



Minemax Scheduler

Strategic Mine Schedule Optimisation

White Paper

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Overview

Mining companies are continuously faced with the challenge of planning their mine's development in a way that is economically optimal. Depending on a company's strategy and the current economic climate, economically optimal can mean optimising net present value, minimizing up-front costs, maximizing contained metal or possibly something else.

Economic forecasts available to miners usually contain a high degree of uncertainty, making it imperative to develop mine schedules that are robust under a number of economic scenarios. Especially in rapidly changing markets, it is essential that mining companies have adequate tools to support their planning and scheduling processes, enabling them to respond rapidly and remain competitive.

This white paper analyses the requirements of mining companies for computer-based tools to support their planning and scheduling processes. It addresses available scheduling methodologies and highlights the advantages and disadvantages of each. In particular, it describes Minemax Scheduler for strategic mine schedule optimisation, and shows how Minemax Scheduler is being used to help mining companies optimise the net present value of new projects and existing operations.



Why Schedule?

Although the question “why schedule” may seem naïve, it is instructive to consider the question. If you didn’t schedule before mining then you could possibly keep your material movement equipment utilized and you may even keep your plant fully utilised. However, from a business point of view, what is the value corresponding to the way in which you mine your deposit? To answer this raises the question, “How do I calculate the value of a schedule?” There are an infinite number of possible schedules in any mining scenario and each one has a value associated with it.

Relationship Between Schedule and Net Present Value

In general the value of a schedule is the revenue obtained from selling the final product minus mining costs, processing costs and fixed costs as shown in the following equation:

$$Val = R_{prod} - C_m - C_p - C_f$$

where,

R_{prod} is the revenue from the final product

C_m is the mining cost

C_p is the processing cost, and

C_f are the fixed costs

Equation 1 Schedule Value

However, without considering the time value of money, all schedules will have the same value. We know that money does have a real time value, so we need to account for this in the equation. Thus **Equation 1** becomes

$$Val = \sum_{t=0}^{T-1} \frac{(R_{prod} - C_m - C_p - C_f)}{(1+d)^t}$$

where,

T is the number of time periods

d is the discount rate

Equation 2 Net Present Value

Examining **Equation 2** with a view to maximizing net present value, there are a number of things worth noticing.

1. We can control revenue, mining costs and processing costs particularly with respect to the time period in which they are incurred.
2. Increasing revenue in earlier time periods tends to maximize NPV (assuming constant product prices).
3. Decreasing mining and processing costs in earlier time periods tends to maximize NPV (assuming constant costs).



It should be clear from the above that cost-effective scheduling directly impinges on the value of a project and the profitability of a business.

Scheduling Methods

There are a number of different methods and associated tools for mine scheduling. Here we will consider manual scheduling and various types of automated scheduling.

Manual Scheduling

Although automated scheduling tools are becoming available, the majority of mining operations still use spreadsheets to support a manual scheduling process. Typically, block model information including geometry, tonnage and grade information is available on one sheet. On another sheet is a representation of the schedule where blocks are manually chosen to be scheduled in certain time periods. When a block is scheduled, various summary information such as ore and waste mined and average grades is updated.

To use these spreadsheets, the mining engineer usually has detailed knowledge of the pits being scheduled such that practical schedules are generated. However, if there are constraints on the schedule such as those that can be associated with achieving grade targets, the scheduling process can be painstakingly laborious. Even if there are not strict grade constraints, it is often next to impossible for an engineer to know if there is significant room for improving the value of a given schedule.

Automated Scheduling

Automated scheduling is a means for automatically computing a schedule through computer software. While automated scheduling relieves the mining engineer from the tedium of generating and evaluating schedules, it is important to know how the scheduling is taking place. This is important because some methods of automated scheduling are not able to satisfy scheduling constraints due to the way the automated scheduling occurs.

