Minemax Scheduler

Integrated Strategic Mine Schedule Optimization

White Paper

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Introduction

Strategic mine scheduling is a fundamental component of the mining business. It is through this effort that the financial goals and overall strategy of the business are translated into time-based operational contexts. It informs downstream planning processes, expresses critical decision elements of the operation in meaningful terms, and provides a quantitative roadmap for the future of the project.

There are several interconnected variables at play in the traditional mine scheduling problem with which the strategic mine planner is faced. In direct terms, the schedule sets forth the spatial and temporal plan to develop resources, allocate assets, handle costs, generate revenue, manage capital investment, meet quality and quantity requirements, and deliver commodities to market in a way that maximizes value for the business. While situations vary widely across commodity and region, in order to achieve this the mine planner is modelling a unique material extraction and processing setting, clearly defining all feasible decisions related to this framework, and leveraging the influence of time and value to deliver a schedule which is most advantageous to the business.

As the strategic mine schedule is such a critical component of the overall business plan, the manner in which this problem is handled (and therefore the merit of the solution itself) have a high degree of influence on real business success. If any aspect of the problem is misrepresented, or if any component is solved in isolation (physically or temporally), then the appropriateness of the resulting schedule (and the business's ability to deliver on expectation) is at stake.

The Integrated Scheduling Problem

So how do we define the complete mine scheduling problem? Inherent and fundamental is the determination of the ideal mining sequence, which is directly influenced by and contributes to the whole of the integrated problem. If and when to mine a particular block in the schedule relates back to that block's position, precedences, and characteristics; as well as that of others assessed in the same period. Blocks must be evaluated in context with the cost/effort required to mine them in addition to the cost/effort to send them to each of many possible destinations.

These costs must be overcome by the collective revenue-generating capability (defined by block characteristics, recoveries, and pricing), evaluated in composite with other blocks processed. Capacities or other constraints (quantities or qualities) at the possible destinations (plants or waste dumps), at the origin itself, or in the means of transport (haulage capacity) may restrict or complicate this decision further. Intermediate stockpiling may be evaluated in context such that some blocks would be stockpiled to allow access to others; and would be available for reclaim and processing in later periods subject to additional costs and conditions.

And finally, capital expenditures should be evaluated in order to understand that if additional capacity is made available to the system for a given investment: when, if, and how many instances to do this to maximize project value. In summary, the optimum answer to the integrated problem can only be made in full knowledge of the interrelationship of the various components after evaluation of the entire feasible solution space.

While this problem varies in size and complexity dependent on the operation in question, the following ten general questions are often asked to define the scope of the total problem:

1. What, and in what level of detail, is initial project information available?
2. What are the decisions that need to be made with respect to material destinations?
3. Are there any pre-defined elements to the problem?
4. Where and how are costs accumulated and revenue generated?
5. Are there options to strategically stockpile and reclaim material?
6. How is waste modelled and in what manner is it integrated?
7. How are infrastructure, fleet, and other capital to be represented?
8. What are the fixed limitations/constraints in the operation, processing or otherwise?
9. What are the scenarios/options/varying parameters we wish to evaluate?
10. How is the resulting schedule to be communicated?

Common Issues with Silo-Based Scheduling Approaches

When the operational complexity evolves in a mining project, the problem is often broken down and solved in smaller, discreet, manageable pieces. While in traditional thought, this may improve the schedule transparency at the individual level, it does not generally lead to a coherent total result, and almost always does not lead to the highest value total solution. The reason for this is inherent in the mine scheduling problem: we are dealing with large periods of time and a complex range of inputs, inter-dependencies, and conditions, all of which have an integral spatial decision component.

Some common examples of piecewise, assumptive, or deconstructed mine scheduling approaches are the following:

- *Pre-determining material pathways, cut-offs, and destinations ahead of the scheduling effort*

  A common though restrictive assumptive practice to reducing the problem complexity is to pre-determine the destinations of material in the model before the scheduling exercise. This can be especially constricting if there is any amount of heterogeneity in the reserve and the available downstream processing or waste dumping options. Further, fixing a cut-off grade at a specific average (or other point criteria) over the life of the mine can greatly erode total potential project value as it does not allow for the time-based influence of the economics or conditions for that critical decision element over the project life.

- *Scheduling on the basis of global (or location-based) flat tonnage per period*

  One traditional assumptive technique to lessen up-front data requirements and decrease problem complexity in haulage-constrained operations is to control (or guide) the mining rate on a flat tonnage per period basis for each period of the schedule. This approach often lies at variance with reality as it is often the equipment capacity (as a result of cycle time variation over space and time) that controls the periodic mining rate. The corresponding tonnage profile, however, may be very different. As a result, using this technique runs the risk of over-generalizing the schedule, and/or can misrepresent the operation’s capabilities to deliver on that plan altogether.

- *Scheduling the mining and processing activities independently*

  Often due to departmental or other organizational boundaries, vertical components of the total mine schedule are separated out (e.g.: mining / processing). In this kind of silo-based approach, each schedule is generated in isolation using some manner of assumptions derived from the other. A common example of this is the series-based heuristic (one schedule is completely derived in isolation and then is used for the inputs into the other). While this may lend itself to departmental-scale transparency, it greatly restricts the opportunity to synergize the whole and derive maximum value out of cross-boundary dependencies that often exist.

- *Generating a dumping plan after the mining schedule is complete*

  Another common deconstructive practice to simplify the mine scheduling problem is to solve for the mining sequence independent of the waste dumping plan. As the operation matures and its waste dumps inevitably grow (or backfill locations open up), a lack of direct consideration of the spatial and temporal linkages between the two can often lead to a whole host of execution challenges down the track. These include unplanned volumetric or access limitations in the dumping locations, poorly estimated equipment requirements, and an overall disjointed project schedule.

