OPTIMIZING CUT-OFF GRADES

Jeff Whittle[1] and Christopher Wharton[2]

INTRODUCTION

It has long been known that there is more to processing cut-offs than just balancing the day-to-day costs of processing against revenue. For some time now the time costs of the mine have been factored into the processing costs, with a consequent increase in the marginal cut-off. However, in 1988, Kenneth F. Lane, of RTZ in England, published a book called "The Economic Definition of Ore" in which he explained in considerable detail the concepts involved in calculating cut-offs which would maximize not the cash flow but the Net Present Value (NPV) of a mine. He showed that in many cases there are considerable gains to be made by taking this approach.

Lane also described a program called OGRE which could be used to calculate the necessary cut-offs. Although a small number of copies of OGRE are in use in the industry, it has not achieved wide distribution, if only because RTZ do not see themselves as software publishers. To our knowledge OGRE is only available to companies for whom RTZ has done consulting.

This paper describes a new cut-off optimization program, called Opti-Cut, which can significantly increase the NPV of most open cut or underground mines by optimizing the cut-offs used during the operating life of the mines. It handles all the variables which occur in real mining, and is easy to use. It was developed over a period of about three years by Whittle Programming Pty. Ltd., of Melbourne, Australia.

HOW NPV CAN BE INCREASED

A million dollars that we receive today is more valuable to us than a million dollars that we receive in a year's time. There are two reasons why this is so. There is the fact that we can invest the million dollars that we receive now and gain significant income from it for the next year, or alternatively we may be able to avoid paying the interest on a million dollars borrowed. There is also the risk of not receiving it at all, due to some unforeseen circumstance.

It is usual to reduce each future cash flow by a certain percentage per year, known as the discount rate, to give its value to us today. For example, Figure 1 shows a constant cash flow of one million dollars per year for ten years, with its discounted equivalent. With a discount rate of 12 per cent,

1. JEFF WHITTLE
Qualifications: Bsc (Hons) Physics, Manchester University, UK.
Memberships: FAusIMM. SME (USA). CIM (Canada). MACS. AIIA.
Experience: AERE and MRC Radiobiological Research Unit, Harwell, UK. Defence Standards Laboratory. Monash University Computer Centre. Victorian Hospital and Charities Commission. Newcrest Mining Ltd. (All in Australia)
Currently: Director and Technical Consultant, Whittle Programming Pty Ltd, Australia.

2. CHRISTOPHER WHARTON
Qualifications: BEng, MEng Sci, University of Melbourne, Australia.
Experience: Lincolne Scott Pty Ltd; Statistical Information Australia Pty Ltd; Consuldata; Ascom Pty Ltd; EPT Pty Ltd; Consulting Environmental Engineers Pty Ltd. Founder: Australian Optimal Computer Systems Pty Ltd (Australia).
Currently: Technical Consultant, Whittle Programming Pty Ltd, Australia.

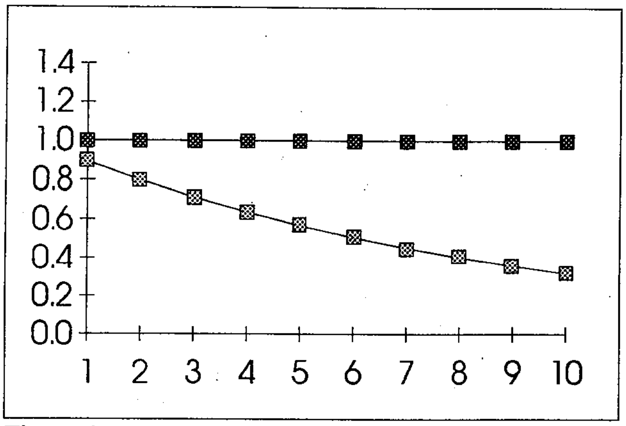

Figure 1. Constant and discounted cash flows

the total of the discounted cash flows is only 5.650 million dollars. This is the project's value today, the NPV. The 10th year's cash flow is worth only 0.322 million dollars to us in today's dollars. Clearly the earlier we can get money the better.

Figure 2 shows the same total cash flow, but 20 per cent higher for the first five years and 20 per cent lower for the last five years. This 10 million dollar total cash flow is worth 5.962 million dollars today, an improvement of five and a half per cent. It also offers the significant advantage of a shorter pay back period for our initial investment.

