

## **A HOLISTIC APPROACH TO MINE PLANNING**

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### Abstract

Understanding and implementing complex material placement for stable and sustainable rehabilitation has historically been very difficult. Often, final waste rock dump designs require significant amounts of detail, time and effort. Determining the practicality of implementing and staging these complex designs is however, often forgone. This can result in operations failing to adhere to plans, which results in significant environmental consequence and breach of mining consent conditions. Additionally, substantial unforeseen costs arise from poor planning, failure to adhere to plans and the cost of rehandle, environmental reparations, and in extreme cases, forced closure or restriction of operations.

A study was conducted to demonstrate the advantages of the incorporation of selective material placement within waste rock dumps in a mine plan, and ultimately ensure the mine's ongoing licence to operate. The focus was to minimise Acid Mine Drainage (AMD) and the harmful effects of contaminated material, thus, reducing the overall rehabilitation liability and cost of the operation and increasing profits and the NPV of the operation. The overall outcome of the study showed that it is possible to create a dynamic and flexible mine plan using advanced software to generate a detailed destination schedule with selective material placement. The final aim being threefold: firstly, to reduce AMD within the waste rock dump; secondly, enabling a smoother transition from operation to progressive rehabilitation and closure due to removing the retrospective aspect of rehabilitation; and finally, reducing costs both during and post mining activities.

In order to minimise costs and reduce rehabilitation liability, it is critical to conduct operational mine planning that fits within the context of closure. Without a holistic approach to mine planning, closure costs can substantially increase and mining companies run the risk of needing to perform maintenance in perpetuity with the real possibility of never relinquishing the mining lease, post mining activities. Figure 1 depicts the risk and the ability or options to change and mitigate risks throughout a project's life. If all aspects of mine planning, from feasibility to operations, incorporate detailed plans that fit within the context of closure, earlier identification of risks is possible so that strategic decisions can be made allowing greater ability to change and mitigate risk.



Figure 1 - Risk mitigation



## Introduction

All mining operations will eventually deplete their economic resources and have to face closure. Some mines may close before fully exploiting their resources, for various reasons, such as labour issues, commodity prices, political instability, insufficient funding, environmental or safety issues. Planning for closure is critical yet it is often overlooked or underestimated in many feasibility studies. Optimizing planning and rehabilitation/closure is critical for longevity of the mining industry. The mining industry is coming under increasing pressure from a large number of environmental and civil groups. The future success of the mining industry is in part dependent on its capability to instil confidence in its ability to achieve successful mine closure and subsequent land use.

According to the Australian Government Department of Industry, Tourism and Resources (2006), a mine is complete when lease ownership can be relinquished and the responsibility handed over to the next land user. At mine closure, the final landscape must be safe and environmentally sustainable and the government, community and stakeholders must be satisfied with the outcome.

Legislation has therefore been developed such as the Environmental Protection Act 1994, where post mining land form must be safe, stable, nonpolluting and able to sustain an agreed end land use (Department of Energy and Resource Management, 2011). The 2010 Amendment of the Australian Mining Act, requires, among other conditions, that mining proposal applications contain details of waste plans, rehabilitation procedures and risk assessments (Department of Mines and Petroleum and Environmental Protection Authority of Australia, 2011). Failure to adhere to legislation can have repercussions on mining licencing and thus most mining companies undertake detailed mine closure planning.

In practice, however, guidelines for rehabilitation are inconsistently followed. This is due to various factors including:

- short term operational interactions,
- production requirements,
- poor understanding of the effect that noncompliance has to the operation and on cost and profitability,

- engineering complexities of incorporating rehabilitation within core mine planning rather than as a separate process and finally,
- lack of cross flow of data and communication between environmental recommendations and mine planning.

Overall, non-adherence to guidelines and requirements can result in loss of licence to operate, withdrawal of mining concessions, substantial fines and a company's damaged reputation, which can affect current and future mining concessions. On an environmental level, poor rehabilitation planning can result in excessive soil erosion, hazardous pollution for many years into the future, contamination of waterways and physical health and safety risks. A case in point is the acid mine drainage challenge that is currently facing the older South African gold mines. Furthermore, there is risk of requiring ongoing and never ending maintenance. Hauling to the incorrect location for just one shift can have huge environmental consequences and result in financial losses due to required rehandle or reparations. The overall result is a loss in profitability and risk of having licences revoked.

