Reducing costs with real waste dumping optimisation

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1. EXECUTIVE SUMMARY

For the past two decades or more, schedule optimisation has relied on extracting the highest value by considering grades and material movements to increase revenues. Considered holistically, optimising the material movement for revenue is only half the task as mine haulage costs often account for more than half of the mining cost. Typically, open pit mine scheduling is based on the following:

- Material movements are generated and then truck requirements are calculated after the scheduling process, not as part of the process.
- Haulage profiles are based on either simplified haulage networks, or on agglomerating data together. That is:
  - reducing the number of source/destination pairs to make a complex problem simpler to derive (i.e. bench by bench averaging, or single point destinations), or
  - by pre-defining destinations.

There is an opportunity to significantly improve value by producing the production schedule whilst dynamically optimising the development sequence and overall shape of the final waste land-form simultaneously. This involves automatically generating the appropriate haul route, calculating the associated cycle time, productivity and fuel burn and therefore the associated cost of haulage.

Both operating and capital costs can be reduced earlier in the mining schedule where it matters the most, i.e. when value needs to be maximised and debt and/or capital needs to paid back.

Evorelution allows the user to achieve the above improvements whilst doing so, up to 10 times quicker than traditional systems.

2. INTRODUCTION

As indicated in the opening summary, there are many instances where a complex problem is simplified to make the overall scheduling process simpler to solve. However, even in simplifying the process, a number of the tasks still take time, are not efficient and often become disconnected from the main objective. In effect, the simplifications cannot realistically model the complex process associated with open pit mine scheduling. Using the traditional tools available at present, it is difficult to holistically schedule multiple objectives. A new archetype or solution is required that can account for the large data sets as well as the many different conflicting objectives. The solutions should take advantage of advancements in the software/hardware systems now available to find practical schedules within the complex, large solution space that exists.

Bill Wilkinson, in a recent article, highlighted numerous challenges to the mining industry which resonate with the above and include (verbatim):

1. Capturing the true complexity of mineral deposits.
2. Updating mine plans with new data from the field.
3. Generating accurate production and budget forecasts.
4. Capitalising on quick changing market and operational conditions.
5. Streamlining the flow of information between the geological modelling, mine planning and mine scheduling processes.

This should not be a wish list anymore. The objectives stated above should be the norm and engineers should be focusing on achieving this standard. With the new technologies now available, there are no longer any excuses not to achieve or improve on any of the above challenges.

EVORELUTION (EVO) is unlike other scheduling tools as it is a scheduler driven by evolutionary algorithms (EAs). In general an algorithm is a set of instructions to solve a particular problem. In the mining case, the problem is trying to develop a practical, high value schedule with, almost invariably, conflicting objectives. A traditional approach (i.e. MILP, or LPs) might involve a long search for the optimal answer. This could take many forms, but it would involve either “direct attack” or a simplification of the problem. Evolutionary algorithms on the other hand approach the problem indirectly. You start with a wide variety of would-be schedules, which then compete with one another. The most successful possible solutions are broken up and recombined in specific ways to ensure they are geometrically correct, to produce a second generation of solutions which are allowed to compete again.
… and so on for many generations. It’s the “survival of the fittest”, where fitness is determined by meeting (or fitting) the defined scheduling objectives. In most cases, EAs will find optimal or near optimal solutions to these difficult problems very quickly. It should be emphasised at this point that when you have conflicting objectives there is no such thing as an “optimal” solution. All solutions will involve a trade-off between the objectives. It is up to the user to determine which trade-off result is the most suitable.

EAs also enable two additional key functions:

- parallel processing, and
- the ability to deal with multiple objectives using trade-off curves.

Parallel processing ensures that populations of solutions can be managed efficiently, and Pareto (or trade-off) optimality provides the best solution to problems with multiple, conflicting objectives.

There are many approaches to generating production scheduling inclusive of haulage estimation. However, almost all of them are disparate processes, and are not holistic in their approach. The purpose of this paper is to examine typical manual methods such as Excel based solutions or utilising fleet production estimators; to a more advanced solution such as EVO where production scheduling, automated route allocation, haulage estimation and optimised waste placement are dealt with holistically and dynamically.