Heuristic Scheduling

Heuristic scheduling is a form of automated scheduling where the scheduling algorithm is based upon *rules* for selecting blocks. Rules are usually related to the production constraints and possibly to some measure of a block's value. Typically a schedule is constructed by iteratively selecting blocks, one block at a time. The advantage of this approach is its speed in constructing a schedule. One of the disadvantages is that it is not guaranteed to produce truly optimal schedules. Additionally, if satisfying grade constraints is important, heuristic algorithms cannot guarantee a schedule which satisfies the constraints, even if a schedule which satisfies grade constraints is known to exist.

Schedule Optimisation

Schedule optimisation often uses a mathematical model to represent the mine and its production constraints. Optimisation algorithms which operate on this model (simplex, branch and bound, dynamic programming and others) are used to automatically compute a schedule which not only satisfies the production constraints, but also optimises the schedule. Normally it is net present value that is optimised although other parameters can be optimised as well.

Requirements for a Mine Schedule Optimisation Tool

Mining companies today require a user-friendly and functionally complete computer based tool for supporting mine schedule optimisation. This section addresses these two high-level requirements.

User Friendliness

Mining engineers have become accustomed to the Windows paradigm of computing and require their planning and scheduling tools to inter-operate within this environment. Companies and the people who work in them become frustrated with systems which require a steep learning curve because they have not adopted the Windows paradigm of computing. Engineers who attempt to use the systems are frustrated because it takes so long to learn how to use the system before they can do anything useful with it. Companies are frustrated because by the time their people know how to use the systems they have moved on to another company, taking valuable skills with them. While the process of mine scheduling is not simple, the computer-based system that supports it can and should be.

Functional Completeness

Secondly, a mine scheduling system should be functionally complete. If the system were viewed as a servant to the engineer, the engineer should be able to say, "Find a schedule that optimises net present value while ensuring that the following conditions are met." Then they would list the conditions that constrain the alternative schedules. The types of items that go into this list relate to the functional completeness of the system. It should include:

- Upper and lower limits on the amount of ore and waste mined
- Upper and lower limits on the grade
- In-pit stockpiles available for stockpiling lower grade material
- Upper and lower limits on material to be moved from specific pits
- Ordering of the extraction of pit stages with minimum and maximum lag between related stages
- Limiting vertical rate of advance

These items are strictly related to the schedule optimisation role of the system. There are other functionalities such as 3D visualisation of mine development and various reporting functions that add to a functionally complete mine schedule optimisation tool.



Minemax Scheduler has been designed to meet all of these requirements and has been relied upon by mining companies for over 12 years to optimise the value of their new projects and existing operations.

Minemax Scheduler: Product Description

Minemax Scheduler has been designed to meet the requirements stated in the previous section. In this section you will see how easy it is to use Minemax Scheduler and why Minemax Scheduler is a functionally complete mining schedule optimisation tool.

How Do I Use It?

This section covers the use of Minemax Scheduler starting with setting up Minemax Scheduler for a new project through to specifying constraints, optimising, viewing results and reporting.

Block Model

The entry point to automated scheduling with Minemax Scheduler is importing a block model. This is a simple process aided by the reserve import wizard in Minemax Scheduler. All of the major general mining packages have a facility for exporting block model data, so Minemax Scheduler works to add value to your current mining software investment. The data Minemax Scheduler needs for each block is simply the coordinates and size, the proportion of each product, the percentage of each quality parameter (grade), total quantity (tonnes), and a block value. A convenient data mapping function is available for mapping your block model to the schedule model in Minemax Scheduler. This includes powerful expressions and look-up tables.