- *Calculating equipment requirements as a post-processing spreadsheet exercise*

  When basing the mining schedule on flat tonnage per period for the purpose of simplification, the requisite fleet/equipment that is necessary to support that schedule is often calculated as a secondary procedure. In this respect, the mine schedule physical results (tonnes / bench / destination /cycle time) are fed into some kind of purpose-built fleet/equipment estimating calculator, and the requirements are produced and evaluated for each period. Unfortunately, however, as the schedule itself was derived from gross tonnage guidance, the resulting equipment profiles are often periodically variable and generally unpractical to execute. These cases often require one or more back-iterations to re-solve the mine schedule in an attempt to smooth the post-processed result. The end product is generally not optimal; and a great amount of time, effort, and resources has been expended to make useable an oversimplification on the front end of the problem.

- *Evaluating capital expenditures independent of the schedule (or) in a post-scenario appraisal*

  Due to the inherent base-load complexity in the mining schedule itself, many look to a discrete, separate, singular means of evaluating further capacity adjustments (through capital expenditure) to the system. Such as the above example, when approached as yet another secondary (post-processing) iteration to the results of the equipment estimation output, this evaluation is completely detached from the principle driver: the mining schedule itself. In a worst case scenario, the straight unsmoothed, unadjusted results from this type of appraisal could be used to justify additional, unnecessary, or inadequate capital expenditures to correct the fleet capacity to match this erroneous model.

- *Solving the problem one period at a time (forward period-based approach)*
  As the total mine scheduling problem is no doubt a complicated endeavor, many look to more basic procedures to overcome the limitations of either tools or techniques – one of which is the manner of solving the problem itself. The traditional myopic approach is to solve a multi-period schedule one period at a time, therein reducing the problem to a heuristic which only makes decisions with respect to the period that is being solved. While it may speed up the process, this approach will inevitably leave value on the table, and often results in the 'paint oneself into a corner' situation with respect to future decisions due to the resulting sequence.

By employing one or more of these types of deconstructed approaches to address the total mine planning problem, the planner is unfavorably biasing the potential results and could be unknowingly preventing the business from achieving maximum value from the project. Further, since mining businesses are major, capital intensive exploits, these initial biases have real operational and economic impacts with far-reaching and long lasting consequences, such as:

- Plant and/or critical infrastructure capacities not fully utilized
- Inability to move material required and divergence from plan
- Inappropriate or inadequate capital investments in mobile or fixed fleet/infrastructure
- Poor accessibility of reserves in later periods
- Off-spec or loss-making products delivered to customers

As any of one of these consequences is a failure of the strategic scheduling effort, it is decidedly important that this work is done in a complete, integrated manner; and that solutions are generated in a way that addresses the intricacies of the total mine scheduling problem while maximizing value for the business.

Multi-Dimensional Schedule Value

While strict net present value objectives allow for economically optimum schedule generation, it is evident that not every resulting schedule will have the same end-user value, or be viewed by the collective business as the best representation of its strategy. Additionally, as mining companies are multi-lateral organizations with many departmental goals, the strategic schedule must meet a broad array of requirements. The mine planner has the difficult task to define these and their interrelationships, and eventually translate them into a balanced solution.

The merit of any resulting schedule is directly correlated to the appropriateness of the inputs used as well as the way in which the complete situation is modelled. So the real question facing the mine planner is this:

How do we model this complete mine scheduling problem in a way that balances our multi-faceted requirements and operational practicalities while seeking maximum value for the business?

Scheduling Methods

There are indeed a number of methods and associated commercial tools available today for helping the mine planner with scheduling tasks. These are briefly explained (in general terms) in order to communicate the Minemax solution in the context of the methods available. These can be summarized in two broad groups: manual scheduling and the various types of automated scheduling.

Manual Scheduling, while more widely used for tactical planning, is essentially that: the use of spreadsheets which contain plan data to manually select a sequence. To operate these sheets, the mine planner 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 without such considerations, it is often next to impossible for a planner to know if there is significant room for improving the value of a given schedule. Basically, using manual scheduling, one can only evaluate the solution that is developed, while having no direct knowledge of what other options exist.

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

Heuristic Scheduling is a form of automated scheduling where the scheduling algorithm is based upon *rules* for selecting blocks. Rules are usually related to 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, however, 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 does is known to exist.

Therefore in heuristic approaches, the total mine scheduling problem must be segmented and solved in parts, with each part's solution not necessarily influenced in the context with its effects on the others. Furthermore, the even if the resulting solutions prove feasible in piecemeal fashion, the aggregate solution will likely prove suboptimal for the business.

Schedule Optimization is a form of automated scheduling which uses a mathematical model to represent the total mine operation and its associated production constraints. Optimization 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 a myriad of operational or production (quantity/quality/location) constraints, but also optimizes the schedule in terms of net present value.

Therefore in optimization approaches, the total mine scheduling problem can be modelled as a single, integrated formulation, which will consider all possible alternatives within the provided constraints, and has the ability to guarantee the highest value solution possible given the range of inputs provided.

The Minemax Scheduler Solution

Minemax Scheduler has been specifically designed to meet the requirements of complex strategic mine planning situations by empowering mine planners with easy-to-use access to leading optimization technology. Scheduler has been commercially applied to solve compound mining problems for over 17 years, and is currently in use by mining companies and consultants in over 35 countries around the globe.