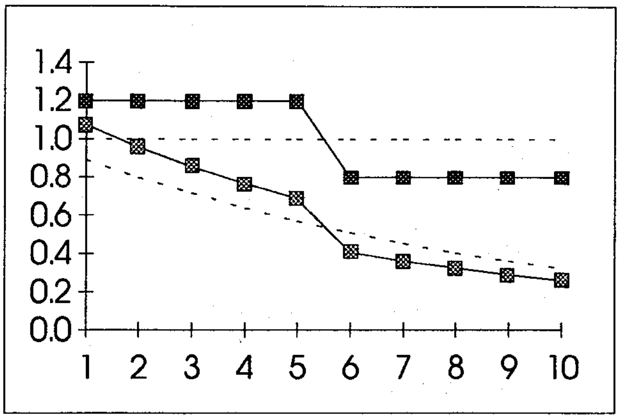

Figure 2. Cash flows and discounted cash flows which are 20% higher for first five years and 2 0% lower for last five years. Constant cash flows shown dashed.

Figure 3 shows a cash flow which is 20 per cent higher for the first five years as in Figure 2, but 30 per cent lower for the last five years. Thus the total cash flow is reduced from 10 million dollars to 9.5 million dollars, i.e. by five per cent.

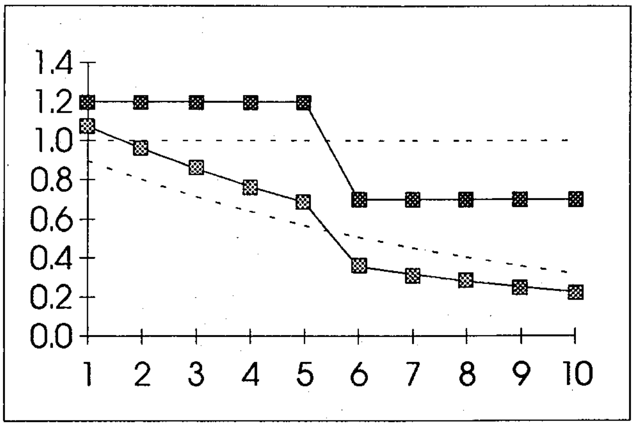

Figure 3. Cash flows and discounted cash flows which are 20% higher for first five years and 30% lower for last five years. Constant cash flows shown dashed.

Nevertheless the NPV is 5.758 million dollars, which is still an improvement of two per cent on that from the original constant cash flow.

This shows that it is possible to increase the value of a project by increasing early cash flows at the expense of later cash flows, even if the total undiscounted cash flow is thereby somewhat reduced.

Can we do this sort of thing in mining? At most mines, yes. Particularly if the production at a mine is limited by the throughput of the mill, there is usually an opportunity to move the cash flows around so as to increase the NPV.

First we have to realise that, if we raise the cut-off above the marginal cut-off, there are two effects. One is that we reject ore that could otherwise have produced a positive cash flow. The other is that we increase the average grade through the mill. Consequently, we increase the amount of product produced by the mine per year, and hence our cash flow per year.

How much, and for how long, should we increase the cut-off? Should we stockpile the rejected material and process it later, even if there are extra handling costs involved? Obtaining objective

As the resource is used up, the NPV of the remainder of the resource tends to fall, and is zero when no further resource remains. Since both the delay and the change costs are dependent on the remaining NPV, they too tend to fall. In general, therefore, optimized cut-offs start high and progressively decrease throughout the life of the project.

• THE STEPS INVOLVED IN OPTIMIZATION

Optimizing the cut-offs for a project for all the years at once, while taking into account the complications of multiple rock types, processing methods and products, is a formidable task, which is impractical with present day computers. Fortunately, Lane has shown that it is possible to break the problem down into a number of smaller problems, by optimizing each year separately within a larger optimization loop.

When economic circumstances are unchanging and the change cost is zero, we start with a pseudo initial NPV for the project and use this to optimize the cut-offs for the first year. The cash flows for the first year allow us to calculate the pseudo NPV at the start of the second year, so that we can then optimize the second year etc. When we get to the end of the resource we can calculate the actual NPV of the project with the cut-offs we have generated. This process is repeated in a series of iterations during which we vary the pseudo initial NPV to find the one which gives the highest actual NPV. The number of iterations varies, but is usually in the range of ten to twenty.

