

## Open Pit Optimization - Strategies for Improving Economics of Mining Projects Through Mine Planning

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**ABSTRACT:** The open pit design and scheduling problem is a large-scale optimization problem that has attracted considerable attention during the last 40 years. The development of the "know-how" to improve economics of open pit mining projects through the use of mathematical optimization techniques goes back to early 1960's. Unfortunately, up until recently, many of these "optimizing algorithms" could not be implemented due to the limited capacity of the computer hardware used in many mining operations. During the last 10 years, advancements in the computer hardware technology along with developments in software technology allowed open pit mines to have powerful desktop computers that can solve complex optimization problems on site. Due to applications of optimization techniques developed in the early 1960's, for example, Chuquicamata Open Pit Mine in Chile re-evaluated their cutoff grade strategy and improved Net Present Value (NPV) of their operations by US\$800M. Newmont Gold Corporation in Nevada, USA has implemented large scale Linear Programming Model that was developed in early 1980's to schedule their entire mine and mill production in the Carlin District, resulting in significant process costs savings. This presentation will outline open pit optimization techniques that are available today and how they can be used to improve overall economics of projects that are being planned or in production.

### 1 INTRODUCTION

The current practice of planning of hard rock open pit mine begins with a geologic block model (see Figure 1) and involves determination of: 1) Whether a given block in the model should be mined or not; 2) If it is to be mined when it should be mined; 3) Once it is mined then how it should be processed. The answer to each of these questions, when combined within the whole block model, define the annual progression of the pit surface and the yearly cash flows that will be coming from the mining operations during the life of mine. There can be many different solutions to the scheduling problem depending on how the decision is made for each of the blocks. Decision as to which blocks should be mined in a given year, and how they should be processed (i.e. waste, run of mine leach, crushed ore leach or mill ore etc.) defines not only the cash flows for that year but also impacts the future annual schedules. What is decided today has long-term implications as to what can be done in the future and all these decisions link together in defining the overall economics of the a given project. The objective of the planning process for an open pit mine is usually to find optimum annual schedules that will give the highest Net Present Value (NPV)

while meeting various production, blending, sequencing and pit slope constraints.

Traditionally, the scheduling problem described above is solved by dividing the problem into sub problems similar to one shown in Figure 2. The solution step starts with the assumption of initial production capacities in the raining system and the estimates for the related costs and commodity prices.

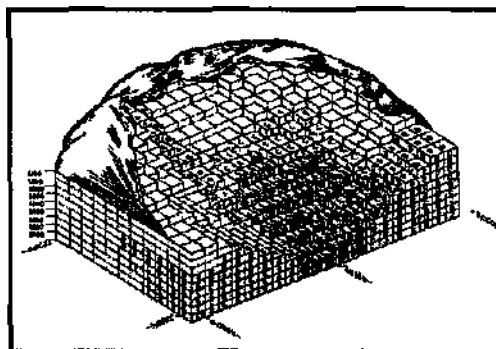


Figure 1 3-D geologic block model representation of a copper deposit.

Once the economic parameters are known, the analysis of the ultimate pit limits of the mine is undertaken to determine what portion of the deposit can economically be mined. Within the ultimate pit limits, pushbacks are further designed so that deposit is divided into nested pits going from the smallest pit with highest value per ton of ore to largest pit with the lowest value per ton of ore. These pushbacks are designed with haul road access and act as a guide during the scheduling of yearly productions from different benches. The cutoff grade strategy is defined as to differentiate ore from waste and further to determine how the individual blocks should be processed. These steps are repeated in a circular fashion as further improvements are made with respect to adequacy of the production capacities and the estimated costs.

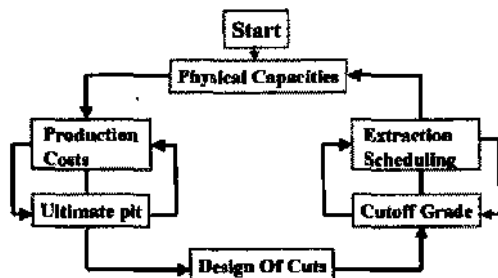


Figure 2. Steps of traditional planning by circular analysis.

