Long Term Planning for Open Pit Mines

Introduction

The profitable exploitation of a mineral deposit requires considerable evaluation and planning. First it must be determined what portion of the deposit is economical to mine (the mineable reserve) and by what mining method. Then considerable effort must be made in planning and scheduling the extraction of the mineable reserve in terms of mining sequence, mining rate, mine design, equipment requirements, etc. The objective of this effort is to determine the most profitable extraction plan and highest rate of return on the money invested.

These tasks are performed under the realm of long term planning (LTP). They involve working with estimated rather than exact data, looking years instead of days into the future, and dealing with evolving economic criteria, e.g. future metal prices. The uncertain nature of mineral evaluation data requires that LTP tasks be done over and over again, evaluating sensitivities, redefining key assumptions, and incorporating new data.

Because of the repetitive nature of these tasks and the need to evaluate large mineral deposits with extraction lives of 50 years or more, long term planners have been using computer software since the 1960s to assist in their evaluations. Mintec, Inc. was one of the first mining software companies to offer LTP software and continues to do so to this day.

This paper describes the key objectives that long term planners are trying to achieve at each step in their evaluations and how Mintec’s software, MineSight®, assists them in achieving these objectives. The paper focuses on deposits amenable to open pit mining.
LTP Tasks

The evaluation of a mineral deposit typically follows two stages of study depending on data available and degree of accuracy required. Stage one involves scoping level studies of orebodies and includes the following tasks:

- Task 1: Determine parts of the mineral deposit that are economic to mine at different metal prices and operating costs, i.e. ultimate pit limits
- Task 2: Determine the best place to begin mining and the best mining direction
- Task 3: Develop a mining sequence extending to the limits of economic ore
- Task 4: Estimate capital costs and schedule mining to the limits of economic ore at different production rates--using fixed or variable cutoff grades--to analyze cash flows, net present value (NPV), and internal rate of return

These tasks provide quick estimates of ore reserves, mine life, and mine profitability; and sensitivity of these estimates to metal prices, recoveries, costs, etc. These tasks can be done with minimal geologic data and simplified costs (scoping level studies) or with complex well-defined orebody models and detailed actual operating costs (continuing studies at existing mines). Mathematical optimization methods (Lerchs-Grossmann for pit limit optimization and Mixed Integer Linear Programming for scheduling optimization) are used during these tasks.

Depending on the results of stage one optimization studies, the mine planning effort may or may not move on to a more detailed design and scheduling stage. This second stage involves the following tasks:

- Task 5: Design detailed mining pushbacks extending to the limits of the economic ore; design waste dumps, tailings dams, roads, etc.
- Task 6: Calculate ore reserves and stripping requirements for the pushbacks and the final pit design
- Task 7: Create detailed life-of-mine (LOM) schedule using designed pushback tonnages and grades; dump capacities; haulage costs based on cycle times between pushbacks and dumps; optimal production rate and cutoff grade strategy; detailed capital and operating costs; recoveries and prices
- Task 8: Determine mine equipment requirements on an annual basis
- Task 9: Calculate annual cash flows, Net Present Value (NPV), and internal rate of return
• Task 10: Create charts and end-of-year maps of LOM schedule

These stage two tasks refine the first stage study results and provide the level of accuracy required by feasibility studies for new deposits and expansion studies at existing mines. These tasks are part of on-going evaluations at existing mines to incorporate new drilling data, evaluate changing economic conditions, updating past plans to account for annual mining progress, etc. These second stage tasks are more time-consuming than the first stage tasks because of their refined level of detail, especially in the mine design work. The results of the first stage optimization tasks provide important guidelines for the detailed work and identify the best scenarios upon which to perform the more time-consuming stage two tasks.

MineSight LTP Software

MineSight provides software to assist the planning engineer at each stage in the mineral deposit evaluation process. For the first stage optimizing tasks, the MineSight Economic Planner (MSEP) suite of programs and MineSight 3D (MS3D) display tools are used. As the evaluation moves on to the more detailed stage two tasks, MS3D design tools, MineSight Haulage (MSHaulage) truck haulage simulator and MineSight Strategic Planner (MSSP) are used.

1. MineSight Economic Planner (MSEP)

MSEP consists of two major evaluation programs and several supporting programs for miscellaneous data handling functions. The two major evaluation programs are:

• MSOPIT for pit optimization studies and
• MSVALP for scheduling optimization studies.

MSOPIT

MSOPIT is used for the aforementioned stage one, tasks 1-3. It uses the Lerchs-Grossmann (LG) and/or floating cone (FC) algorithms to determine economic pit limits based on a set of economic assumptions and pit slope criteria. The mine planner’s objectives at this point are to find the ultimate pit limit (task 1), the best starting pit location (task 2), and the best mining sequence from starting pit to ultimate pit limit (task 3). With its ability to quickly determine different economic pit limits for sets of different economic assumptions, MSOPIT assists the engineer in achieving these objectives.