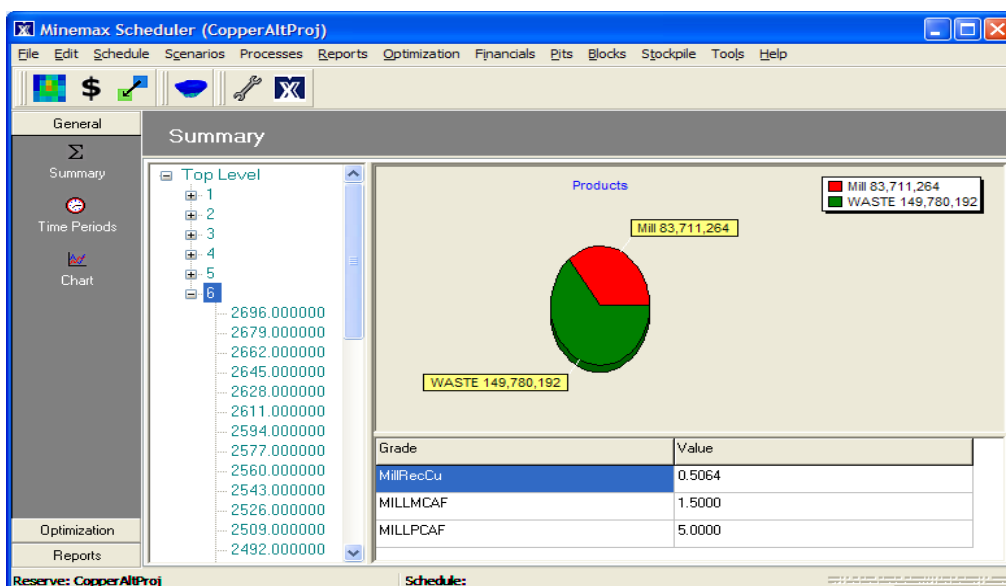


Figure 1 Summary View



Note that block models do not have to form a regular grid. Minemax Scheduler happily accepts models composed of blocks with differing sizes. Additionally, Minemax Scheduler has a facility for re-blocking; that is, combining groups of smaller blocks into a large block. Re-blocking enhances performance and is useful in the initial investigative stages of scheduling when you wish get a rough feel for how the schedule will look and what the magnitude of the net present value will be.

Once you have imported your block model, you can view tonnages and grades on a mine, pit, or bench basis as shown in Figure 1.

Setting Constraints

After importing a block model, there are a number of constraints that you can set. These constraints correspond to both the practical mining requirements of your ore body and your production requirements. For practical mining requirements, precedence constraints are automatically generated based upon a number of control parameters that you can set. These include maximum pit slope at any given time and mining direction. Different parameters may be used for different pits. Production constraints include product tonnage targets, allowable grade ranges and pit constraints. Product tonnage targets can vary for different time periods. They can also have a deviation quantity (+ or -) associated with them. You can specify different grade ranges on any grade parameters existing in your block model as shown in Figure 2. Finally, you can specify minimum and maximum pit movements for each pit in each time period.