There are many sophisticated software packages in the mining industry to perform ultimate pit limit analysis, design of pushbacks and to determine yearly mine plans and schedules. These computer programs are regularly used by the mining engineers in generating mine plans and schedules that are feasible. These plans are regularly implemented in actual operations without questioning whether they are the best that one can do in obtaining the highest returns possible on the capital invested.

The underlying principal for the analysis of each step in these packages tend to be similar. The ultimate pit limits, the pushbacks and the cutoff grades are all designed and analyzed on the basis of breakeven analysis first without any consideration given to time value of money. There are serious shortcomings with these commonly followed practices if the goal of the enterprise is to maximize NPV of a given project. It is not realistic to believe that plans and schedules obtained on the basis of breakeven analysis will give the highest NPV possible for a given project. This paper will discuss why certain mine planning practices result in sub optimal exploitation of resources when NPV is used as the evaluation criteria and provide suggestions and alternative solutions to overcome the

shortcomings of current open pit planning and scheduling methods and practices.

## 2 ULTIMATE PIT LIMIT DETERMINATION

The final pit limits define what is economically mineable from a given deposit. It identifies which blocks should be mined and which ones should be left in the ground. In an effort to identify the blocks to be mined, an economic block model is created first from the geologic grade model. This is done by assuming production and process costs and commodity prices at current economic conditions (i.e. current costs and prices). Then using the economic block values, each positive block is further checked whether its value can pay for the removal of overlying waste blocks. The analysis is based on the breakeven calculation that checks if undiscounted profits obtained from a given ore block can pay for the undiscounted cost of mining the waste blocks. This analysis is done by using computer programs that either utilize the "cone mining" method or the Lerchs and Grossmann (LG) algorithm (Lerchs and Grossmann 1964; Zao and Kim, 1992). The LG algorithm guarantees the optimality with respect to defining the pit limits that maximize the undiscounted profit while cone-mining routine is heuristic and may give sub optimum results.

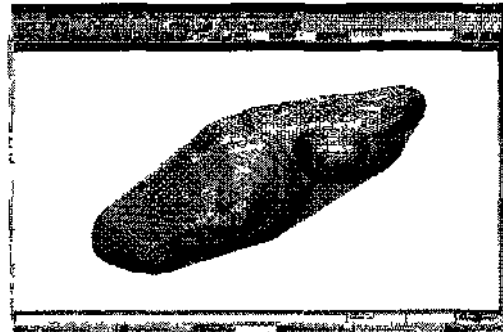


Figure 3 Ultimate pit limits with designed haul roads

The decision as to what should be mined within the ultimate pit limits is time dependent and proper solution needs to take into account the knowledge of when a given block will be mined and how long one needs to be stripping the waste. The analysis of pit limits which maximize NPV requires that the time value of money is taken into account in defining which blocks should be mined and which blocks should be left in the ground during the life of the project. The pit limits that maximize the

undiscounted profits for a given project will not maximize the NPV of the project.

To overcome this, it is suggested that one carries out a preliminary complete pit design and annual scheduling first. Then determines a new economic block model by using time dependent revenues and costs knowing when a given block will be mined and how it will be processed. Using this new economic block model, ultimate pit limits are determined again to reflect the effect of time value of money on the final pit limits. It has been our experience that this new pit is always smaller than the previous one in terms of both contained ore and waste tons and give higher NPV for the cash flows generated from it. This is due to the fact that the discounting effect on the economic block value calculation tends to reduce ore block values to be mined in the later years of the deposit while the waste mining costs to reach these blocks have to be incurred sooner. As such, the ore blocks that are very marginal in value drop out from the ultimate pit.