There are many advantages of integration of rehabilitation/closure planning into the mine plan. These include but are not limited to minimise both the short and long term operating costs, minimal rework, an integrated mine plan, a practical solution to complete successful mine closure and progressive rehabilitation that complies with legislation. It also provides the means to communicate requirements in a timely manner to operators, staff, the community, key stakeholders and the government. A fully integrated plan enables the ability to analyse plans in more detail and to make better decisions in areas such as geotechnical, geochemical and water quality in order to fulfil the final agreed post mining landform use.



This paper demonstrates that through planning using a detailed haulage analysis, specifically the incorporation of selective material placement in waste dumps, engineers can run different scenarios to determine the sensitivities as well as identify where the designs cannot be achieved and modify plans to operating practices to align to a closure strategy. This being achieved by using detailed haulage estimates and costs, staged and final landform shapes, location and mineralogical makeup of the waste rock dump. These processes are efficiently completed by incorporating the mining closure study as part of the mine planning processes instead of it being an afterthought or separate process after the mine plan is developed.

# Selective Material Placement

Knowing and understanding the final destination and characteristics of waste material can greatly impact the overall outcome of rehabilitation and pollution risk both during and post mining operations. This can significantly reduce costs through reduction of remedial works and enable planning and investigations to be more precise and cost effective as well as reducing the risk of soil erosion and failure of revegetation. (Department of Industry Tourism and Resources, 2006)

It is becoming more evident that the classification of waste rock types and the overseeing of their excavation and knowledge of their placement during waste dump rock construction are important. For example, materials adverse to plant growth can be buried and water contaminating materials and acid forming waste can be appropriately placed or removed. Material salvageable for rehabilitation can also be suitably stockpiled and later used during waste dump construction.

Failure to plan for rehabilitation throughout every phase of mining can adversely affect environmental protection and result in rehandling of materials and reworking of plans and designs.

# **Destination Scheduling**

Mine design and scheduling can be a complex process due to the number of interactions and the dynamic nature of the coupling of the mine plan to the waste rock dump. In the past simplifications were made in order to make solutions possible. These simplifications allowed planners to manage with the tools available at the time. However, over the past few years computers and software development have advanced dramatically. Tools now exist that allow engineers and planners to incorporate more detail into mine plans.

Landform construction using truck haulage is an area of increasing concern and focus for many mining operations. Part of this push is a focus on reducing costs, as a significant portion of the operating cost of a mine are associated with the haulage of material. It is therefore imperative that significant planning is completed to reduce haulage costs and to correctly quantify the trucking requirements and reduce risk of not being able to achieve the plan.

Studies have also shown that scheduling and planning to fully utilise a truck rather than the loading equipment can significantly increase profitability of an operation (Graskoski, et.al. 2013). This can be a balance between a variety of factors. Figure 2 shows that sometimes the minimum unit cost (trucking cost thus minimum number of trucks) can cause an operation to lose value. It is therefore imperative that an operation does not focus entirely on minimising the cost of one single factor but rather look also at the holistic effects they may have on the total operation.



Figure 2 - Number of trucks to maximise business value (Doig 2014)



Traditionally, truck cycle times were calculated using a centroid to centroid method whereby the centroid of a mining bench or block was identified and a haul route was drawn manually to a centroid position of the waste rock dump or stockpile destination. Studies however have shown that this can be an incredibly time consuming process and produce significant errors or variations due to a number of factors including (Doig and Kizil, 2013 and Graskoski, et. al. 2013):

- Final position within the dump
- Swell factors
- Mining interactions
- Actual distance from the dig or dump centroid.

A study conducted by Doig and Kizil (2013) showed that, in a strip mining configuration, by varying the mining block size, cycle time variations of up to 15% could be seen as shown in Figure 3. This can be further compounded by various dump block sizes and selective material placement strategies.



 Horizontal block size increase for all strips All strips with total strip and vertical bench height increase Strip 6 400m block size with vertical bench height increase Strip 7 400m block size with vertical bench height increase

- All strips 400m block size with vertical bench height increase All strips 700m block size with vertical bench height increase
- Strip 6 700m block size with vertical bench height increase Strip 7 700m block size with vertical bench height increase

Figure 3 - Cycle time variance (Doig and Kizil, 2013)

Although estimating cycle time is crucial for estimating truck productivity, significant planning improvements can be made by carrying these estimations through to the mining schedule. Recent advancements in computers and mining software have enabled mine planning tools to incorporate truck limited scheduling. This enables planners to quickly run multiple cases where they can limit both the number of trucks and number of loading equipment in order to develop an optimal solution for the operation. Although truck numbers have been calculated as part of a mining plan for a long time, they have typically been calculated after the mining schedule has been created or determined. Because of this, it is often a long and difficult process to then change the mining schedule to match the number of trucks available. Advanced software is now available where this process of haulage estimation and destination scheduling is incorporated as part of the scheduling process. Figure 4 shows the iterative process that is performed internally as part of the truck limited scheduling algorithm within the Landform & Haulage Scheduling software.