For example, let’s consider a copper/molybdenum mineral deposit under evaluation. The section below shows the MSOPIT LG ultimate pit limit defining the boundary between
economic mineralization and uneconomic mineralization for this deposit based on a specific set of economic assumptions:

Uneconomic mineralization is either low grade mineralization, mineralization requiring excessive stripping, or both. The LG algorithm uses graph theory to identify economic and uneconomic mineralization based on a specific set of economic criteria consisting of metal prices, recoveries, and mine/mill operating costs. The metal prices used are normally specified by corporate management for ore reserve estimation purposes.

MSOPIT can quickly generate LG ultimate pit limits (LG shells) at different metal prices to determine the price sensitivity of the deposit. These multiple-price break-even shells can, in turn, be evaluated at constant prices to produce graphs for evaluating the cumulative tonnage versus cumulative value relationships, as shown below:
The multiple-price break-even shells also help determine where the best starting pit location should be and what the best mine advance direction is (task 2). The overriding concept is that economic mineralization determined by the LG ultimate pit limit at a very low metal price is the best ore in the deposit because only high grade low stripping ore is economical at low prices. Tracking the LG ultimate pit limits at progressively higher prices shows the progression (i.e. best direction of mine advance) from the best ore in the deposit out to the break-even ore defined by the ultimate pit limit at the corporate guideline price for official reserve estimations. The section below shows this progression:
Once the starter pit and best mining direction are determined, MSOPIT creates additional LG shells illustrating the mining sequence from starter pit to final pit in the best mining direction. MSOPIT assigns geometric controls to these shells to emulate pushbacks and offer more reasonable stage one scheduling. An MSOPIT-generated mining sequence with geometric controls is shown below in section and plan view, respectively:
MSVALP

MSVALP, the second major evaluation program in MSEP, schedules the mining sequence shells using cutoff grade optimization techniques to maximize the NPV of the deposit (task 4). The optimal schedule is based on economics, ore production rates, maximum mining capacity, and discount rate information provided by the planning engineer. The mine planner’s objectives for this task are to 1) find the best production rate and associated mine life for the deposit based on the best NPV evaluations; and 2) capture the cutoff grade strategy that produces this best result. MSVALP performs the calculations to get these answers. It quickly evaluates any number of production rate possibilities utilizing MineSight’s efficient multi-run functionality.

For each case evaluated, MSVALP will find the cutoff grade to use each year to maximize the NPV of the schedule. The cutoff grade determination is based on using any available excess mining capacity to mine higher grade material earlier in the schedule to increase the NPV.
Sequential user-specified cutoff grade increments (or bins) are evaluated each year in the following way:

a. Replace material going to the processing plant from the lowest cutoff bin with higher grade material and re-compute the schedule economics.

b. If the value of the higher grade material is sufficient to pay the opportunity costs associated with the replaced material (i.e. the value of the higher grade material must cover 1) the value lost by not processing the lower grade material; and 2) the additional mining costs associated with mining more material which includes the material sent to stockpile and any additional waste mining required to access the higher grade ore) then the replacement is implemented because it improves the NPV of the schedule.

c. Increment the cutoff to the next bin in the sequence and repeat steps a. and b. The optimization for each year stops when there is no improvement in the NPV of the schedule (i.e. when the test done in step b. fails) or when there is no longer any accumulated excess mining capacity in the period.

While optimizing, the scheduler will also test the economics of reclaiming ore from stockpile versus mining ore in the pit. If the value of the highest grade ore bin on the stockpile is sufficient to pay the opportunity costs associated with the pit ore that it is replacing (i.e. the value of the stockpiled ore must cover 1) the value lost by not processing the pit ore and 2) the additional stockpile re-handling costs) then the replacement is implemented because it improves the NPV of the schedule. The scheduler thus has the capability to consider the effect of reclaiming stockpiles during the cutoff grade optimization/maximize NPV process.

Certain assumptions are made to quickly perform the cutoff grade optimization. These assumptions include:

- Excess mining capacity is accumulated by the scheduler. This means that the capacity constraint is the cumulative excess mining capacity and not the period excess capacity (i.e. if the total mining capacity is underutilized in earlier periods, it will be assumed that this underutilized amount is available for later periods).

- The reserves are grouped into mining units or reserve records which are tonnes and grade units categorized by shell, bench, best destination, material type, and cutoff
The mining units have a maximum size based on a tonnage specified by the user.

- Stripping can be moved to earlier periods based on available excess capacity. Whether or not this movement is geometrically reasonable is not considered.

- Selectivity in the stockpiles is based on the mining units.

- Mining sequence is defined by progressively mining the shells one at a time. Stripping the next shell however can begin earlier to coincide with ore mining in the current shell if excess mining capacity exists and if the earlier stripping is required by the cutoff grade optimization results for improving the NPV of the schedule.