If the economic circumstances change with time, we first carry out the optimization described above, starting the project at the year of the last economic change. This requires no estimate of the change cost because it is, by definition, zero. We then repeat the optimization starting a year earlier and using the previous optimization's results to calculate the change cost. We repeat this until we have optimized the project starting in the first year, and thus have the results we require.

If the last economic change were expected to be in ten years time, this approach would involve repeating the optimization ten times. However, experience seems to indicate that starting five years hence is enough, no matter how far into the future a change is expected. In any case, who can be certain of the economic circumstances ten years hence?

INPUT DATA

All data is input to Opti-Cut in the form of two text files. The Sequence Text File describes the material which is to be mined in the sequence in which it is to be mined. The Economic Text File describes the economic and operational conditions under which mining is to take place.

• THE SEQUENCE TEXT FILE

A Sequence Text File has the following structure:

A description of the sequence
The product(s) to be produced
Any significant poisons
The rock types
One or more "Increments" consisting of:
    An Increment description
    One or more "Groups"

answers to these questions involves difficult calculations which depend in complicated ways on the throughput capacities, on the grade distribution of the mining sequence, and on the prices and costs throughout the life of the mine. This is why it has taken Whittle Programming so long to produce its cut-off optimizer, "Opti-Cut". We started three years ago, and it has required a significant amount of research as well as programming.

HOW THE OPTIMIZATION IS ACHIEVED

• THE SPECIAL COSTS

Lane explained that, in addition to the normal cash costs which must be considered in the processing cost when calculating cut-offs, there are two pseudo costs which are also important. We refer to these as the "delay cost" and the "change cost".

Both these costs take account of the fact that any mining or processing activity takes time, and therefore delays the exploitation of the rest of the project.

For example, consider a scenario where we have a resource consisting of ten million tonnes of ore and waste. We have fixed the way that we are going to exploit the last nine million tonnes of the resource, and hence the consequent cash flows in today's dollars, but we are considering two different methods, A and B, of exploiting the first million tonnes.

If method B takes six months longer than method A, then, in addition to having a different cash flow from A, it will also delay all the cash flows from the exploitation of the last nine million tonnes by an extra six months. That is, the exploitation of the last nine million tonnes starts six months later if we choose method B.

If the discount rate is 12 per cent, the net present value of the last nine million tonnes will be decreased by about six per cent, and there is therefore an effective cost of one per cent of the NPV of the last nine million tonnes for every month that we spend exploiting the first million tonnes. Since it depends on the time taken rather than on the tonnes exploited, it is a type of time cost, and we call it the "delay 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 any accounts.

Everyone knows that cash flows are higher if we exploit our resource when the price of the product is high, and vice versa. Using the previous example, if we delay the exploitation of the last nine million tonnes to a period of lower prices, we reduce the cash flows for the nine million tonnes, and hence the NPV of this nine million tonnes. Since this effect will generally get bigger with increasing delay, we again treat it a type of time cost, and we call it the "change cost". It is different from all other time costs because, if the price of the product increases with time, it can be negative. That is, it can be advantageous to delay part of the project. Note that, if the economic circumstances are constant, the change cost is zero.

If the project is mill limited, both the delay and the change costs should be added to the processing cost when calculating the cut-off. Consequently, the delay cost, which is always positive, increases the cut-off. The change cost can increase or decrease the cut-off, depending on whether the economic circumstances are deteriorating or improving, respectively.

Each line type is identified by an alphabetic code and contains items separated by spaces.

In this context an "Increment" is a particular section, phase or cut-back of the mine. It will usually contain sufficient tonnage to satisfy at least a few months' production. Increments should appear in the sequence in which they will be mined. Opti-Cut makes no attempt to modify this sequence.

If only a fraction of a particular increment is mined during a particular time period, the same fraction of each part of it is assumed to be mined. This is not how mining takes place in practice, but it has no appreciable effect on the cut-offs.

Each increment consists of a number of "Groups" which, collectively, describe the rock types and grade distributions in the increment. Depending on the amount of detail available about the grade distributions there may be anything from a handful to tens of thousands of groups in an increment.

Each group has a rock type, a tonnage, and, for each product or poison in that rock type, a grade range and average grade. It can also carry positional cost adjustment factors for mining and processing costs.