Figure 4 - Scheduling and trucking requirements process

This study was completed using a full resource based schedule, scheduling every second of time.

The schedule and the design were dynamically linked which enabled the design, schedule and landform modelling to be considered in a more integrated and holistic approach. Figure 5 shows the typical linear planning process.



This study took the concept one step further by incorporating the schedule and landform together in order to make a seamless mine plan including all factors from mine production, truck scheduling, rehabilitation, stockpiling and final landform.

This can enable planners to quickly create and validate mine plans incorporating most aspects of mining to closure including selective material placement where the planner can see what material has been placed, at what location at any point in time. This helps planners to make more strategic decisions in order to reduce the more tactical decisions required to deal with short term mining intricacies.





## **Case Study**

### **OVERVIEW**

The case study was conducted on a copper-gold deposit with multiple material types which include a reactive, potential acid forming material, saline material and small amounts of a clean, non-acid forming material. The selective placement of these materials within the waste rock dump was crucial in order to create a sustainable landform during the mining life and post mining activities.

Selective material placement was critical in order to reduce AMD and potential for spontaneous combustion. It was also a requirement to mine the reactive, potential acid forming material during the dry season in order to reduce the potential for oxidation and a chemical reaction during the wet season. It was therefore critical to have a mining schedule that had the flexibility to target different material types within the given season.

Due to confidentiality, the author is unable to publish the original data this work was completed on. In order to demonstrate the method and the work, a project was completed using similar principles and objectives to the original project. This paper shows the work completed from a generic dataset with these principles and constraints applied.

The main deliverables of the project included:

- An achievable mining schedule with constraints based on the construction of the waste rock dump, such as cover depth of Potential Acid Forming (PAF) material
- Detailed truck estimates with truck limited scheduling
- Final landform surface
- Disturbance prediction
- Progressive landform surfaces
- Optimised cases to reduce PAF exposure during landform construction
- Progressive material characteristic surfaces to show exposed areas of the various material types over the life of the mine
- Final material placement prediction.

The deposit is in an area that suffers from extreme climate changes throughout the year with dry seasons during some months and significant monsoonal events during other times of the year. These wet seasons can cause significant waste dump erosion as well as flooding from a nearby river. It was therefore critical that the operation carefully managed its water and risk of water flowing offsite and polluting nearby rivers and waterways.

The material characteristics within the pit shell vary and include:

- Topsoil
- Clay
- Clean Non Acid Forming (CNAF) material
- Dirty Non Acid Forming (DNAF) material
- Potential Acid Forming (PAF) material, and
- Reactive Potential Acid Forming (RPAF) material

It was critical that uncapped PAF material was minimised and treated before the wet season.



#### **PIT DESIGN**

The pit area was in a relatively flat part of the deposit. A single ramp was designed in the pit to a total depth of approximately 140m. Benches were included in 16m intervals.

Figure 6 and Figure 7 demonstrate the pit design and layout. As can be seen in Figure 7, the majority of the pit consists of a PAF and DNAF material, with a small amount of CNAF towards the surface. In order to manage the material, it was identified that additional CNAF material would be required in order to cover the PAF material. As part of this, it was identified that in order to minimise the impacts of mining operations, the additional material could be taken from underneath the waste rock dump footprint. This material could then be stockpiled if unable to be hauled to the final landform position at that point in time.



Figure 6 - Pit layout



Figure 7 - Pit section

#### WASTE ROCK AND DUMP DESIGN

A number of waste rock dump options were considered for the analysis. The aim or determining factor in deciding the landform shape was set by the overall cost and risk. Options for designs included but were not limited to:

- Low batter angles with wide footprint
- Low batter angles with a higher dump to reduce footprint
- High batter angles with wide footprint,
- Steep batter angles with higher dump to reduce footprint,
- Variations of various stage increments and various capping thicknesses
- Clay capping options

These scenarios were run to include destination schedule haulage cost as well as the additional cost of treating material with lime, compaction cost, water treatment and cost of additional dump disturbance.

