Risk Based Selection of Pit Shells for Scheduling
Dr. Clive Seymour

Qualifications: BSc Mining Engineering, University College Cardiff, UK.
               PhD Strata Mechanics, University College Cardiff, UK.
Membership: AusIMM, SAIMM.
Experience:
            National Coal Board (UK).
            De Beers Corporation (RSA).
            Anglo American Corporation of South Africa (RSA).
            Steffen, Robertson and Kirsten (RSA).
            Seven years production experience.
            Ten years consulting experience specialising in computerised mine planning and risk assessment.
Currently: Managing Director, Steffen, Robertson and Kirsten (Australia).

Abstract

Four-D has allowed mine planning engineers to generate a nest of optimised pit shells that consider the numerous factors that have a major effect on the success or otherwise of a mine plan. The nest of pits is generated using a range of MCOSTM values for which one can assume a fixed mining cost (COSTM) and a variable revenue (PRICE). During analysis, the expected costs and revenues are used to investigate the cashflow and sensitivities. Ultimately, the final pit and incremental shells are selected for a given expected price.

This paper proposes an alternative method for incremental pit shell selection that considers the risk the mine is prepared to accept.

The life of mine is divided into a number of Business Risk Periods (BRP). The BRP represents the period of time over which the owner is prepared to invest capital. During each BRP, the mine will then operate at a selected investment cost that is generally equal to or greater than the minimum required to meet production targets.

In this way, a robust mine plan can be produced which allows the mine to react to change without having to alter the incremental shell limits while maintaining a strategic risk profile.

This paper will summarise factors to be considered in selection of the BRP and how Four-D can be used to select the incremental pit shells within the BRP.

Introduction

The use of Four-D has been covered by a number of papers and the process of running Four-D is well understood, judging by the acceptance of the system by the mining community worldwide.

This paper deals mainly with an analytical technique involving the planning of open pit mines that has been refined using Four-D. Normally planning procedures assume a target price and then develop a mining plan according to specific economic criteria. By definition, such a plan is only ‘correct’ if the price assumption is correct. For a mine with a reasonable life of say more than 5 years, price projections become highly speculative, and revised plans have to be generated as the price projections change. This can lead to gross inefficiencies in the mining layouts since the plans are usually sensitive to price. In actual fact, the technical planning function is concerned with the volume and cost of production delivered from the pit. The result does not usually influence the market price directly, unless the mine is the major world producer of the commodity, so the price of the product need not be the only key parameter in determining the technical planning process.

In this paper it is suggested that the risk can be adequately defined by the cost of production and resulting flexibility incorporated into the mine plan. Fundamental decisions during the course of planning have to be made which define the overall mine plan adopted and these fundamental questions are considered on the basis of a risk assessment.

Mineral Resource Estimation and Slope Stability

All open pit mine planning functions begin with an appreciation of the mineral resource estimate and slope stability. Both fall outside the scope of this paper but since they form a major risk item some comment is made.

The resource statement can be categorised into measured, indicated and inferred, referred to as CAT1, CAT2 and CAT3 respectively and each
classification is effectively a statement of confidence or risk.

This can be shown in a tonnage grade curve as presented in Fig 1.

Generally, the slope design requirements only become apparent once a prospective mineral resource has been discovered. The exploration core will usually have limited value for slope design purposes as the target areas for slope design are not necessarily the same as those for the orebody. A limited drilling programme may be conducted for geotechnical purposes but it is not uncommon to have a slope design which has a much lower level of confidence than the orebody.

By definition, the mineable reserves within the resource are determined by applying a mine design that could economically exploit the resource. Within a life of mine for example, resources of different confidence categories will be included, i.e. CAT 1, CAT 2 and CAT 3 resources. By applying the mine planning procedures, these resources will be reclassified as proven, probable and possible reserves respectively.

Maintaining a consistent assessment of confidence would require that the confidence of the slope design should match that of the mineral resource estimation between different categories. It has been proposed (Steffen, O.K.H. 1997) that for open pit designs, the confidence for slope designs should be categorised using the same fundamental approach as that adopted for resource/reserve definitions.

Planning Processes

Typically, the mine plan has to be used at different levels in any mining organisation. Corporate decisions are made at the board level with regard to strategic and global direction, stockmarket and shareholder announcements etc. Mine management have to make capital expenditure decisions and optimise the utilisation of resources and infrastructure. Mine operators have to control the mine to ensure the production targets are met.

Each of these three “users” of the mine plan will require the same plan presented in a different way to a different level of detail. A single plan will not meet this objective.

As a result, there are three distinct levels of mine planning that are required, as follows:

- Life-of-mine (LOM).
- Long-term plan (LTP), which follows from the LOM.
- Short-term planning, (STP) which in turn follows from the LTP.