It is not appropriate in this paper to give a detailed description of the file, but the simple Sequence Text File below will give the flavour of it.

```
! Description
  SEQ Simple sequence with 1 increment
!   Product code and decimal places
    PR  GOLD  2
!   Rock type information
    RO OXIDE
      ELP GOLD
    RO WASTE
! Increment
  IN The only increment
  GR WASTE 7000000
!                       Min    Avg     Max
  GR OXIDE   470000
    ELR     GOLD        0.25   0.78    1.0
  GR OXIDE 1428000
    ELR     GOLD        1.0    1.48    2.0
  GR OXIDE   715000
    ELR     GOLD        2.0    2.42    3.0
  GR OXIDE   239000
    ELR     GOLD        3.0    3.41    4.0
  GR OXIDE    77000
    ELR     GOLD        4.0    4.41    5.0
  GR OXIDE    71000
    ELR     GOLD        5.0    6.61   10.0
```

This represents a ten million tonne gold resource which is to be mined as a single increment.

The first "group" shows seven million tonnes of waste. The last six show three million tonnes of oxide ore with a log-normal grade distribution averaging 1.94 g/T.

The lines starting with an exclamation mark are comment lines, which can be inserted anywhere.

The indenting on the left, and the multiple spaces between items on the data lines, are merely cosmetic. Any spaces added to the one required to separate items are ignored.

In a very simple case, a Sequence Text File might be produced with a text editor, as this example was. More commonly it will be produced by a generalized mining package or by Four-D.

• THE ECONOMIC TEXT FILE

Although Economic Text Files are not large, and are usually prepared with a text editor, they can contain very complex information, because economic reality can be complicated.

The minimum Economic Text File has the following structure:

```
A description of the economic scenario
The length of a period
The time costs
The discount rate
The required cut-off accuracy
The price
The mining cost for each rock type
One or more processing path definitions:
  The Method/Rock-type combination
  The processing cost and recovery
The throughput limits
```

The following simple example, illustrates this.

```
! The period length in months
  PL 12
! Annual time costs
!  (can be monthly by using M)
  TC A 600000
! Discount percentage per year
  DI 12
! Grade discrimination
  GD GOLD .01
! Product line - the price
  PR GOLD P 12.40
! Rock type lines
!  with their mining costs
  RO OXIDE M 1.20
  RO WASTE M 0.80
! Processing path definition
  ! Processing OXIDE ore
  !  in the MILL costs $9.60 per tonne
    MT MILL OXIDE 9.60
     ! The recovery is 90 per cent
       MTP GOLD R 90
! The annual MILL throughput limit
  TL MILL A 250k
```

SIMPLE CASE

If we use the above sequence and economic data without optimization and a constant marginal cut-off of 1.08, the mine life is 9.92 years, the total cash flow is 21.507 million dollars, and the NPV is 12.375 million dollars.If we optimize, the cutoffs and cash flows vary as is shown in Figure 4. The mine life is 7.70 years, the total cash flow is 20.398 million dollars, and the NPV is 13.147 million dollars. This is an improvement in NPV of 6.2 per cent, even though the total undiscounted cash flow has decreased by 5.2 per cent. However, the mine life has been reduced to 7.70 years, and this would not usually be looked upon with favour.

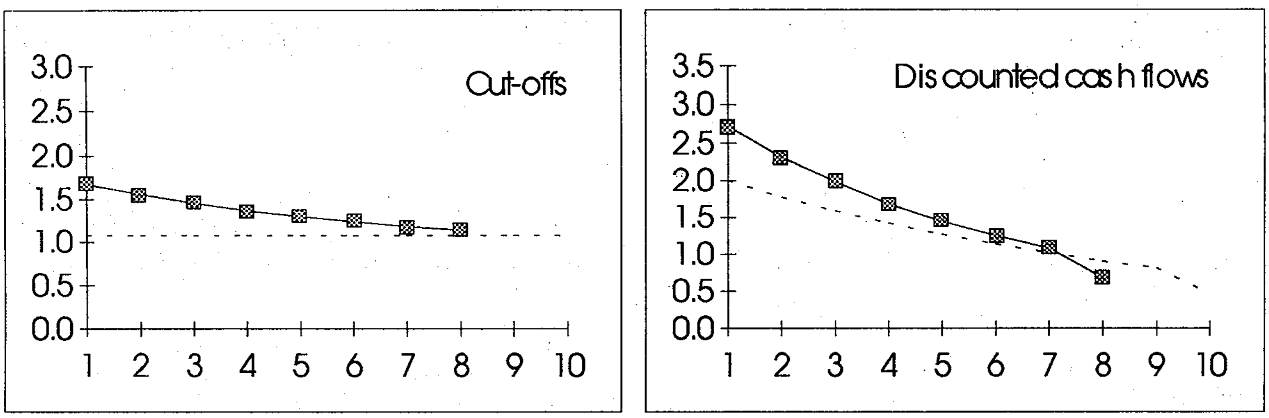

Figure 4. Cut-offs and discounted cash flows with optimization. Un-optimized figures are shown dashed.