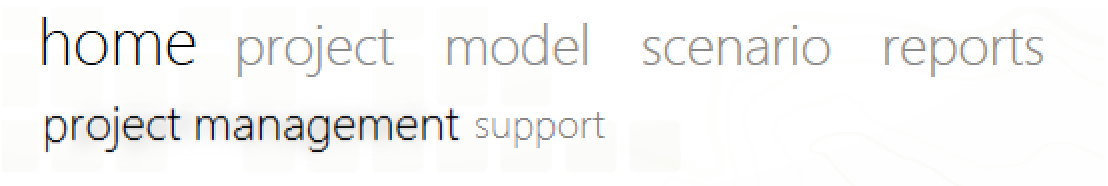
What sets Minemax Scheduler apart from the rest is its ability to flexibly handle the total mine scheduling problem in a way that balances multiple practical constraints with the integration of an alternative (options) process methodology, allowing users to evaluate all known options simultaneously while generating an economically optimal schedule. This framework is completely customizable and provides functionality to directly model any existing or potential decision. Some examples:

- The determination of economic cut-off grades
- The ore destination (e.g. plant vs leach) and/or ideal product mix
- The waste destination and dump sequence and/or backfill integration
- The influence of installed capacity on the problem (e.g. existing truck capacity)
- The option for capital expenditure and associated capacity expansions (e.g. truck purchases).
- The balancing of the schedule to satisfy multiple constraints (quantity, quality, or location)

All of this is accomplished in the context of determining the optimum block sequence, which is derived through time-based valuation assessment of all potential options. As the mine scheduling problem often spans many years, the impact of time on decisions and subsequent project value is extremely important. This is incorporated through the mathematical optimization of the net present value objective.

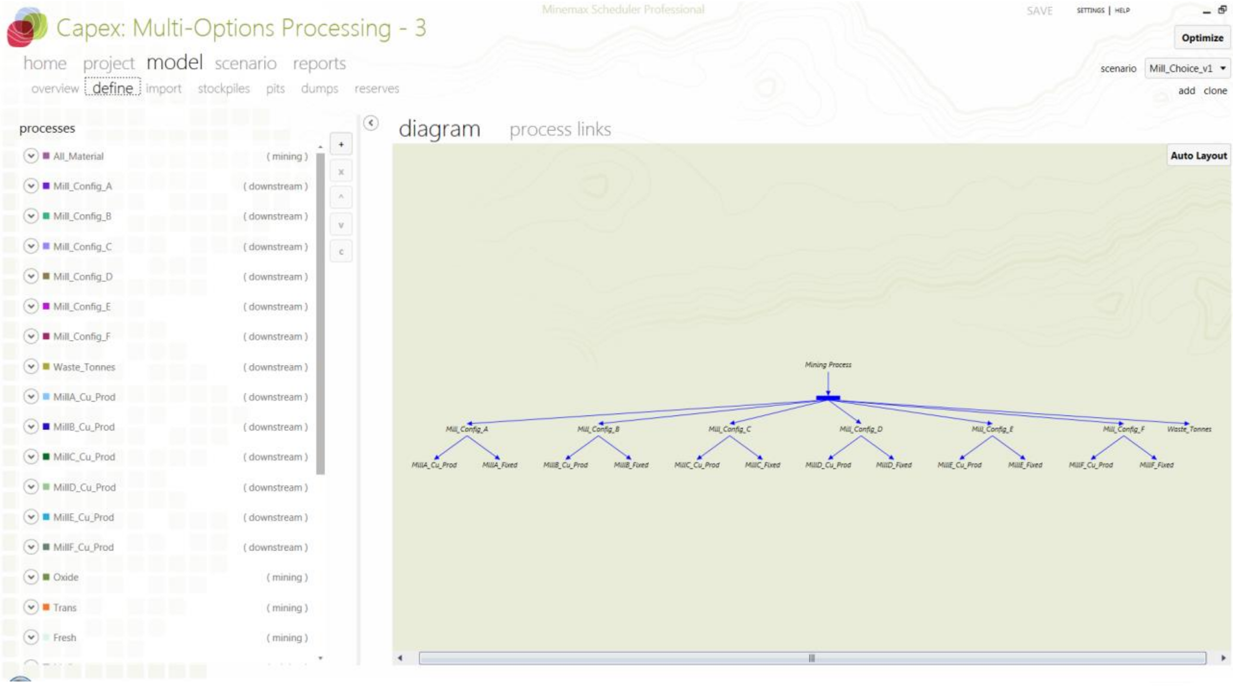
The Minemax Scheduler Workflow

Minemax Scheduler has been specifically designed for ease-of-use, while providing powerful, flexible functionality. A streamlined workflow guides the user from start to finish through the project. This section covers the use of Minemax Scheduler starting with setting up a model through to specifying parameters, optimizing, and viewing/reporting results.