Each of these stages of planning represent different levels of risk and have different objectives. It follows therefore that the planning criteria for each planning phase should be different but each of the steps will be interlinked; for example, every activity in the short term plan should benefit the long-term objectives as defined in the life-of-mine. The interaction can be illustrated diagrammatically as shown in Fig 2.

This paper concentrates on the first two planning stages i.e. the LOM and the LTP. If these two stages are sufficiently robust the resulting short term plan can concentrate on control of the operation to achieve the LOM and LTP targets.

Life of Mine (LOM)

Development of the LOM is the first step in the planning process and has the following objectives:

- Define the inventory of ore reserve that is mineable within the assumed economic parameters
- Define the production capacity for the remaining life of mine
- Define the infrastructure requirements
- Determine the fixed capital costs
- Provide information for strategic decision making.

To achieve these objectives, certain planning criteria need to be adopted.

Cut-Off Cost Planning Criteria

The life-of-mine open pit represents that outline of the open-pit boundary faces beyond which no further reserves should be recovered by open-pit methods.

This limiting boundary can be defined by:

- the total ore reserve being exhausted
- the marginal increment of mining cost exceeds the expected income and that the economic limit of open pit mining has been reached
- an underground operation becomes more profitable than the incremental open pits.

But for the first one, the limit of these criteria is defined by the incremental mining cost exceeding a
specified value. To determine the open pit boundary, a criterion that is sensitive to mining cost should be used to define the LOM limit. For this reason, a cut-off cost criterion is proposed which is the cost of producing the finished product from the final increment.

Typical financial criteria, such as net present value (NPV) or internal rate of return (IRR), are relatively insensitive to the boundary limit location. These criteria are more sensitive to the price assumed for the product, the production schedule for mining, as well as the assumed discount rate. Since the mining schedule is still unknown at this stage, these criteria cannot be used effectively for this purpose. When defining the total inventory available for exploitation, it is important that every block be afforded an equal opportunity to contribute to the profitability.

The cut-off cost criteria can be summarised as follows: The LOM pit limits are such that no ore is mined which will result in the final product having a production cost greater than the cut-off value. The specification of this cut-off cost is related to an acceptable risk.

The first objective of the life-of-mine plan is to determine the maximum inventory of open-pit mineable reserves. The common process, assuming a block model, is to assign total rock tonnage, mineralised rock tonnage and total units of metal to each block. FDOP is then used with a range of revenue and cost ratios to define a series or nest of pits, each of which is optimal for a particular economic scenario. “Optimal” can be defined as the maximum net result of revenue minus costs for a given set of economic inputs.

The maximum ore reserve available will therefore be a function of the value assigned to each of the blocks. Ore blocks will have positive values when revenue exceeds costs, and waste blocks will have negative values.

The life-of-mine thus provides the outline of the ultimate pit providing the maximum mineable inventory, from which the infrastructure development can be properly located. This prevents expensive relocation at later stages or compromises the ore development programmes, when market conditions change. Compared to the traditional cut-off-grade approach to pit design, the essential difference lies in the emphasis on determining the mining costs, be it either to the ore process point or to a stockpile or waste location. Should there be no difference between the trammimg costs to the crusher or the dumping location, then the adoption of a marginal cut-off grade for process only, will result in the same design as the use of the cut-off cost.

The procedure suggested here, however, emphasises the decision based on a cost of production rather than a profit that is related to an assumed price. The life-of-mine is therefore a definition of the inventory available which then has to be exploited and managed in order to provide the maximum value to shareholders in accordance with corporate policies and philosophies.

Assuming different cut-off costs, the total inventory available for each incremental cost can be calculated and presented on the curve as shown in Fig 3. The data for this curve can be produced using a series of FDAN analyses on a nest of pits generated by FDOP. During the FDAN run, a range of metal prices are entered with the expected marginal mining cost. FDAN will calculate which shell is optimal for the price (cut-off cost) scenario such that the marginal cost of production will not exceed the price (cut-off cost) of the product.

Defining an Acceptable Cut-off Cost

Deciding on an acceptable cut-off is a business decision. It reflects the optimism and the risk which the company is prepared to accept in investing in the particular ore reserve. Some guidelines and principles underlying such a decision can, however, be postulated as follows:

Firstly, the tonnage vs. cost relationship (Fig 3) for the ore reserve can be a first indicator. Should the relationship indicate an inflection point then this could be taken as a decision on cost limit since the risk of increased cost is not matched with a corresponding increase in product. Since the risk level is largely determined by the ore reserve reliability, this point indicates a natural cut-off point. From previous case studies, not all ore reserves display this inflection point.