What happens if we stockpile some of the material we have rejected, and process it when we run out of material from the mine?

THE EFFECT OF ADDING A STOCKPILE

Adding a stockpile to a mining operation adds complication and cost. The application of two cut-offs needs care. There are also re-handling costs.

Opti-Cut can deal with this. In fact it can handle multiple stockpiles for different rock types and different grade ranges. It also has the ability to use stockpile material to top up the mill if it is starved by a period of unusually high stripping ratio.

In the next example we define a stockpile with a re-handling cost of 60 cents per tonne and a cut-off of 1.13. Note that this is higher then the normal marginal cut-off of 1.08 because of the re-handling cost. All we have to do is add a few lines to the Economic Text File:

```
!      init.size    rehandling cost
        SP OXIDE    0.0   0.60
!        cut-off
             SPD    GOLD  C       1.13
```

If we optimize, the cutoffs and cash flows vary as is shown in Figure 5. The cut-offs are even higher initially, and mining is completed after 5.13 years, but the mill continues to operate for another 4.19 years. The total cash flow is 21.465 million dollars, and the NPV is 13.763 million dollars. This is a total improvement due to optimization of 11.1 percent, and an improvement over the optimization without a stockpile of 4.9 per cent.

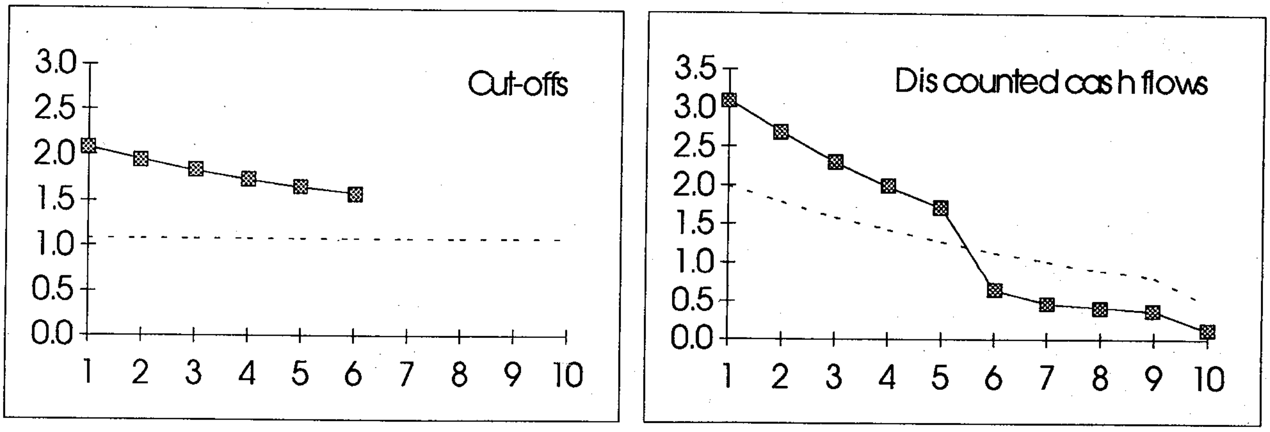

Figure 5. Cut-offs and discounted cash flows with a single stockpile. Un-optimized figures are shown dashed.

Note that, initially, the cash flow is 50 per cent higher than the marginal cut-offs case. This would usually significantly shorten the payback time for the mine.

Of course, the high cut-offs in the early years produce high stripping ratios. What happens if we set a maximum on the mining capacity as well as on the milling capacity?

THE EFFECT OF LIMITING THE MINING CAPACITY

The stripping ratio in the first year was 8.79 in the above case. If we restrict it to 6.00, Opti-Cut sets the cut-off so as to balance the mining and milling for the first three years. The result is that mining continues for an extra year at the expense of milling time at the end. The total cash flow is unchanged 21.465 million dollars and the NPV is 13.704 million dollars, a reduction of about half of one per cent. The graphs are shown in Figure 6.