Continuing with the previous copper/moly deposit example, the mining sequence shells are scheduled at different annual ore production rates to find an optimal rate. The general premise assumed in preparing the input data for this example was that as plant size increases capital costs increase but operating costs decrease because of economies of scale. At what plant size does the increased capital cost outweigh the benefits of lower operating costs? This is one of the questions that an MSVALP evaluation answers. The MSVALP results from evaluating 5 different annual ore production rates ranging from 20,000 Ktonnes to 40,000 Ktonnes are shown in the graph below:

![Production Rate Evaluation](image-url)
In this case the 30,000 Ktonne/year production rate is optimal. The cutoff grade strategy, annual cash flows, NPV graphs, etc. from this best case and any other case can be graphed or charted for presenting results to management. Some examples are shown below:

Annual Cutoff Grades:

![Graph showing annual cutoff grades](image)

Annual Cash Flows:

![Graph showing cash flows](image)
Cumulative NPV comparisons:

2. MineSight 3D Design Tools

Completion of the first four tasks provides the mine planner with guidelines for more detailed design and scheduling, should the project warrant such time and effort. In terms of feasibility studies, this would move the evaluation from scoping/pre-feasibility levels of detail to full feasibility levels of detail.

Mine Pushback or Phase Design

Existing mines and new projects being evaluated at full feasibility levels of detail need more operational mining pushback designs than simple LG shells. Detailed toe/crest designs including ramps, safety berms, recommended bench geometries, etc. are needed for starter pits and each successive pushback extending to final pit limits. The MS3D Pit Expansion tool allows the planner to use CAD tools to build 3D pushback designs. This is usually done using the LG mine sequencing shells from task 3 as guidelines for locations of the pushbacks or phases. In the figure below, a LG mine sequence shell created with MSOPIT is shown on the left with its corresponding detailed phase design with toes/crests and ramps designed using the MS3D Pit Expansion tool on the right:
MS3D CAD tools allow quick clipping of pit designs into surrounding topography to create complete pit design surfaces:

Mine Dump Design

MineSight 3D has two CAD tools to assist the mine planner in designing waste dumps, leach pads, stockpiles, tailings dams, or any other rock/earth structure required by the overall mine plan. These tools are the Pit Expansion tool and the Extrude tool. Since a
dump (wide at the bottom and narrow at the top) is the inverse of a pit (wide at the top and narrow at the bottom), it is easy to see how the Pit Expansion tool can be used for both design functions. In fact the pit expansion tool offers four design modes:

- Design a pit from the top down
- Design a pit from the bottom up
- Design a dump from the top down
- Design a dump from the bottom up

All design modes can include haulage ramps, conveyor slots, variable face slopes, variable berm widths, etc. All designs can be easily clipped into surrounding topography.

The Extrude tool is similar to the Pit Expansion tool but does not include ramps in the designs. It is useful for quickly designing stockpiles, tailings dams, side-hill dumps, etc. The dump designs built with the Extrude tool are also clipped into the surrounding topography for complete surface displays (see below):

![Diagram of a pit and dump designs](image)

**Road Designs**

MineSight 3D CAD tools can also be used to design overland roads from pit exit points to surrounding destinations such as dumps, truck shops, crushers, etc. Road centerlines are digitized and road width templates are attached, extruded, and clipped into the surrounding topography to show the finished road layout and computed cut and fill volumes required by
the road construction. A surface with road design results along with the cut and fill volumes required is shown below:

![Road Design Results](image)

**Truck Haulage Times**

One important responsibility of long term planners is to determine mining equipment requirements over the life of the mine. To determine truck requirements, estimated haul cycle times between the mine phases and the different destinations are needed. MineSight 3D CAD tools and MineSight Haulage are used to define haul profiles, specify truck types/speeds, and calculate cycle times for all haulage profiles assumed to be used over the mine’s lifetime. The cycle time output file is set up in the format required by MSSP, the detailed life-of-mine scheduling program.

Examples of haul profiles, truck speed data, and resulting cycle times are shown in the three figures below:
3. Reserve Calculations

Throughout the long term planning effort, reserve estimations are required, including preliminary reserves based on simple LG shell geometries or final reserves based on detailed pushback and final pit design geometries. MineSight offers several reserve calculation routines with results based on partial block accuracy. These routines can be used to simply report proven, probable, and possible reserves or report a more complex reserving scenario using up to 4000 different geological categories based on cutoff grade, alteration, rock type, etc. Grades for up to 30 different elements (metals, contaminants, etc) can be reported for each reserving category. The reserves are typically broken down using bench-by-bench reserve reporting (constant bench height or variable bench height) for metal mines and seam-by-seam reserve reporting for coal mines.