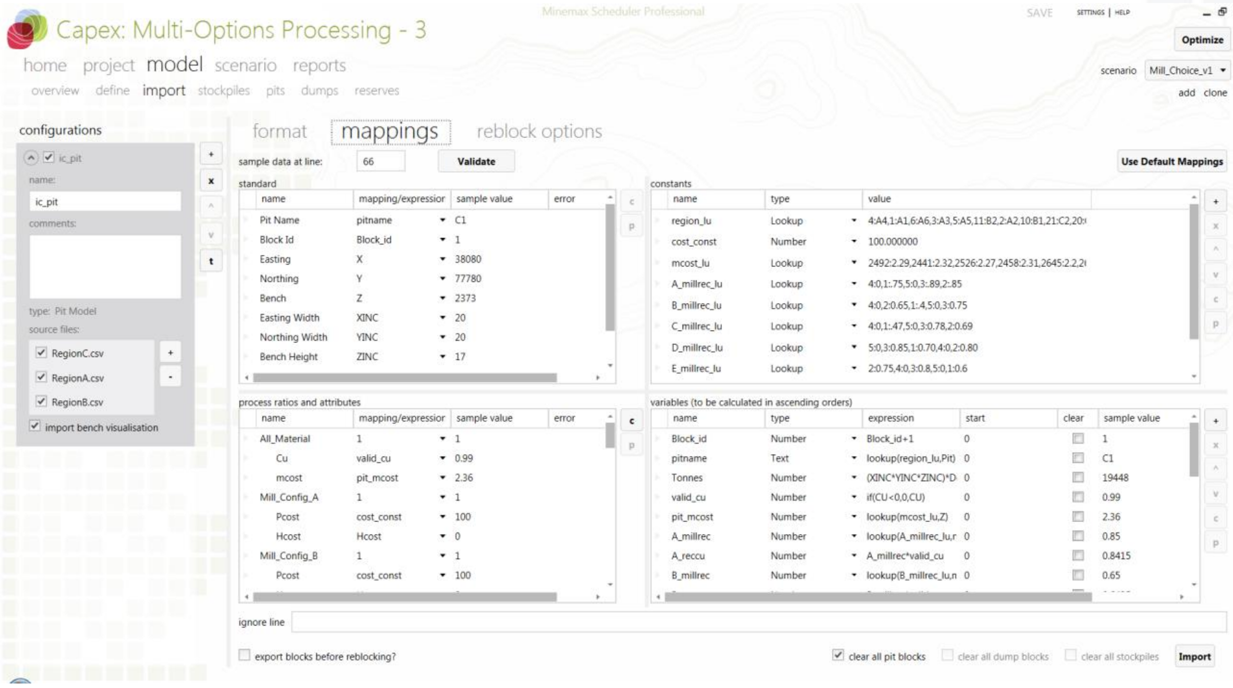
Decision Framework Definition

Defining a simple or complex decision model is fast and straightforward. Users have the ability to define multiple processes and linkages which specify the logic of interrelationships and material contribution for the project. This provides an extremely flexible platform to model all kinds of alternative processes (such as decisions related to economic cut-off grade calculation, evaluation of multiple possible processing destinations, multiple possible waste dump destinations, etc).



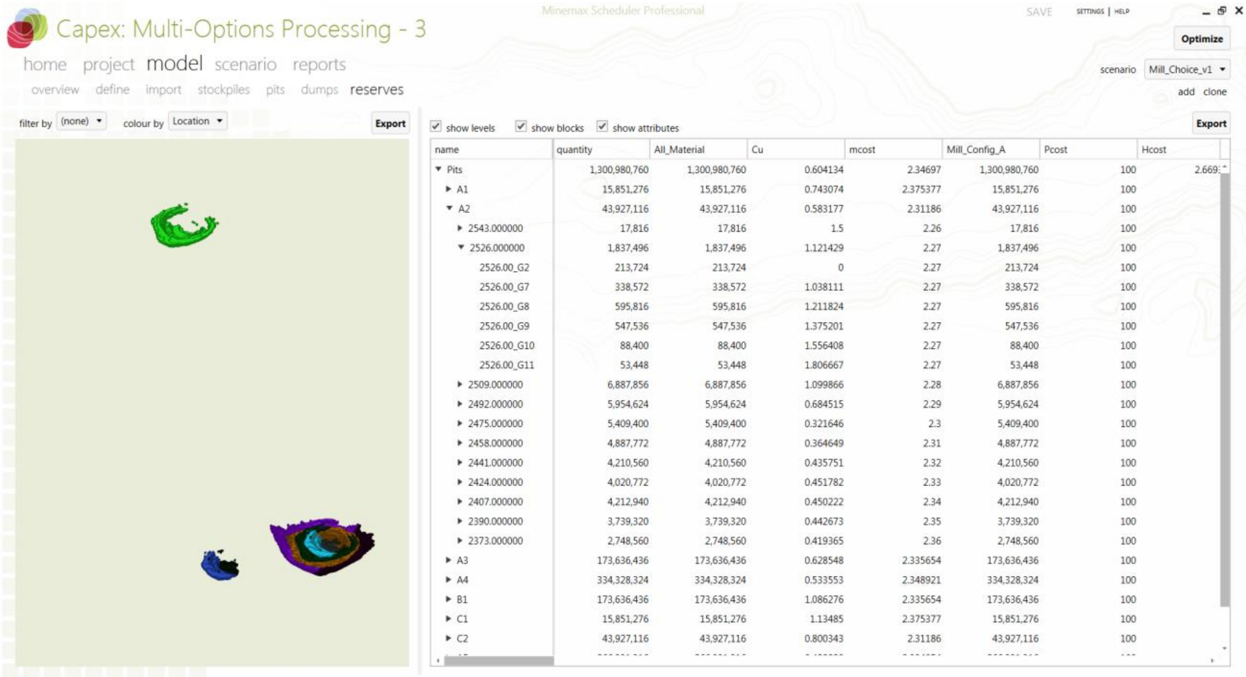
Block Import and Mappings

The core data requirement is the import of one or more block models in text file formats to define the reserve. As all major mining packages have the facility to export block model data into text file formats, Scheduler adds to your existing software investment. The essential data requirements are block coordinates and size, as well as quantity and qualities of material contained. A powerful mapping platform allows users to link this block data to their processes as well as generate new attributes using lookup tables, variables, and expressions.



Note that block models do not have to form a regular grid. Minemax Scheduler happily accepts models composed of blocks with differing sizes. Additionally, a grade and geometry re-blocking facility allows users to combine and aggregate blocks to enhance performance, or to get a rough feel for a high level schedule.

The imported reserves can be viewed in tabular and 3d visual formats, allowing for a dynamic validation of the complete model.