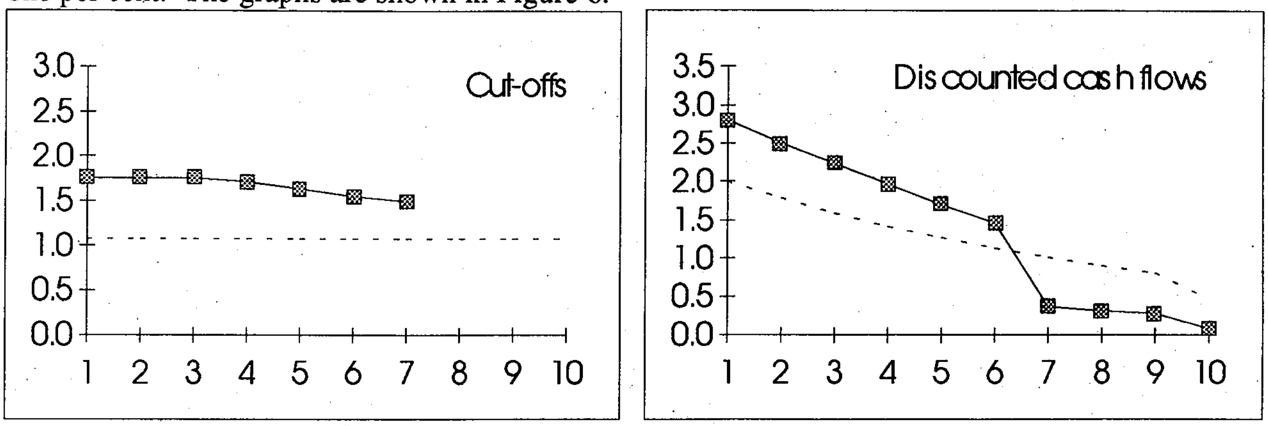

Figure 6. Cut-offs and discounted cash flows with a single stockpile and stripping ratio limited to 6. Un-optimized figures are shown dashed.

The above three cases, which are all for the same price and costs, are summarised in Table 1.

Case	Life	Cash	NPV	%
Marginal cut-offs	9.92	21.507	12.375	-
Optimized cut-offs	7.70	20.398	13.147	+6.2
.. plus stockpile	9.32	21.465	13.763	+11.2
... plus mining limit	9.32	21.465	13.704	+10.7

Table 1

THE EFFECT OF A PRICE CHANGE

When the product price is high, it seems to make sense to lower the cut-off, because lower grade material can still be processed profitably. However, as Lane pointed out, if the mine is processor limited, this means that we sell less product when the price is high and more when the price is low. This doesn't seem such a good idea.

Lane showed, and Opti-Cut can demonstrate, that it is better to raise the cut-off during periods of high price, and vice versa.

In Figure 7 we show what happens to the case with a stockpile but no mining limit, if the product price is 50 per cent higher during the first three years. The cut-off goes very high and mining is completed in three years, although processing goes on for another 6.32 years.

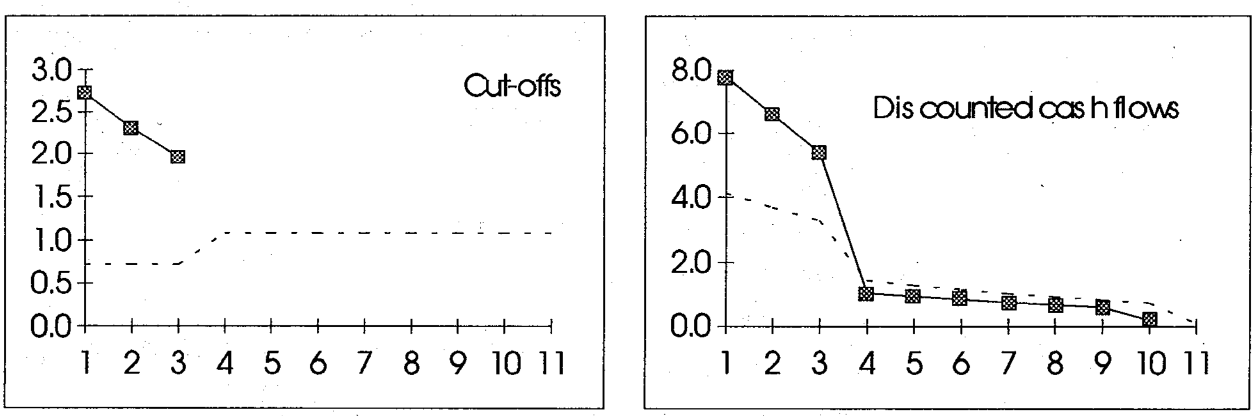

Figure 7. Cut-offs and discounted cash flows with price 50% higher in first three years, and a single stockpile. Un-optimized figures are shown dashed.