These factors were all considered for cost and risk with an optimal case being chosen. For the purposes of presenting this paper, a simplified case was designed and utilised. This incorporated the base layer being removed and stockpiled to be used for capping the final dump. The dump was then designed in the context of a total shell incorporating the following layers in the order which is also shown in Figure 8 and Figure 9:

- 1. Compacted base layer of DNAF material with drainage incorporated
- 2. PAF cell dumped out in 5m lifts
- 3. DNAF capping compacted in 5m lifts
- 4. CNAF capping dumped out with DNAF in order to maintain an operation running width for trucks
- 5. Final topsoil layer to be placed after the dump had settled, one strip later



Figure 8 - Final landform isometric view





Figure 9 - Waste rock dump section

The PAF cell was designed to be larger than actually required in order to allow for additional material to be hauled to the cell. This allows the PAF material to be diluted with intermediate capping as required without any subsequent rehandle.

Additional drainage and dams, as shown in Figure 10 were also designed in order to catch all runoff water during the construction phase of the waste rock dump. This allows for any potential contaminated water to be treated. Additionally, these dams can be used post mining as an initial barrier between the waste rock dump and the downstream environment in order to reduce the risk and minimise potential water contamination until the land is fully restored to its post mining use.



Figure 10 - Waste rock dump and drainage section

Stages were then designed to be incorporated within the total dump shell. These stages were designed in order to work back towards the pit so as to enable the earlier stages to be rehabilitated progressively as shown in Figure 11. This serves two purposes, first to reduce the rehabilitation liability of the operation during the life of the mine. Secondly, the operation has a chance to complete the rehabilitation in small sections. That enables it to test the planned methods in the context of end land use, adapt and improve where possible, as well as prove to the stakeholders, community and regulators that the rehabilitation strategy is successful.



Figure 11 - Isometric landform with staged surfaces

#### **SCHEDULE**

The mining schedule was created whereby targets were set to achieve the required ore tonnes for the processing plant. Restrictions were applied to the various material types in order to ensure reactive, potential acid forming material was not mined during the wet season as seen in Figure 12. The benefits of this allowed multiple scenarios to be run by altering the targets progressively with the landform scenario in order to minimise the impacts on the landform and maintain a smooth production output.



Figure 12 - Waste material movement by type

A destination schedule was setup. This incorporated a detailed haulage solver which produces a block by block detailed haulage calculation. The waste rock dump was split into ten strips or stages. These stages were then benched out every 5 m and blocked into 50 m segments. Haul roads were designed up each of the ramp faces from the pit. Slot connectors were then created to connect each mining and dump solid to the relevant segment on that haul road. This created the basis of the haulage network in which potential haulage paths were generated and from which subsequent cycle times were calculated. Dumping dependencies were then generated to limit the available dumping blocks to a logical progression and ensure blocks below were dumped before the block above could begin.



Finally the haulage scenario was configured with the relevant material mappings. This was to define where material could potentially flow. In this case study, a number of priorities were included in order to achieve the most desirable landform configurations.

Some of the priorities included hauling the RPAF material to prioritise the centre of the dump, in order to minimise the amount of RPAF and PAF under the battered slopes. Additionally, the PAF material was mapped to all of the dump cells with a priority of 1 on the PAF and increasing priorities as it went through the DNAF and PAF cells. This enables material to still be hauled even if the most desirable location is not available at that point in time. Additional mappings were created in order to allow material to be hauled to stockpiles where required. The material that was hauled to stockpiles was then made available to be withdrawn during the landform scenario as required to cap the PAF material.

This mine plan also enabled users to quickly change parameters such as machine types, mining rates, and the mining schedule and dump designs to obtain accurate results. This allowed better strategic decisions to be made in the context of the life of mine to reduce both costs and the rehabilitation liability.

In order to determine the effects of being under or over trucked on the operation, a truck limited haulage scenario was also incorporated. The costs of the progressive rehabilitation, government securities, water management etc. were able to be incorporated within these costs due to the detail contained within the mine plan.

### Results

One of the key results of the study was the progressive landform haulage destination schedule. This model can be played through time so that the user can visually see the progression of the dump. This is also a critical tool in communicating the plan to managers and operators in order to show the progression and direction of the plan in addition to showing the importance and rationale behind particular decisions.