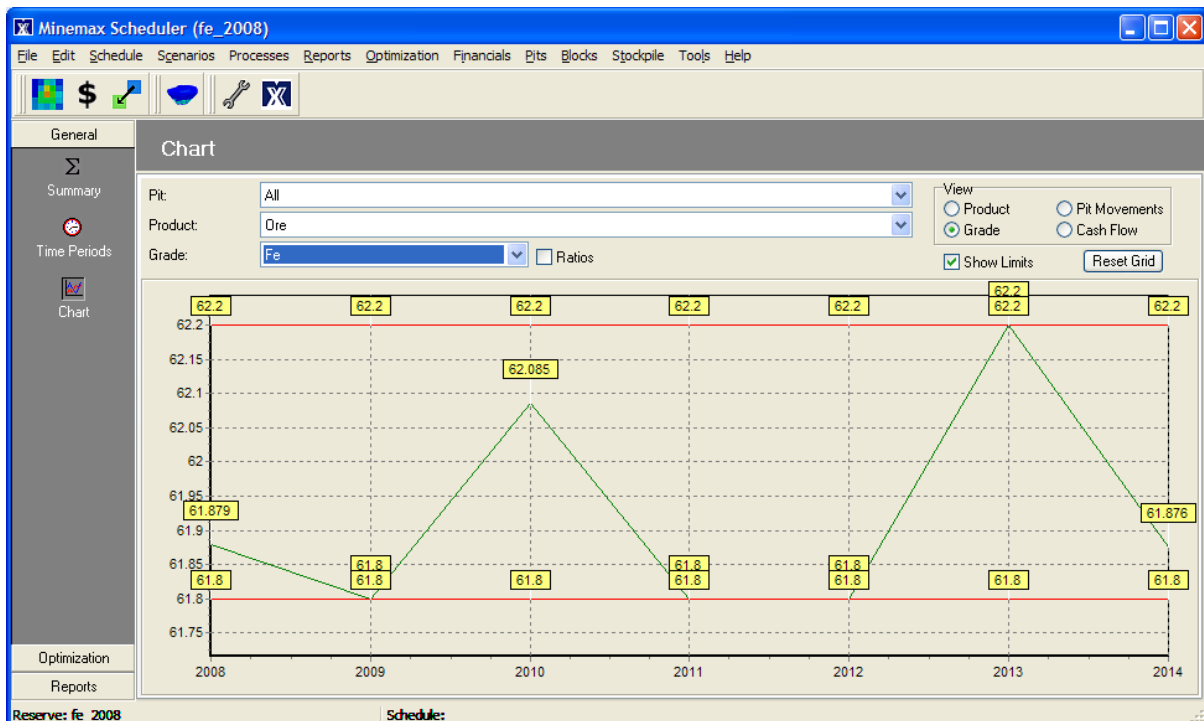


Figure 2 Grade Constraints



Intermediate Stockpile Definition

Any number of stockpiles can be defined in terms of grade ranges. These are normally used to temporarily hold lower value or off-spec ore so that higher value ore may be accessed. Once stockpiles are defined, the mathematics of Minemax Scheduler determines if it is more cost-effective to stockpile certain ore regions or to mine them for downstream processing. Additionally, Minemax Scheduler determines when to reclaim from stockpiles. An example of intermediate stockpiling may be seen in Figure 3.

One of the advantages of stockpiling in Minemax Scheduler is that you can carry out scheduling and cut-off grade optimisation simultaneously. Without pre-classifying any ore blocks as waste based on their grade, Minemax Scheduler determines whether a block goes to the intermediate stockpile or plant. After completing a schedule in Minemax Scheduler you can inspect all blocks which were scheduled for processing in the plant for each time period. The lowest grade block going to the plant in a particular time period determines the cut-off grade for the period.