### 3 PUSHBACK GENERATION

As part of the planning and scheduling process, the intermediate pits leading to ultimate pit limits are determined to see how the pit surface will evolve through time. The procedure followed in the existing software packages to generate nested pits is by varying commodity price, costs or cutoff grades gradually from a low value to a high value. By changing the commodity price, for example, from a low value to a high value, one can generate a number of pits in increasing size and decreasing average value per ton of ore contained in the pit. Since the smallest size pit contains the highest valued ore, the production is scheduled by mining smallest pit first followed by the production in larger pits (see Figure 4). The incremental mining from the smallest pit to larger pit is referred to as pushback mining and there are cases where production is scheduled from more than one pushback simultaneously. Once the nested pits are generated, smoothed and haul roads are added, they are used as pushbacks underlying practical plans from which yearly schedules are generated.

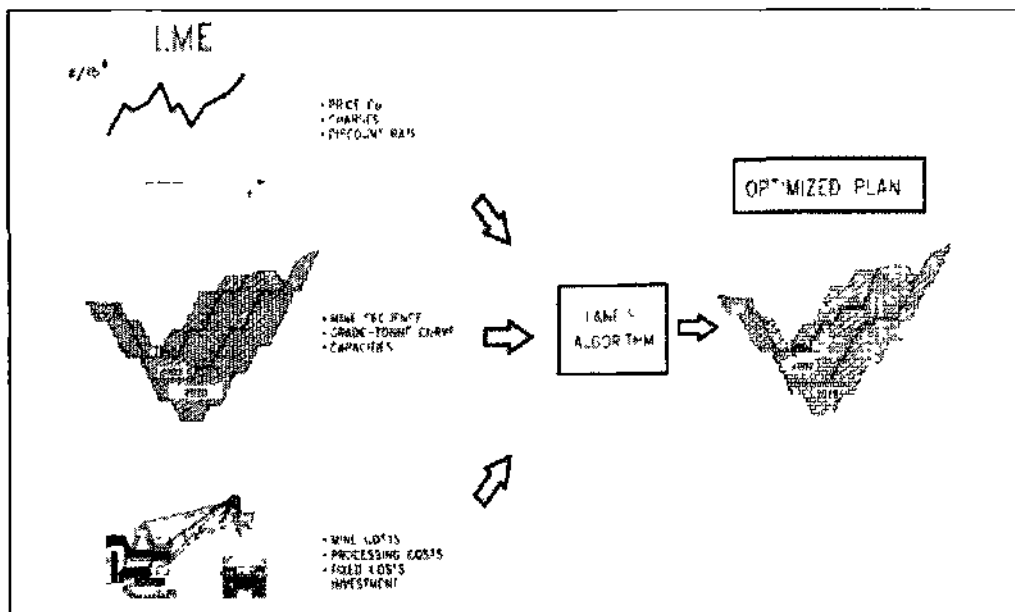


Figure 4: The nested pits showing pit progress leading to ultimate pit limits (Camus and Jarpa, 1996).

The nested pit generation also does not take into account time value of money. They are generated assuming undiscounted value of the blocks. The pushbacks that will maximize the NPV of a project can be significantly different than the ones found by

using existing procedures. It can be shown (See Bemabe, 2001) that the nested pit generation on parametrizing a single factor such as the metal price or the production costs or the metal grades will lead

to sub-optimum results when more than one process type exist for the ore types in the deposit.

#### 4 LONG TERM YEARLY SCHEDULES

Once the pushbacks are generated and designed for haul roads and minimum width requirements, the next step is then to come up with yearly progress maps within the pushbacks by dividing the pushback further down into smaller increments. The yearly progress maps are usually generated by taken into account annual waste and ore raining tonnage requirements for different material types. Ore and waste discrimination is normally done on the basis of breakeven cutoff grades. In the simplest case, yearly schedules are determined by mining from the top bench of the smallest pushback towards the bottom bench. Once a given pushback is exhausted then the mining from the top bench of the next pushback starts and continues until it is exhausted. In many cases, this approach does not result in best yearly schedules that maximize the NPV of the cash flows. Realizing this, the newest schedulers in the mine planning packages are designed to work with multiple pushbacks simultaneously and the mining activity can be scheduled from 3 or 4 pushbacks at the same time. In one scheduling package (see Cai, 1993) a schedule for a given year is determined by generating plans for all the possible mining scenarios between benches of the pushbacks and choosing one plan that gives the highest profit. This process is repeated for each year one year at a time until whole deposit is mined out. In another scheduling package possible (see Tolwinsky, 1998) yearly mine plans between pushbacks are further linked together year by year and analyzed with respect resulting overall NPV. The overall plan that links together yearly schedules resulting in highest NPV is chosen as the optimum. In another package (Whittle, 1999), yearly ore mining is scheduled within the individual pushbacks in the pushback sequence by mining ore from the benches of the pushbacks without any consideration given to waste tonnages. The schedule obtained by using this process results in fluctuating waste tonnages from one year to another. As such, these fluctuations are further smoothed by mining from multiple pushbacks in a given year.