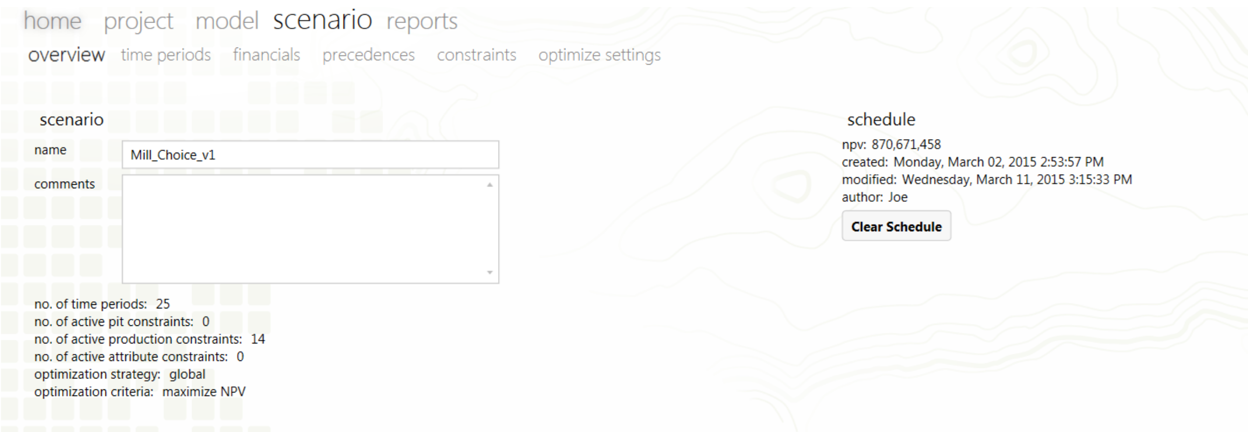


Intermediate Stockpile Definition

Any number of stockpiles can be defined in terms of grade ranges. These are typically used to model the temporary storage of lower value or off-spec ore such that higher value material can be accessed. Once stockpiles are defined, the mathematics of Scheduler determines if it is more cost-effective to stockpile certain blocks or to send them to one of the downstream processing options. Additionally, Scheduler determines when and how much to reclaim from stockpiles.

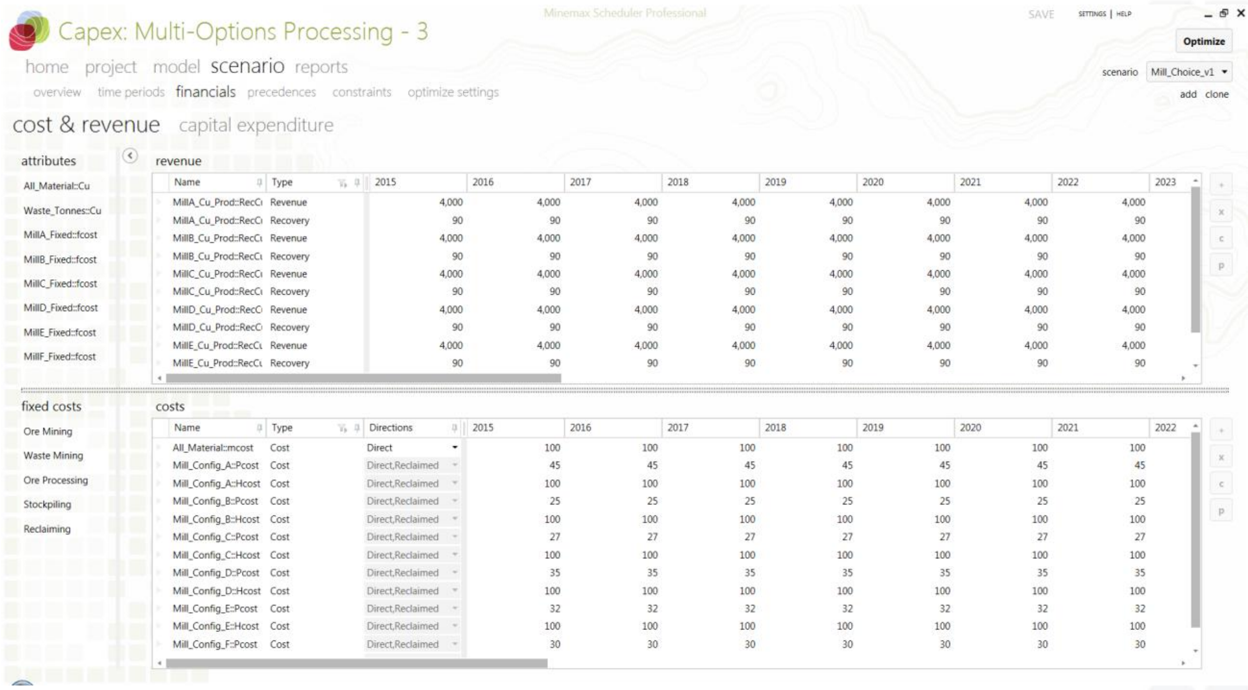
Scenario-Based Framework

Once the imported model and stockpiles are defined, a scenario-based architecture enables the remainder of the critical variables to be modelled in a framework. This allows understanding the effects of varying parameters on the project by running and comparing multiple scenarios of the same base model. These parameters are the time periods, the financial model inputs, the location precedences, the model constraints, and the optimization settings.



Financial (Operating Cost and Revenue) Model

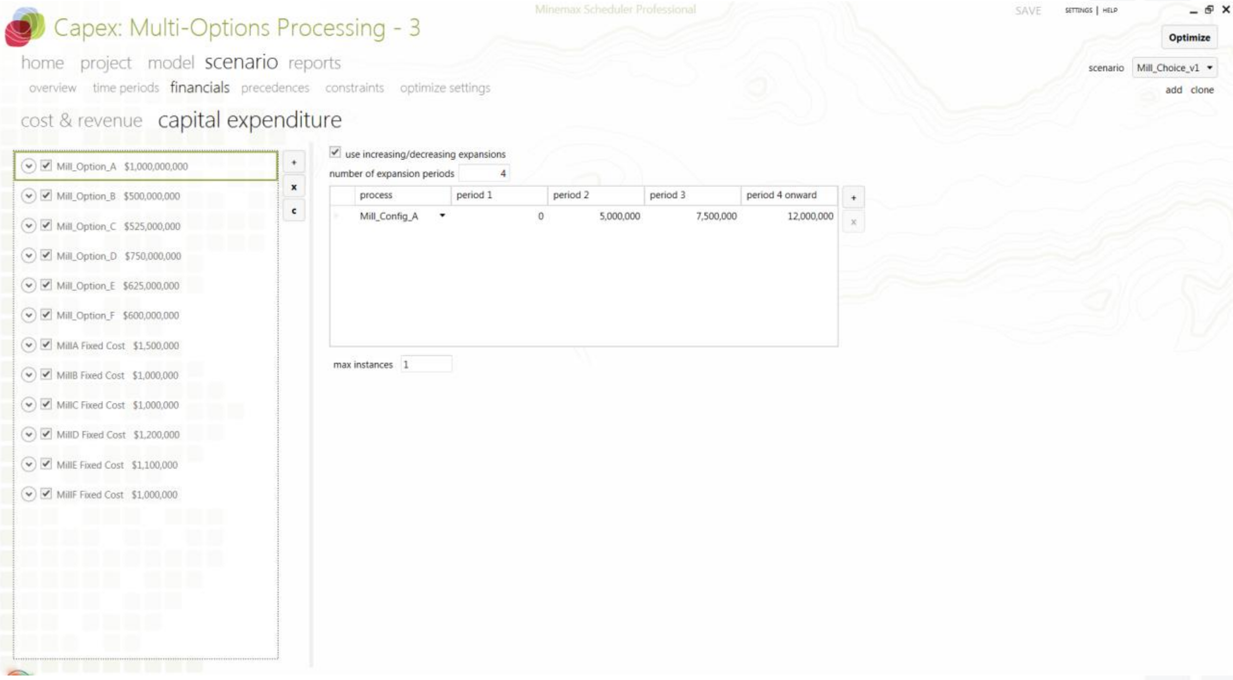
The critical financial information which will be used to calculate block values during the optimization can be easily entered into the financials workflow. For revenue, required inputs are the commodity prices in terms of grade or tonnage, and the corresponding recoveries. On the cost side, both simple and complex costing models can be designed such that the fixed and variable costs for mining, stockpiling, processing, and reclaiming are accounted for.