4. Detailed Life-of-Mine Scheduling

The LTP efforts culminate in preparing a detailed LOM plan for the mineral deposit. The level of detail used at this stage of the evaluation is required both by financial institutions for full feasibility studies of new mines and at existing mines to ensure that the long term future mining plan can be used effectively by the short and medium term planners as guidelines (or boundaries) for their work.

The MineSight Strategic Planner (MSSP) scheduling program assists the LTP engineers with their detailed LOM scheduling duties listed earlier as tasks 7-10 on the long term planners’
work list. MSSP builds an annual LOM schedule using optimal production rates, optimal cutoff grades, and detailed bench-by-bench reserves from mining phase designs, all determined and developed in earlier tasks in the work chain. Annual truck requirements for the schedule are determined using detailed dump design volumes and detailed cycle times between the different mining phases and the different destinations (dump locations and mill crushers). MSSP has a number of different scheduling objectives that include maximizing NPV, minimizing stripping, maximizing metal production, etc. The schedule is optimized based on the selected objective using linear programming techniques.

In addition to evaluating the detailed scheduling data described above, MSSP has a complete list of additional scheduling controls to aid the mine planner in producing operational long term mining plans. This list of additional scheduling controls includes, but is not limited to, the following:

- Phase mining controls
  - Daily mining rate control by phase, by bench, and by period
  - Number of partially mined benches allowed by phase and by period
  - Vertical advance limits by phase and by period
  - Specific phase mining controls by period:
    - Do not mine
    - Must mine some benches
    - Must mine to a specific bench
  - Different cutoff grades allowed by phase and by period
- Phase dependencies over time by:
  - Elevation (phase 1 must be deeper than phase 2)
  - Elevation range
  - Specified phase/bench combinations
- Destination (dumps, pads, crushers) usage controls
  - Availability by period
- Tonnage allowed per period by dump and by lift
- Maximum usage rate (tonnes/day) by destination and by period
- Leach dump control by time increment within a scheduling period (i.e. use a different leach dump each month)
- Material placement control
  - Different waste types on different dumps (acid generating; non-acid generating)
  - Blending of different waste types (coarse and fine)
  - Precedence controls for dump sequencing
- Stockpile handling
  - Building up stockpiles
    - Placement on stockpile by cutoff (variable by period)
    - Existing stockpile inputs
  - Retrieving stockpiles
    - Automatic retrieval: Maximum % of feed from stockpile controlled by period
    - Manual retrieval: User specified stockpile and amount by period
    - Stockpile can have placement and retrieval in same period
- Production targets
  - Tonnes requirements by period
  - Head grade requirements by period
  - Metal production requirements by period
  - Contaminant controls by period
MSSP finds a set of feasible mining patterns that satisfy targets, controls, and constraints for each period. It then evaluates each one economically to find the best mining pattern for each period based on the chosen scheduling objective. The economic data used for this is summarized below:

- **Basic price/cost/recovery data**
  - Fixed mining costs (excluding loading and hauling)
    - Additional “variable by bench” cost allowed
  - Loading and hauling costs (truck & shovel $/hour costs)
  - Processing costs
  - Net price and recovery
  - Capital investment by period

- **% Variation by period**
  - Constant
  - Variable

- **Cost classes – cost variation by material**
  - Mining and processing costs
  - Equipment operating costs and parameters

Detailed loading and hauling costs per period are based on equipment simulation results (number of truck and truck operating hours required; number of shovels and shovel operating hours required) and hourly equipment costs.

The LOM scheduling results are summarized into sets of Excel tables and charts. End-of-period maps are created quickly via the Period Maps tool in MS3D. This tool combines the scheduling results, phase designs, and dump designs to produce plan maps showing the planned status of phases and dumps at different periods over the mine life. Examples of the MSSP outputs are shown below:
### Summary Mining Results

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### Summary Mining

**Graphical Representation**

- **Waste 1**
- **Leach 2**
- **Leach 1**
- **T2_Stockpile 3**
- **T2_Stockpile 2**
- **T2_Stockpile 1**
- **T2_Ore**
- **T1_Stockpile 3**
- **T1_Stockpile 2**
- **T1_Stockpile 1**
- **T1_Ore**

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Mining: 0 to 120,000

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Revised November 2009

Minesight
Annual Cash Flows and NPV

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Revised November 2009
5. Conclusions

Mintec offers a complete package of long term planning tools and scheduling programs to assist the long term planning engineer. Mintec has been in the computerized mine planning business since the beginning and has built up considerable expertise in this area, both in its software and in the professional services personnel supporting the products. This paper shows how Mintec’s software can assist the planning engineer at each step of a mineral evaluation; from initial scoping studies to final feasibility studies.

For additional information about Mintec’s long term planning products, or to set-up a one-day demonstration on the use of this software, please contact the marketing department at Mintec, Inc.