This is extreme. The stripping ratio in the first year is 17.88, and the stockpile would be very large, but the NPV is increased by 34.2 per cent over the marginal cut-off NPV for these prices, and the cash flow is almost doubled in the first year. It raises the question of whether we could achieve the necessary mining rate with the aid of contract mining. The enormous increase in NPV makes it worth looking at.

However, if we apply the same mining limit as before, and restrict the stripping ratio to 6.0, we get the results shown in Figure 8. Now mining continues for six years with the total mine life unchanged. The gain in NPV over the marginal cut-offs case is now 25.2 per cent.

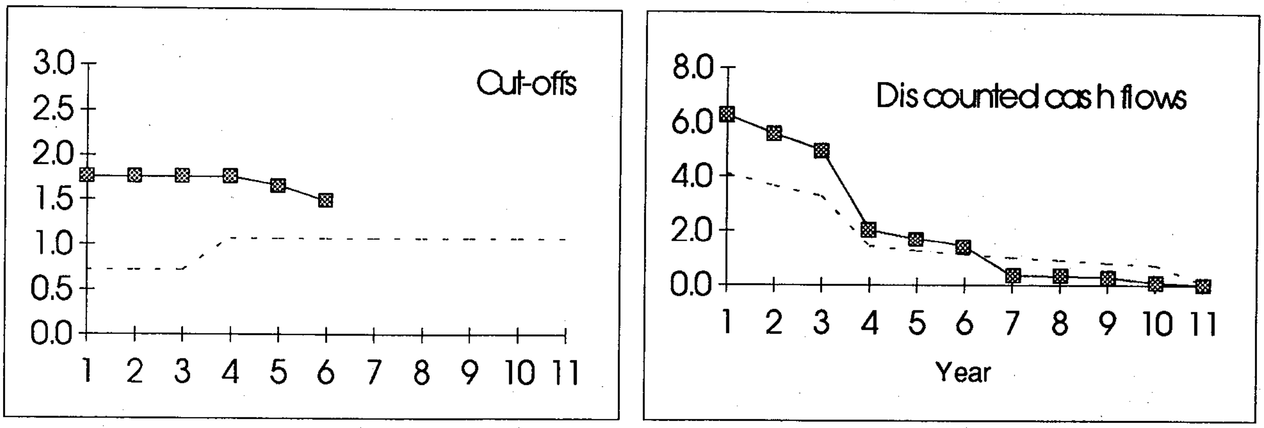

Figure 8. Cut-offs and discounted cash flows with price 50% higher in first three years, a single stockpile, and stripping ratio limited to 6. Un-optimized figures are shown dashed.

FLEXIBILITY

The above examples are all very simple, in that they involve one ore type and one processing method. However, Opti-Cut can deal with the real world of mining.

In addition to the facilities already mentioned, Opti-Cut can handle:

- Multiple rock types
- Multiple processing methods
- Multiple products
- Multiple poisons
- Capital injections in nominated periods
- A non-zero terminal value
- Sales costs
- Environmental costs
- Recoveries and processing costs which depend on the grades of poisons as well as of products
- Maximum and minimum cut-offs
- Variation of mining and processing costs with position
- Multiple stockpiles with initial tonnages and grades
- Stockpile degradation with time
- Complex throughput limits

Almost all the quantities in the Economic Text File can be given as arbitrary expressions which vary with time.

CONCLUSION

Opti-Cut is a practical tool which can be used to significantly increase the NPV of any mine where the mine life is more than two or three years, and where production is limited by something other than mining capacity.

ACKNOWLEDGEMENT

The authors wish to thank Kenneth F. Lane. Although, in the final analysis, none of his optimization methods were utilised, this project would not have been started, or completed, without access to the explanations and insights contained in his book "The Economic Definition of Ore".

REFERENCE

Lane K F, 1988, The Economic Definition of Ore. *Mining Journal Books Limited*, London.

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