Capital Expenditures

An extremely powerful capital expenditure evaluation utility is also available within the financials workflow. This will allow for the definition of any process expansion which can be quantified by a capital expenditure. The lifespan of the capacity expansion can be modelled directly, such that both the expansion and the decay is modelled appropriately. Likewise, the number of instances that the capital expansion can be defined.

As an example, a new truck purchase can be defined as a process expansion of the amount of hours a new truck would provide to the fleet if purchased at a given price. The expected lifespan of that truck could be modelled to indicate the ramp up during commissioning of that new unit, as well as the reduction in performance as the asset ages over time. All of this is considered during the optimization to determine if, and how many instances of, this new truck capital expenditure is worth purchasing considering total project value.



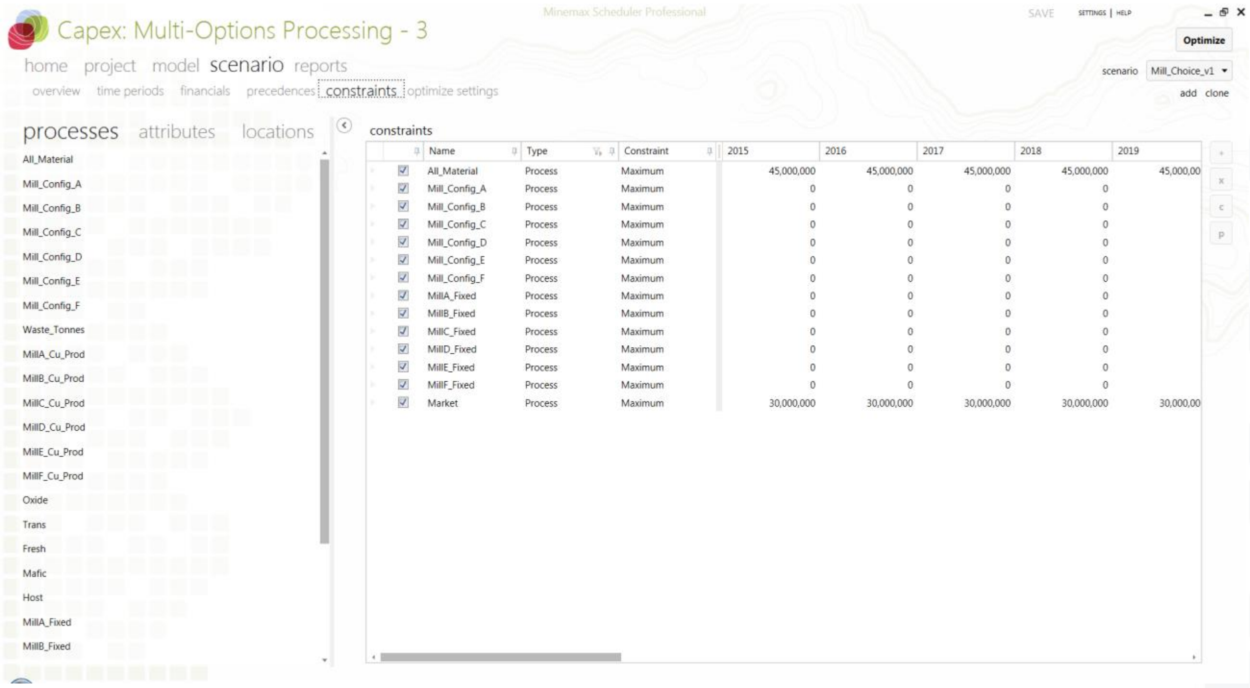
Precedence Definition

To ensure practical mining development with respect to phase and bench interaction, precedences can be defined on either whole or bench lag relationships between mining and dumping locations. Vertical advance in the mining locations can be controlled such that development cannot exceed more than a specified number of vertically stacked benches per period. Further, if a waste dumping model is integrated, precedences can be defined for it which will guide the development of the lifts in both horizontal and vertical directions.

Constraint Definition

The powerhouse of the optimization engine is the constraint set, which is defined by the user for any maximum/minimum of a process quantity, quality or location on a period basis. This flexible facility allows for a myriad of departmental controls on the model to achieve a practical, balanced solution for the total business.