The results highlight that there is no need to accept an average single solution given the “size of the prize” potentially available to engineers. EVO can produce practical solutions for mining operations which can potentially improve the value of their operations significantly, simply through the use of this innovative scheduling technique.

3 MINE SCHEDULING

Production scheduling and haulage estimation can be completed in a number of ways, including:

**Excel based:**

- Production schedule – defined by an ore target as well as a material movement limit.
- Bench data by phase and by ore/waste, rarely by lithology.
- Mining flags to mine a percentage of material by bench for each period.
- Simplistic calculators taking into account:
  - the difference between the bench elevation being mined and the surface
  - average distances in the pit
  - average distances to the waste dump
  - average distances on the waste dump
  - average speeds

**Fleet production estimator:**

- Production schedule – defined by an ore target as well as a material movement limit.
- Based on this, waste movements are known and depending on the level of detail may include lithological data as well.
- The engineer then has to determine where the waste will go. This will depend on the pit ramp location, the number of destinations and the capacity of each destination.
- For each source/bench/destination, a haul route needs to be created as highlighted in Figure 1. Haulage profiles are digitised in a general mine planning package and then exported to an ASCII file. This is generally not completed for every source/bench, rather 2 to 4 benches are accumulated and an average profile is calculated as highlighted schematically in Figure 1 and with the actual profiles in Figure 2.
- This approach is also used for the progress of the destination as well. At best the waste dump will be split into individual lifts and possibly sectors on each lift. The destination lift/sector is determined on the basis of the mining schedule already completed, and an assumed “filling” of the dump by the scheduled waste. This process, at its most complex, may involve the planning engineer determining which lift/sector is the “cheapest” to fill with the waste being presented. However this is a hugely laborious and time consuming process. The complexity is compounded and rendered very difficult to solve when deleterious material needs to be encapsulated.
The profiles generated can then be uploaded into a haulage productivity tool and a suitable equipment fleet will be selected. The tool will then calculate the overall cycle times, associated productivities and equipment requirements, and if possible fuel burn. The data generated is far more accurate than the spreadsheet solution as more detail can be included such as traffic, acceleration curves etc. However, whilst the cycle times are more accurate, the final results are approximate due the averaging of the input data and destination assumptions.

If the schedule is changed, then destination assumptions may no longer be valid and the whole process should be re-done. In general, cycle times are not re-done due to the time and effort required.

The critical downfall of this approach is that the choice of waste destination, and the cost associated with that choice, is a pre-scheduling or post-scheduling decision and is not an intrinsic part of the scheduling process. A huge number of open pit operations are, to all intents and purposes, waste mines due to high stripping ratios. The cost of waste mining effectively drives mining costs, and therefore failing to optimise the waste cost as part of the scheduling process inherently reduces the ability to generate an optimal schedule and maximise value.
Advanced Scheduling: EVO’s approach is to combine each of the processes into a continuous flow of information. The scheduling process flow is as follows:

- Define a set of haul profiles only for the in-pit ramps, the ex-pit roads and the waste dump ramps.
- Import the haul profiles and attach an equipment fleet(s) to the set of profiles.
- Create a production schedule/automated route allocation/cycle time analysis & equipment requirements as well as a final optimised waste landform shape - simultaneously.
- If the schedule needs to be changed, then all of the above changes as well.

Evorevolution achieves this on a block-by-block basis to ensure the integrity of the geo-metallurgical model is not smeared or averaged. Waste material that needs to be encapsulated can also be modelled and accounted for. Calculating haulage hours during a schedule requires the destination of waste to be determined on the fly. When choosing which block to mine, EVO considers all objectives and constraints, whilst also considering the cycle time of each block to reach its final destination. Therefore, waste blocks are dynamically assigned to their most economical locations within a waste dump, resulting in a development sequence for building the waste dumps as the pit is being mined (outlined in more detail below).

The number of trucks and the resultant truck hours per period are the variables used in scheduling. The mine planner conducts an iterative process whereby periodic truck numbers are altered to drive the material movements. For instance, increasing or decreasing truck numbers will respectively increase or decrease material movements for the period. Therefore mine planners aim to find the right trucking level to move the required tonnes of ore, whilst minimising the tonnes of waste. Another practical issue is to maintain smooth, step-wise changes to truck numbers. A common issue related to material movement focused schedules is the difficulty in avoiding large variations in the truck fleet. By using a truck count as a variable, the user can dictate truck fleet numbers to ensure they produce a practical solution whilst meeting ore production. On the flip side, if an existing operation wants to maintain their operation with their current fleet, EVO can quickly determine if this is possible.