Because of the visual nature of the tool, engineers also have the opportunity to validate the practicality of the scenario as well as identify potential risk and opportunities to the operation. Figure 13 and Figure 14 show the progressive landform at a particular point in time and the final landform respectively.



Figure 13 - Progressive landform



Figure 14 - Final landform

The progressive landform destination schedule produced a number of key results which included:

- Selective material placement location
- Updated resource based mining schedule based on trucking constraints (landform has the ability to slow down the mining schedule and progressively make more strategic decisions during the processing of the landform run)
- Progressive landform surfaces
- Exposed surface areas throughout the mine life for calculating water quality
- Truck requirements including, cycle times, required truck hours and fuel burn
- Volumetrics stockpile management
- Interactive landform model.

The key result of the landform model was that every material could be selectively placed and the source position identified. This enables the waste rock dumps to be examined in detail including the material types and properties that were hauled to those entities.



Geochemical block models can then be created from these entities so as to be examined in detail by other experts for geochemical and water quality properties. Figure 15 illustrates a cross section through the waste rock dumps showing the actual material classifications determined through the destination schedule.



Figure 15 - Final waste rock dump

An additional advantage of understanding the material placement throughout time is the ability to report and produce surfaces with the predicted material placement within given time periods. This enables further financial and geochemical analysis to be conducted on the predicted exposed area of given material types to give superior estimates for the prediction of the exposed area by material. This can also be used to show to the company, community and the government the progressive capping and associated mitigated risks. Additionally, risks can be identified; in particular harmful material area exposed for too long or during the wet seasons and plans can be put in place to mitigate them.

Figure 16 and Figure 17 shows the waste rock dump surface areas over time with the associated material classifications. These surface areas can be calculated and visually displayed and exported at any desired point in time. The pie-chart demonstrates the surface areas for the model run at a particular point in the life of the mining operation. These surfaces are highly valued for the purposes of estimating water quality and determining the water management plans both during mining operations and post mining operations. The mining engineer can export surfaces from the landform haulage model and examine as part of their normal planning process. This can enable them to take more ownership on the water quality and the exposed materials as well as reduce the cost of rework required for environmental studies and increase the accuracy of models.



Figure 16 - Waste rock dump surface areas



Figure 17 - Waste rock dump progressive surface area

### Conclusion

Mine planning is a crucial element to ensuring sustainable and profitable operations. Good mine planning however is not possible when it is not considered within the context of final mine closure and relinquishment. Given the advances in software, mine planners now have the ability to look at the whole operation within one model to determine the true costs of the operations. This enables users and businesses to make enhanced strategic decisions with accurate understanding of the implications to the operation.

Through incorporating a life of mine landform haulage model within the mining schedule and closure requirements, optimal solutions can be determined to minimise risks and maximise the NPV. Through detailed planning, engineers and planners have the ability to make more strategic decisions for the future of the operation instead of having to make decisions through the implementation stage that can significantly affect costs and closure outcomes in the future. In the case study conducted, the mining schedule was altered to mine more favourable material during the wet seasons in order to minimise the exposed PAF material.



Additionally, multiple scenarios were run in order to determine a strategy to minimise the amount of CNAF material required whilst also minimising the exposed PAF materials and any given time.

Additionally, the exposed areas and the final placement or makeup of the waste rock dump can easily be determined. This can allow for more precise studies to be completed to evaluate the effects of acid mine drainage, erosion control, water qualities and the stability of the final landform. This gives operations, regulators, investors and the general public more confidence on the mine plan. This can reduce operating costs, rehabilitation liability and delays to the operation. Additionally it can help to ensure that the mine will be able to eventually reach relinquishment and reduce the risk of the loss of social licence.

There are many advantages of integration of rehabilitation into the mine plan. These include but are not limited to minimal rework, an integrated mine plan, a practical solution to complete successful mine closure and progressive rehabilitation that complies with legislation, ability to run multiple scenarios in order to maximise profit and reduce risk, minimal rehandle and understanding and anticipating potential risks. It also enables the ability to communicate requirements in a timely manner to operators, staff, the community, key stakeholders and the government. Additionally, it enables the ability to analyse plans in more detail and to make better decisions in areas such as geotechnical, geochemical and water quality in order to fulfil the final agreed post mining landform use.

Please contact your local Deswik office for further information about the above case study or about any of the tools used.

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