For instance, mining can be limited by total truck hours to represent a haulage-constrained operation with a variable haulage network over the life of the mine. One or more process plants or leach pads can be modelled with specific upper and lower feed grade limits and/or specific production capacities per period. Downstream of the process plant, there may be fixed infrastructure (for example rail or port) which is limited by total export capacity as well. And finally, the market by which the product is sold into may be limited with respect to the availability to take product from the operation. The evaluation of this entire network, over the life of the mine, is a multi-dimensional problem. In Scheduler, all of these controlling elements can be modelled and imposed simultaneously, in isolation or in a network of possible options, to determine the best balanced mine schedule solution for the business.



Mechanics of Solution Generation

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 the constraints that limit those decisions. Minemax Scheduler then applies a transformation algorithm to the mathematical model. This algorithm examines the constraints and the possible scheduling decisions to reduce the size of the model so that it can be solved more efficiently. The reduced model is not 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 some infeasible choices.

The reduced mathematical model is then optimized by a tailored branch and bound algorithm. Branch and bound is a general purpose algorithm for solving MILP problems. Specialization of branch and bound for particular types of problems requires insight into the structure of the problem. Substantial research effort has been invested into specializing Minemax Scheduler's branch and bound algorithm to enable it to efficiently solve mine scheduling optimization problems.

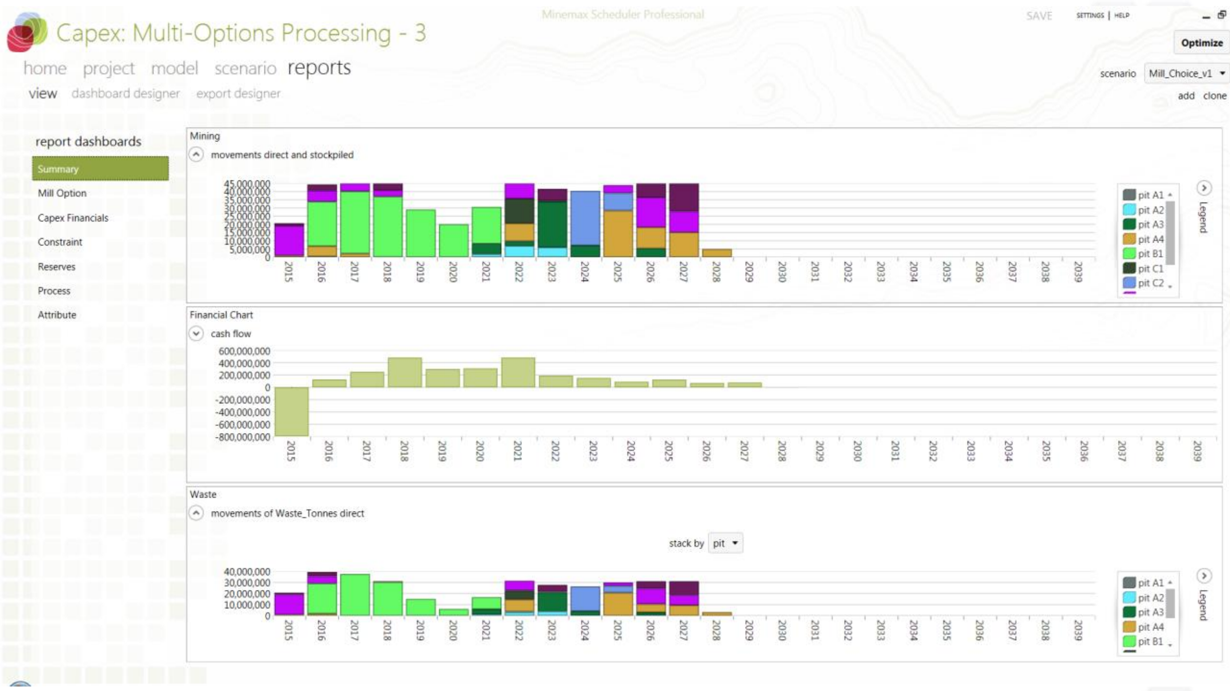
The branch and bound algorithm determines how much of each block should be mined in each period and if it should be stockpiled or processed. If there are alternative processing options, it also considers the destination of the block.   It ensures that all quantity, quality, and location-based constraints are satisfied and that the resulting schedule is optimal.