The two ways to increase project value are to reduce costs or increase revenue, particularly early in the mine life. EVO allows scheduling of higher value ore in parallel with ensuring the lowest cost mining approach is followed. This can be achieved by limiting the number of trucks required in start-up years, which impacts both capital and operating costs during this time, both of which are amplified due to the “time value of money”. The user needs to balance the benefit of deferring truck usage as late in the schedule as possible without generating a “wall of waste” down the track which requires an infeasible level of productivity to resolve.

In order to obtain accurate haulage hours for scheduling, the accuracy of waste locations becomes very important. The approach taken to achieve this with EVO is quite different. The user only needs to create three sets of haul profiles as outlined below in a general mine planning package and exported to a CSV file format.

- In-pit haulroad – this polyline is snapped to the haul road and the user can also include other information including rolling resistances and maximum speed.
- Ex-pit haulroad – this polyline is also snapped to the ex-pit haul road to the toe of the waste dump. The starting point is also snapped to the end point of the in-pit ramp so that there is a connection.
- Waste dump haulroad – this polyline is also snapped to the haulroad on the waste dump, with the starting point snapped to the endpoint of the ex-pit road to ensure a valid connection.

Note if there are multiple destinations, then the user has to digitise a new haul route between each ex-pit road and waste dump road. The waste dump itself is effectively an upside-down block model which is constrained by the ultimate shape of the waste dump and the topography. It represents the maximum size of the dump that can then be filled by EVO within any topographical, environmental or geotechnical constraints. The shape can have a far larger capacity than required. The point is that EVO will then fill what it needs in the most cost effective manner.

The evaluation of a waste block’s haulage path to its final resting space within the waste dump consists of two components. Firstly, EVO uses a shortest path goal to find the closest dump ramp toe for a waste block. Then a lowest cost search algorithm, Dijkstra’s algorithm, is applied to allocate the waste block to the cheapest cell within the waste utility, given that any other dependency requirements have been satisfied. The reason for using a cost algorithm, as opposed to a shortest path algorithm, is the relationship between vertical and horizontal haulage. A shortest path method does not capture the differences in fuel burn between a vertical and horizontal haul. Fuel burn is a significant cost of haulage and increases significantly for vertical hauls. Therefore, a shortest path method may favour vertical hauls when they may not be the cheaper option. Consequently the cycle time consists of two components; travel to the waste dump ramp toe and travel within the waste dump with return times.
Whilst on the waste dump, the horizontal vs. vertical nature of waste sequencing can be modified to reflect different requirements. For example, rehabilitation and environmental policies can be accelerated by changing these cost ratios such that final faces of dumps are completed earlier to allow for phased rehabilitation. While bringing forward these type of costs goes against NPV maximisation, this approach allows the engineer to determine the delta value in bringing these costs forward against the benefit to the social license to operate.

EVO can also consider waste swell factors by regolith type, precedence requirements and variable material types by dump location. This can be important for practical requirements such as:

- Building infrastructure with waste rock such as the ROM pads
- Storing material such as growth material for future rehabilitation
- Storage of low-grade or mineralised material

EVO can also handle multiple mines, mills, equipment fleets and destinations.

### 4 CASE STUDIES

#### 4.1. Tropicana Gold Mine

As highlighted in an earlier paper (Graskoski, 2013), the Tropicana Gold Mine (TGM) block model used for scheduling contains around 44,000 blocks with 15 x 30 x 10 metre dimensions. There are three open pits which include ten mining stages. The haulage network contains eighteen in-pit ramps, connecting to thirteen waste dump entries and one ore location as highlighted in Figure 3. Building the ROM and the first lift of the TSF perimeter bund are essential to commissioning the mill by the end of Year 1. Therefore, all waste material in Year 1 will be allocated to the ROM and TSF construction.