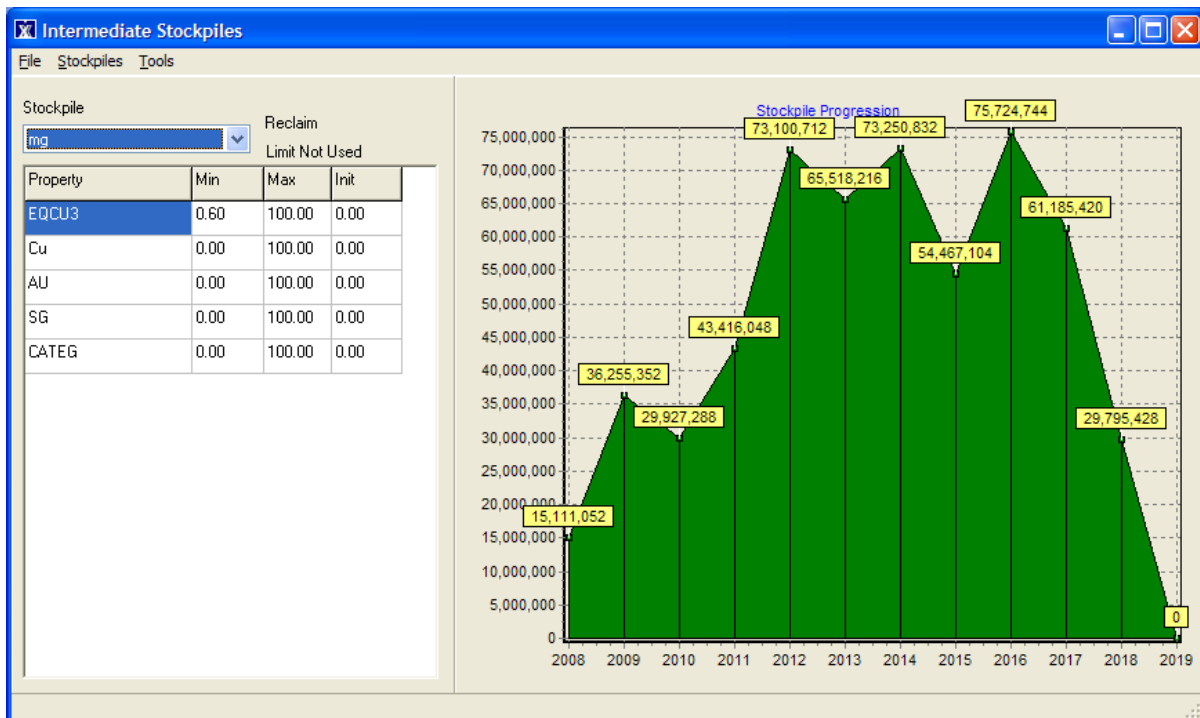


Figure 3 Intermediate Stockpiling

Financial Model

Minemax Scheduler's financial model is used to generate block values used in the optimisation algorithm. On the cost side of the financial model, you simply need to specify ore and waste mining costs, stockpile rehandling costs and ore processing costs. On the revenue side you enter metal prices and recoveries as shown in Figure 4. All of Minemax Scheduler, including the financial model, caters for multiple products and multiple grades.



Item	Revenue	% Recovery
EQCU3	1,500.00	100.00
Cu	0.00	100.00
AU	0.00	100.00
SG	0.00	100.00
CATEG	0.00	100.00

Item	Cost
Ore Mining	0.55
Waste Mining	0.72
Stockpiling	0.72
Reclaiming	0.35
Ore Processing	3.65

Figure 4 Financial Model

Automated Scheduling

After setting up the constraints (a default set is provided to get you started) and optionally defining intermediate stockpiles, all you have to do is tell Minemax Scheduler to generate a schedule which satisfies all of your constraints while optimising according to the criterion you have selected. Currently, there are four criteria with which you can optimise. Firstly, you can choose to merely generate a schedule that satisfies the mining and production constraints. This option is useful when you wish to investigate whether or not your production requirements are too rigid compared to what your ore body is able to deliver.

Other options for optimising are Net Present Value (NPV), intermediate stockpile size (minimize) and up-front waste movement (minimize). NPV is most commonly used when there is complete financial information available regarding ore and waste mining costs, processing costs, recoveries and product prices.

Visualisation

If you wish to view development in three-D Minemax Scheduler has a 3-dimensional viewer for displaying your mine in block model format at any stage in its development (Figure 5). By stepping through the pit development over time, you are given instant visual feedback regarding the practicality of the schedule.

