 60 & 40 Millions Respectively)

Year	5	6	7	8	9	10	11	12	13	14	15	16
Revenues	1844	1816	1789	1793	1777	1757	1747	1757	1759	1759	1759	696.8
Royalty @ 5%	92	91	89	90	89	88	87	88	88	88	88	35
Tons Mined	46	41	37	36	33	31	30	31	31	31	31	12
Tons Processed	25.1	25.1	25.1	27.44	27.92	27.92	27.92	29.08	29.39	29.39	29.39	11.65
Operating Cost	109	104	99	104	102	100	99	103	104	104	104	44
Property Tax	115	112	109	108	106	104	102	104	103	101	101	41
Severence Tax	20	20	19	19	19	19	19	19	19	19	19	7
Net after Costs	1508	1490	1471	1472	1461	1446	1440	1443	1446	1447	1447	570
Explo. & Dev. Deductions	3.6	2.4	1.2	1.2	0	0	0	0	0	0	0	0
Depreciation - Mine	33	57	41	29	21	21	21	19	14	10	7	5
Depreciation - Mill	56	96	68	49	35	35	35	31	24	17	12	9
Net after Depreciation	1415	1334	1361	1393	1405	1390	1384	1393	1408	1420	1428	556
Depletion	262.7	259	255	256	253	250	249	250	251	251	251	99
Net after Depletion	1152	1075	1106	1138	1152	1140	1135	1143	1157	1170	1178	457
Colorado State Tax @ 5%	58	54	55	57	58	57	57	57	58	58	59	23
Federal Taxable Income	1095	1022	1051	1081	1094	1083	1079	1086	1099	1111	1119	434
Federal Income Tax @ 35%	383	358	368	378	383	379	377	380	385	389	392	152
Alt. Minimum Taxable Income	1362	1344	1336	1347	1343	1329	1326	1318	1309	1316	1346	533
Minimum Tax @ 20%	272	269	267	269	269	266	265	264	262	263	269	107
Federal Income Tax	383	358	368	378	383	379	377	380	385	389	392	152
Net Profit	712	664	683	702	711	704	701	706	715	722	727	282
Explo. & Dev. Deductions	3.6	2.4	1.2	1.2	0	0	0	0	0	0	0	0
Depreciation - Mine	33	57	41	29	21	21	21	19	14	10	7	7
Depreciation - Mill	56	96	68	49	35	35	35	31	24	17	12	12
Depletion	262.7	259	255	256	253	250	249	250	251	251	251	99
Operating Cash Flow	1067	1078	1048	1037	1020	1010	1006	1006	1003	1000	997	400
Capital Expeditures	0	0	0	0	0	0	0	156	0	0	0	0
Net Cash Flow	**1067**	**1078**	**1048**	**1037**	**1020**	**1010**	**1006**	**850**	**1003**	**1000**	**997**	**400**
Net Present Value	**2670**											