Where the inflection point is absent, the next option is to consider the cost in relation to other world producers. Reference to a world producer cost curve is therefore necessary as shown in Fig 4. The relative position of the planned operation on the world producer cost curve is a function of corporate philosophy, for example some companies would tolerate only an operation with a limiting incremental cost which falls within the lower 50 %,
others within the lower two thirds (66.7%) or others, again, within higher limits e.g. 85%. This decision represents the corporate philosophy on investment risk as well as market image. The higher the limit, the higher the risk since the possibility of the price of the product dropping below the cut-off cost is greater. However the higher the limit, the greater the utilisation of the available resource.

It is necessary to distinguish between the cut-off cost and the average operating cost. World producer cost curves represent the average operating costs and not the marginal costs of any particular operation. Since the cut-off cost is that at which it is proposed that the operation cease to produce onto the market, the cut-off cost chosen must be based on comparisons with other operations which are likely to have a comparable effect on the world market if they were to cease operations. It also represents the acceptable margin of risk compatible with the stated mission and philosophy of the company. The margin of risk acceptable to a life-of-mine definition is also a function of the certainty with which the information is known, for example ore reserves and slope angles.

Thirdly, the cut-off cost could be based on the break-even equivalent underground operating cost. These cost comparisons are made on an operating cost basis only, ignoring capital. Clearly, the capital cost for underground development and establishment needs to be included in the total evaluation exercise. The allocation of the boundary ore reserves to underground and open pit operations can readily be incorporated into a Four-D run by assigning values to these boundary blocks equal to the difference in value obtained between underground and open-pit operating costs.

Based on the appropriate cut-off cost criteria, the final limit can therefore be established and total reserves and inventory determined. This information is then utilised for the establishment of infrastructure requirements and life-of-mine capital investment requirements. Strategic decisions can now be made in regard to production rates. The LOM can be presented as a series of graphs that summarise the inventory, cost of production, resource / reserve depletion and capital expenditure as shown in Fig 5. This can then be used to present the LOM to others who were not involved in the compilation of the LOM, for example shareholders, the Stock Exchange and stockbrokers.

Long Term Planning Principles

Having defined the inventory and spatial location of reserves and dumps from the LOM, the long-term plan (LTP) must now devise an operating and mining strategy to achieve the following objectives:

- Maximise value for investors
- Minimise risk to investors
- Maximise life of mine.

These objectives are to some extent contradictory and a maximum NPV cannot correspond to a minimum risk or a maximum life. A suitable compromise therefore must be developed in the LTP.

A suggested ranked order of design criteria for the LTP are:

- An acceptable return for shareholders corresponding to the market sector and corporate philosophy
- An acceptable operating cost to final product relative to world producers
- Flexibility requirements within plan e.g. upside potential: to increase product volume by 15% within 6 months sustainable for 12 months; downside potential: to reduce unit operating costs of final product by 10% within 3 months sustainable for 24 months.

Fig 6 provides a flow diagram illustrating the input, design processes and the outputs of the inter-relationship between the LOM plan and the LTP.

Discounted cash flows are the common basis for evaluating shareholder returns and are expressed in terms of NPV or IRR or similar. Typically a NPV calculation is most sensitive to the following parameters:

- The price of the product
- The discount rate
- The time sequence of the mining schedule
- The cost of production.

The last two parameters are generated by the mine planners while the first two are beyond their control. Risk on the other hand is sensitive to price fluctuations, flexibility within the plan and management skills. The life of the mine is sensitive only to the mining strategy or grade utilisation, i.e. the scheduled mill head grade and the development costs.
The need for compromise decisions between maximising a short term financial return with a longer term acceptable risk can readily be illustrated in a simplified diagram as shown in Fig 7. The minimum cost curve in Fig 7 is determined during the LOM process. Should the future price of the product vary as indicated in the diagram, the mine is at risk of premature closure. Since the reserves were developed at a minimum cost in the attempt to maximise the NPV, it implies that there is no flexibility within the system in order to vary the production costs. Therefore the risk associated with maximising the NPV is high. Flexibility comes at a cost and will result in a lower NPV. However, flexibility has value to the shareholder and the value should be added to the cashflow. This value can be determined using option theory and added to the cash NPV to give a total value, also expressed in NPV terms. The total NPV should be maximised in the planning process.

Should the cost of production be managed differently, e.g. the LTP allows for advanced stripping above that required by the minimum cost curve, then the cost could typically be as represented in the ‘managed’ cost curve shown in Fig 7. For this case, the total benefit exceeds that of the previous minimum cost case, i.e. a retrospective analysis would show a higher NPV for the latter case due to the introduction of a decision on risk. In Fig 6, the metal price curve is unknown while the other two curves are determinants.