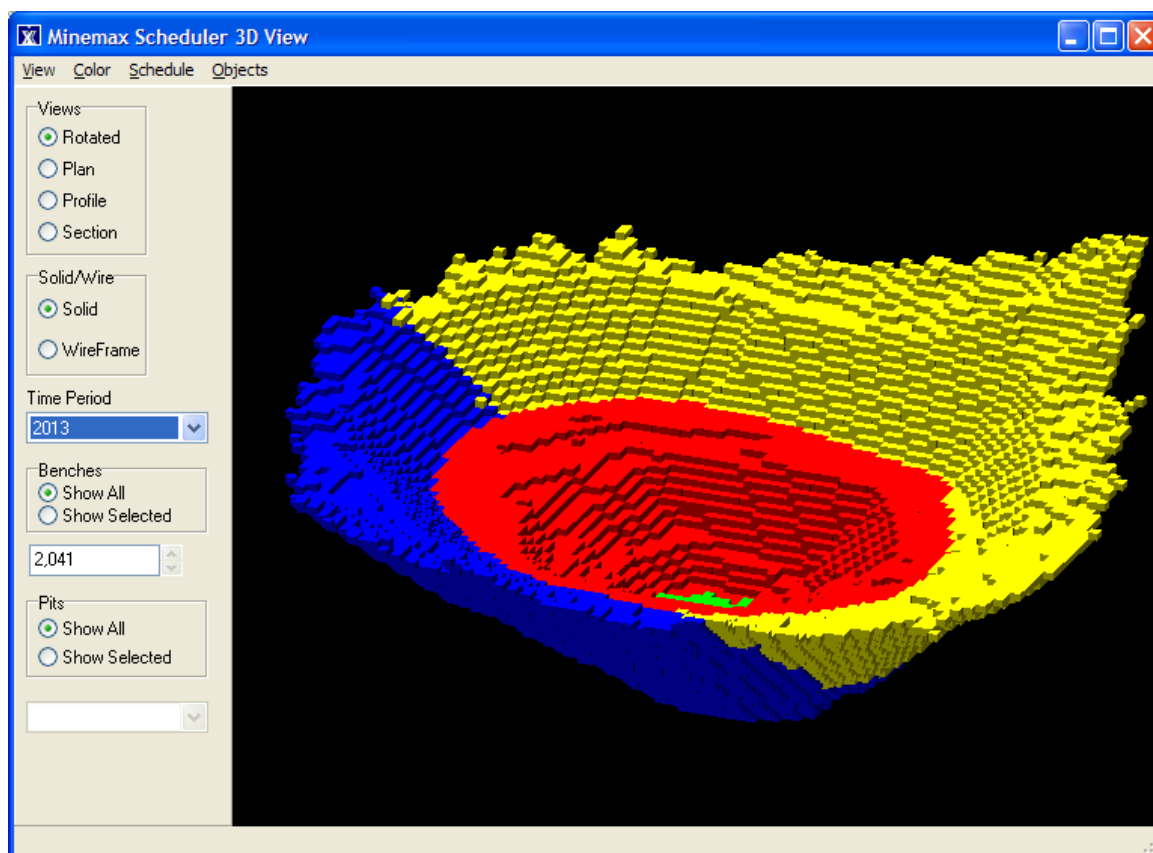


Figure 5 Three-D Visualisation of Schedule

Reporting

After generating a schedule, you can view a number of charts that report on product tonnes, grade, stockpile activity and pit movements over time. These charts can be copied into the Windows clipboard for inclusion into reports. There are also a number of standard tabular reports available in Minemax Scheduler. These may be previewed saved as csv.

How Does It Work?

Once you import your block model and specify your constraints, Minemax Scheduler constructs what is known as a mixed integer linear programming (MILP) model of your mine. This is a mathematical model that contains the scheduling decisions that can be made and constraints that limit those decisions. Minemax Scheduler then applies a transformation algorithm to the mathematical model. This algorithm examines the constraints and possible scheduling decisions to reduce the size of the model so that it can be solved more efficiently. The reduced model is no different than the original. No approximations have been made. The transformation algorithm simply uses the logic of the constraint set and the scheduling decisions to combine some constraints and possibly eliminate infeasible scheduling decisions.



The reduced mathematical model is then optimised by a tailored branch and bound algorithm. Branch and bound is a general purpose algorithm for solving MILP problems. Specialisation of branch and bound for particular types of problems requires insight into the structure of the problem. Substantial research effort has been invested into specialising Minemax Scheduler's branch and bound algorithm to enable it to efficiently solve mine schedule optimisation problems. The branch and bound algorithm determines how much of each block should be mined in each period. It also determines if the block should be processed or stockpiled for reclaiming in a subsequent period. If there are alternative processing options, it also considers the destination for a block. It ensures that all tonnage, grade and material movement constraints are satisfied and that the resulting schedule is optimal.

Where To From Here?

- Are you confident that your mine schedules are maximizing the net present value of your project?
- Is your scheduling process driven by economics or "rule-of thumb"?
- Is your stockpile management strategy economically and operationally optimal?
- Are you able to easily visualise the development of your mine in 3D to ensure that schedules are practically feasible?

Contact Information

For more information on Minemax Scheduler and how your operation can apply mine schedule optimisation to maximize net present value, contact us at:

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