The underlying concept in determining yearly schedules in all of the commercially available scheduling packages assumes that the previously designed pushbacks will guide the scheduling process to result in distribution of cash flows that will give the highest NPV. Of course this is not the case for many open pit mines, particularly for the ones where strip ratio varies significantly from one area of the pit to the other areas as well as for open

pit mines that require blending of different material types.

#### 5 CUTOFF GRADE STRATEGIES

The cutoff grade is the grade that is used to discriminate between ore and waste during scheduling. The most open pit mines are designed and scheduled by using cutoff grades that are calculated by using breakeven economic analysis. The use of breakeven cutoff grades during open pit planning results in schedules that maximize the undiscounted profits (Dagdelen, 1992). The cutoff grade that maximizes the NPV of the cash flows is not only a function of economic parameters but also mining, milling, and refinery capacity limitations as well as the grade distribution within the deposit.

Lane (Lane, 1964) proposed an algorithm to determine cutoff grades that maximize the NPV of a project subject to mine, mill and refinery capacity constraints.

The cutoff grade strategy that results in higher NPV for a given project starts with high cutoff grades during the initial years of the deposit. As the deposit matures the cutoff grades gradually decline to breakeven cutoff grade depending upon the grade distribution of the deposit.

Various computer packages are developed using Lane's algorithm (Lane, 1988; Dagdelen 1992; Whittle, 1999). Application of these programs in determining optimum cutoff grade strategy has resulted significant improvements to NPV of the projects (see Jamus and Jarpa 1996).

#### 6 FUTURE

The ultimate pit limits cannot be determined without knowing when the individual blocks will be mined. Determination of when a given block will be mined cannot be done without knowing pushback sequence and the cutoff grade strategy. The pushback sequence and the cutoff grade strategy are themselves a function of when the blocks will be mined in the block model. As such, the optimum solution to the problem we have identified initially deals with many interdependent variables and currently solved by using heuristic techniques that are trial and error.

The determination of ultimate pit limits, yearly mine schedules and the cutoff grade strategies for a given open pit mine can be formulated using large scale LP/IP models (see Johnson (1968) and Dagdelen (1985)). These models include over one hundred thousand variables and fifty to one hundred thousand constraints (see Akaika and Dagdelen, 1999; Hoerger, 1999).

The hardware and software technology with respect to implementation of the optimization techniques based on Linear (LP) and Integer Programming (IP) have advanced to a point that we can now solve some of these problems without any difficulty.

A good example of a large-scale LP application is Newmont Mining's Carlin operations involving multiple open pit mines and plants. The implementation of a large scale LP model by the Newmont engineers in actual operations involved over 100K variables and close to 30 K. constraints. The model is proved to be successful resulting in significant improvements in maximizing NPV of these projects (see Hoerger 1999).

## 7 CONCLUSIONS

The large-scale open pit operations are looking at ways to improve economics of their operations using NPV as a criterion. The mine planners of the new millennium are looking beyond the optimization techniques that traditionally provided the highest undiscounted profits. The available commercial packages are retooling their programs to overcome shortcomings of traditional mine planning techniques in providing NPV maximized mine plans and schedules. It is matter of time before the latest operation research based optimization tools become commercially available and regularly used. The use of these optimization tools by mine planners provides great opportunities for increased returns on large amount of capital being invested on these projects.

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