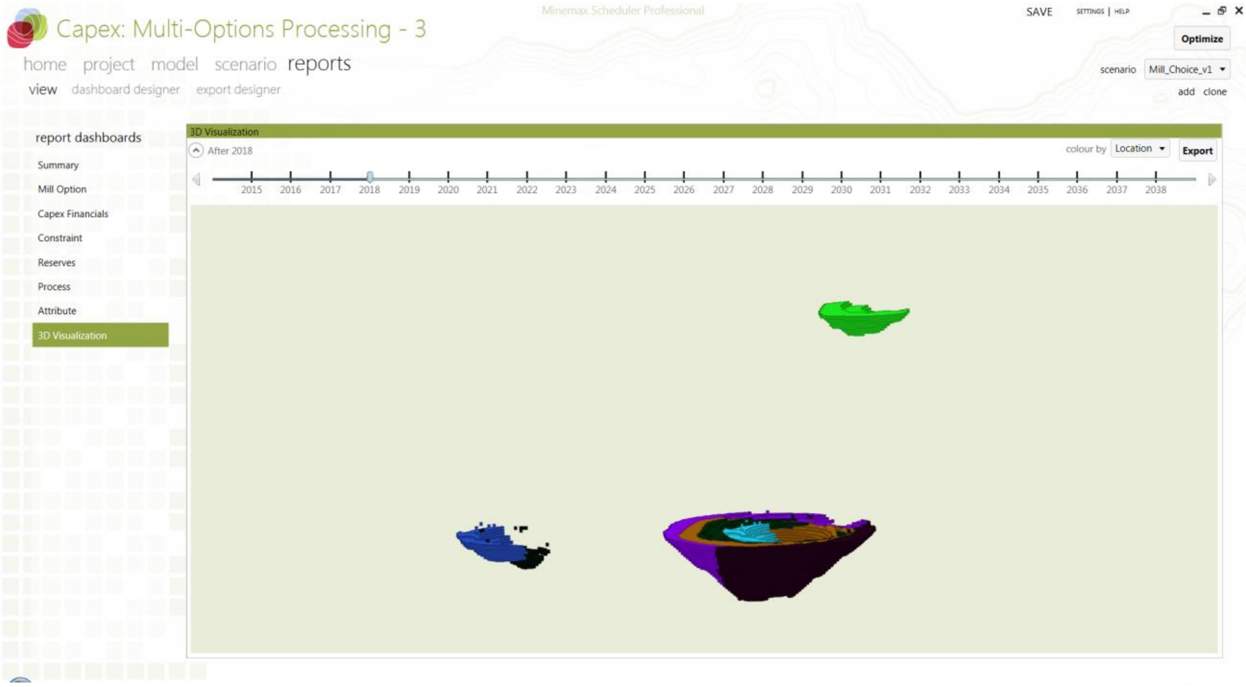
Multi-Period Optimization Capability

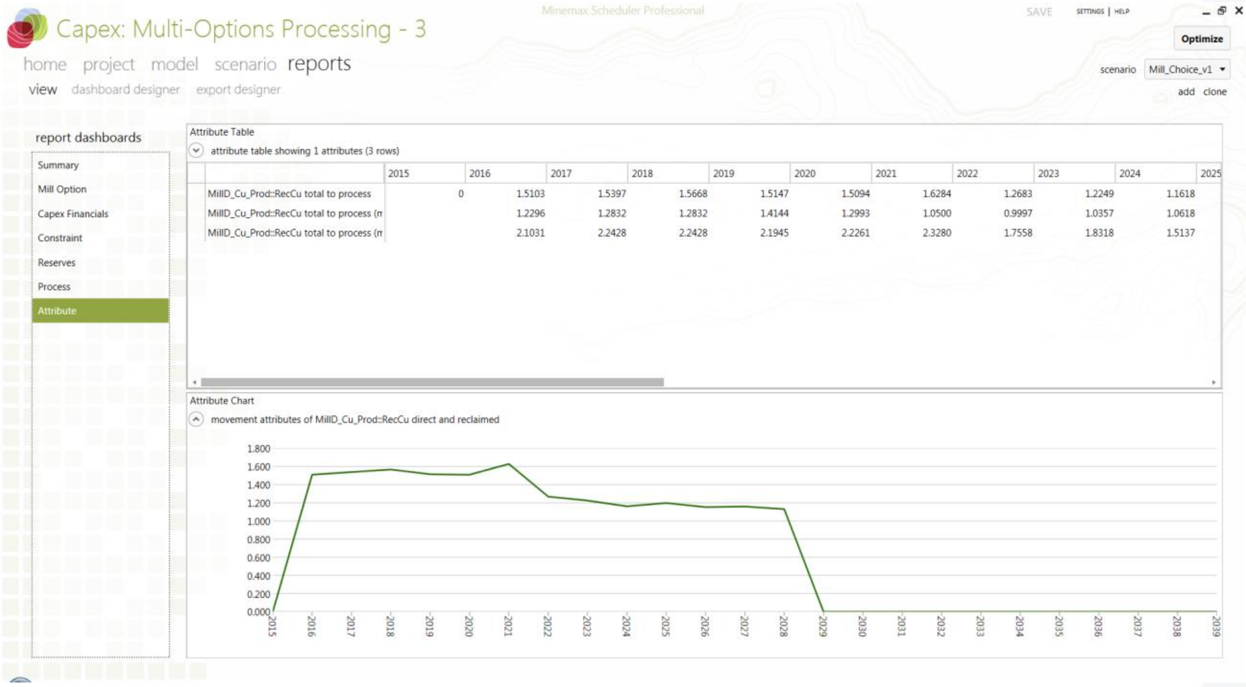
Minemax Scheduler provides the capability to optimize all periods simultaneously, forming what is a true (or Global) optimization. This is decidedly the most pure method and will deliver the best solution from a mathematical point of view. If, however, the circumstances are such that the situation requires a more step-wise approach, a sliding window method is available which allows the user to solve for a specified number of periods simultaneously, save a portion of that solution, advance and re-solve until it reaches the end of the schedule.

Dashboards and Reporting

The results of the optimization can be quickly viewed in custom dashboard form, or evaluated to other applications using a flexible exporting tool. The dashboards provide the flexibility to directly view key schedule indicators in tabular, graphical or three-dimensional form.







More Information

For more information on how Minemax Scheduler's integrated strategic mine schedule optimization solution can help you improve your mine planning process, visit http://www.minemax.com.

About Minemax

Minemax specializes in mine planning and scheduling solutions and has its headquarters in Perth, Australia, a global mining hub. Our solutions cover the whole spectrum of strategic and operational mine planning, and they help mining companies achieve production requirements, maximize resource utilization, and optimize business value.

Our company was founded in 1996 with the vision that mining companies should have access to easy-to-use software applications for creating practical and economically optimal plans. Since then, Minemax has been at the forefront with its product innovation track record:

- Minemax Planner for high-level strategic mine planning enables companies to quickly understand the potential value of projects with minimum time investment.

- Minemax Scheduler is the original solution for strategic planning and has set the standard for strategic schedule optimization at mid-to-large-size mining companies world-wide.

- iGantt is the first product in the market to integrate a Gantt chart, 3D mine visualization, and dynamic reporting in a single application.

- Tempo is currently the only product in the market for integrated and optimized mine planning and scheduling in a collaborative environment.

Our software is now used in over 35 countries by companies including Anglo, Barrick, BHP Billiton, Newmont, Rio Tinto, Vale and Xstrata, making us a leading vendor in the market for such systems.

At the strategic level, Minemax software is used for strategic business-level optimization that considers existing operations, potential new projects, and potential acquisition targets.

At the operational level, Minemax software manages the day-to-day scheduling of mining production to meet targets and provide a consistent feed of product from a mine to the process plant or downstream logistics.