![Figure 3 – Tropicana Layout for EVO](image)

A manual approach used a simplified layout with four waste locations, LTA, LEA, LWE, TSF, a stockpile, for Year 1 whilst pre-stripping is occurring, and the mill with a limitation of only one waste location allocated per mining stage. In this case a spreadsheet tool was used to calculate the appropriate cycle times, productivities, haulage hours and the number of trucks to achieve a particular schedule. The key items for comparison were the number of trucks required and truck productivity.
The EVO approach includes a higher level of complexity such as building the ROM and TSF perimeter and allocating mineralised waste to a separate dump. In this case study, the remaining TSF perimeter will have precedence over all other waste locations and will be finished within the first few years. In addition to the ROM and TSF, another two dumping locations were included:

- The Mineralised Waste Dump (MWD) which is effectively a low-grade stockpile.
- The South Dump (LSO) which is simply another waste location.

When comparing the results between the manual schedule and EVO as highlighted in Figure 4, EVO requires less trucks during the first 6 years due to a significant increase in truck productivity for the same period. This changes over time as the schedule progresses. The haul cycles increase in length and require more trucks later in the schedule (after Year 6) when compared to the manual method. Graskoski cites that overall mining costs are approximately 6% lower over the life of the operation when comparing manual methods to an optimised method. What is also important to realise is that these cost reductions occur early in the mine life when it is critical to improve NPV and pay back capital.

![Figure 4 – Comparison between manual methods & EVO](image)

4.2. Polaris – Carina Iron Ore Mine

A detailed scheduling study was undertaken for the Carina iron ore mine during August 2012 using EVO. The aim was to produce a mining schedule which:

- maximised value,
- was practical,
- produced a consistent SiO2 blend, and
- kept iron grades consistent over the mine life.

Various ramp up strategies were also examined. Value maximisation was achieved by minimising costs early in the mine life. This involved reducing material movements to match ore production and also minimising excavator movements.

A monthly schedule was completed after depleting the model with an as-mined surface. The schedule also accounted for:

- 4 fleets
- Ore production ramp-up
- Dry/wet seasons

The results of this study highlighted that a practical, high value schedule could be completed. This work was extended in July 2013 to include a far more complex scenario that included:

- extra mining areas,
- increasing the ore target,
- maintaining stringent grade and contaminant targets, and
- high sulphur waste encapsulation.
All these were undertaken whilst balancing truck requirements.

This involved producing haul profiles for all source/destinations including multiple pits, waste dumps and associated encapsulation areas as highlighted in Figure 5. Speeds and rolling resistances, etc, are allocated along each profile and an overall cycle time & productivity can then be calculated.

![Figure 5 – Carina Pit Haulage Network](image)

A comparison between using pre-defined haul profiles as compared to on-the-fly haul profiles in Evorelution is highlighted in Figure 6. There is a significant reduction in haulage distance generated by EVO, as the algorithm will short-haul and focus on producing a waste dump with minimal haulage cost. This compares to the “global average” nature of a single profile for a given source/destination pair.

![Figure 6 – Carina – Variations in cycle times & distances](image)

The reduction in distance significantly improved the cycle time within top 50 metres of stripping to a point where 3 less trucks were required to achieve the same material movement over the first 11 months of the revised mining schedule. The effect of the delay in capital spending (in the order of $5M), as well as the reduction in operating costs, was substantial (in the order of $6.5M).

Carina continue to use EVO for LOM scheduling and have recently completed the 2013/14 plan.
5 CONCLUSIONS

There are numerous techniques available to calculate truck requirements for a given schedule. By using a manual method, the engineer will in all likelihood be simplifying the problem and will not provide an accurate estimate of the required haulage hours.

If the engineer chooses to use a manual method, either in a spreadsheet or by applying haulage profiles after a schedule has been completed, the likelihood of achieving an optimal high value schedule is doubtful.

If the engineer also pre-determines where material can go, then the opportunity to optimise the haulage fleet and improve project value is also lost.

All objectives including development of the production schedule, the automatic allocation of the haul route, the calculation of the cycle time, productivity and fuel burn as well as placing the waste in the most cost effective location on the waste dump needs to be undertaken dynamically within the scheduling space.

The case studies above highlight that more complex mines, where there are multiple objectives, sources and destinations, will require high-end solutions to derive the maximum value whilst producing practical production schedules.

6 BIBLIOGRAPHY