Most large open pit mines in the world operate on this basis by adopting an average stripping ratio over the life of mine. While the waste to ore ratio does define costs of mining to a large extent, it is more appropriate to focus on actual cost of production rather than just one of the parameters contributing to cost of production. Cost should also be based on total cost of final product, not only of the mining operation. It is therefore suggested that the cost of operation for the mine be determined by a management decision having regard to the minimum cost possible but incorporating an assessment of risk while satisfying the return necessary for the investment made. The basis for an assessment of risk is associated with a period of time for which additional development costs are acceptable.

**Business Risk Period (BRP)**

In developing the concept of a business risk period (BRP), it is necessary to distinguish clearly between the risks associated with business decisions which are time related from those risks which are related to nature, e.g. such as geology, ore reserves, slope angles, weather etc. The business risk period is one of the most fundamental parameters which need to be defined for any business, and relates to the length of time that is anticipated the business would remain sound. It is also the period over which certain investments are required to produce profits and the investment policy is therefore determined by the business risk period. The BRP is not dissimilar to a payback period. For mines the business risk period is a function of the following parameters:

- New discoveries which create competitive changes in the market
- The time taken for new mines to be brought into production
- Changes in technology of geological, metallurgical and mining applications
- The position on the world producer cost curve of the operation
- Payback requirements on investments, which would include a political risk.

Periods associated with each of these parameters as an example could typically be as follows:

- New discoveries: 1 year
- New mines into production: 4 years
- Technology changes in mining: 10 years
- Position on world producer cost curve: 5 years
- Pay-back period: 5 years

From the above example, a weighted average of approximately 7 to 8 years would result for the business risk period (BRP). Hence the mine would be prepared to make non-recoverable investments for a period of 7 to 8 years, i.e. advanced stripping for a 7 to 8 year ore exposure commitment. The accepted cost of production can then be related to a business period as illustrated in Fig 8.

In the first year of the business period, it is proposed that the average of the minimum cost over the total business period be adopted. The actual cost curve over the life of mine is therefore taken from successive mean averages of 7 or 8 year periods, making the suitable adjustment for investments already made in the prior years. In this way the planned long-term cost curve can be extrapolated over the life of mine, resulting in a maximum risk exposure which is confined to the business risk period at all times.
From this curve, the ore reserve corresponding to the business period can be determined from an FDAN analysis in a similar way to that described to produce the data for Fig 3 i.e. for a selected cost, what is the optimal pit shell? The pit outline corresponding to the end of the first business period can be selected and developed in a normal manner, as shown schematically in Fig 9.

All overburden stripping should therefore be confined to within the limit of this pit outline. Should the decision be made for any unforeseen reason to close the pit prematurely, then no stripping outside of a defined risk period would have been undertaken.

Since operating slopes are generally much flatter than the final pit design slopes, the scheduling of overburden stripping will progress to the outline of the business risk final pit profile, until such time as space constraints prevent the achievement of production targets. Stripping is then scheduled to within the boundary of the next business period outlined, as indicated in Fig 8. Each BRP pushback must be designed as if it is a final pit, i.e. incorporating maximum slope angles.

**Conclusions**

Integration of the three planning levels from life-of-mine, to long-term, to short-term planning, provides a robust planning procedure which allows for good communication between all levels of concerned personnel. That is, from the planning engineer through management to marketing departments.

The cut-off cost criteria for planning is a practical and a more useful means than the normal price estimate or cut-off grade approach; reduces the amount of work involved and concentrates the efforts and skills of the planning team on those issues which they can contribute most to, i.e. improvement of the mine plan. The application of the cost-based long-term planning scheduling means that risks can be properly assessed in terms of a business risk period and the best solution obtained between return on investment and risk of operation. The end result of the planning process is a maximum exposed ore reserve for a given cost of production.

The difference between the proposed procedure and that which is commonly in use today, is that the planning process is driven by the competitiveness of the ore reserve on the world market. Management participate actively in planning decisions and determine the planning criteria. These concern the expected rate of return for shareholders, the risk levels acceptable to the company, the flexibility required in the operation and the acceptable cost of operation.

Conscious decisions need to be taken about certain fundamental parameters, such as the period of risk defined as the business risk period and the cut-off cost at which the mine is prepared to operate.

Experience has shown that the improvement in communication and understanding of decision-making between management and planning engineer has added considerably to the growth in shareholder’s value.

**Bibliography**


SRK Internal Reports.


Larrain M and Thiele C. Anaconda, Chile (for Fig 5)
Fig 1 Characterisation of Resources / Reserves

Fig 2 Planning Procedure
Fig 3 Reserve Marketability

Fig 4 World Producer Cost Curve
Fig 5 LOM Presentation
Fig 6 Planning Process Flow Diagram (Larrain & Thiele)
Fig 7 LTP Cost Schedule Within A BRP

Fig 8 Simplified Risk Diagram
Fig 9 Pit Sequence