Open pit scheduling features to improve project economy

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The standard approach to open pit mine design typically applies a pit optimization process followed by basic scheduling within the defined final pit limit. Often, as a result of this process, the mine operates at a higher strip ratio during the initial period and moves towards a lower strip ratio to the end of the mine life. The impact of this is an annual production schedule that does not follow a sequence that maximizes the net present value (NPV). The objective of this paper is to compare and contrast the standard and pushback approaches for open pit mining, with the aim of demonstrating that a pushback approach is practical and can increase the NPV of a project. The pushback method minimizes the stripping ratio in the early years and defers some of the equipment purchasing until later in the mine life. The results of the study show that the project NPV can be increased by the application of pushbacks by delaying and smoothing capital expenditure on equipment and waste stripping while maximizing the grade to the process plant.

Keywords: pushback, optimization, cash flow, NPV.

Introduction

The principal focus of a standard open pit mine design process is to produce a net present value (NPV) that is positive and robust enough to support the development of the mine. In addition, the design will typically try to achieve a high resource recovery. This ‘standard’ approach will typically use pit optimization software, followed by basic scheduling within the defined final pit limit. Often, as a result of this process, the mine operates at a higher strip ratio during the initial period and moves towards a lower strip ratio towards the end of the mine life. The impact of this is an annual production schedule that does not follow a sequence that maximizes the NPV.

Another approach to mine scheduling is to follow a method that mines the pit in a series of campaigns or ‘pushbacks’. This pushback approach to mine design and production planning aims to maximize the NPV.

The objective of this paper is to compare and contrast the standard and pushback approaches for open pit mining on a medium-sized gold project. The aim is to demonstrate that a pushback approach is practical and can increase the NPV of the project by delaying capital expenditure on equipment and waste stripping while maximizing the grade to the process plant.

The gold deposit presented as a case study in this paper is characterized by steeply dipping quartz veins systems that occur within wide zones of pyritized and silicified siltstones and sandstones. The vein systems vary in length from 60 to 500 m and have variable widths. The mining method is a standard open pit operation using truck-shovel combination. Drilling, blasting, loading, hauling, and dumping are the main mining activities.

Planning and scheduling

Pit optimization software produces nested pit shells at varying prices depending on the revenue factor specified. These revenue factors scale the base selling price to produce different pit shells that are optimal for different prices. Such optimization takes no account of mining width in the generation of pit shells; consequently, an optimized pit shell which is used as a starting point for the design of a final pit can have a floor that is too narrow, or has irregularities in the pit walls that cannot be followed easily in practice. It is often not possible to mine the incremental pit shells generated by pit optimization software because of the practical constraints of equipment at the base of the pit shell. Furthermore, mining the deposit from the top down, bench by bench, within the final pit outline is not desirable because this approach is unlikely to expose sufficient ore in any given period unless substantial pre-stripping is carried out.

For the standard approach (Figure 1) to open pit scheduling, the following steps are typically followed:

- Optimize the pit
- Select final pit shell
- Design the final pit shell with access ramp(s) and benches

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• Schedule the life of mine following the ramp-down, exposing sufficient ore to feed the process plant capacity allowing the stripping requirements to fluctuate.

This results in low-grade material being prioritized ahead of high-grade, while the stripping ratio and equipment fleet requirements will fluctuate. The NPV of the project can be sub-optimal as a result of this approach.

For the pushback approach (Figure 2) to open pit scheduling, the following steps are adopted:

Optimize the pit
• Select a pit shell(s) as potential intermediate pushbacks. These are selected from the nested shells taking into consideration the practical mining constraints such as minimum bench working width. It is worth noting that the nested shells are produced as a result of a lower revenue factor so can be considered as small higher-grade or lower strip ratio open pits. If they are followed as production stages, they will provide higher grade to the mill and / or lower strip ratio

• Schedule the chosen intermediate shells or pushbacks to verify if production targets can be met with sensible equipment requirements. This is an iterative process that typically involves 3-4 iterations

• Select the final pit shell as being the last pushback that generates positive cash flow from the nested optimized shells. The final pit may be slightly smaller than in the standard approach

• Design the access ramp(s) and benches pushback by pushback from the start of the operation. Every pushback will have a different ramp design. It should also be noted that shallow starter pits can sustain steeper slope angles and this can further reduce waste rock stripping in the early years of a project

• Schedule the life of mine following each pushback, making sure that the schedule is practical and ramp accesses are maintained to provide sufficient working places. Equipment utilization is kept high by allocating equipment that has exposed enough ore for a given period to commence stripping for the next pushback. Pushbacks or intermediate pits can help in better capital phasing for mining equipment purchase, consistent ore feed to the mill, and improved utilization of the mining fleet, and secure healthy cash flow in the early periods of project life.
Case study and discussion

Design and optimization parameters

The case study design used a starter pit followed by two pushbacks to transition to the ultimate pit shell. The pushbacks were each designed based on the previous optimization shells as well as taking account of the location of high-grade ore pods within the geological model. The pit design parameters are presented in Table I.

Table I. Pit design parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bench height</td>
<td>m</td>
<td>20</td>
</tr>
<tr>
<td>Bench face angle</td>
<td>degree</td>
<td>70</td>
</tr>
<tr>
<td>Bench width</td>
<td>m</td>
<td>7</td>
</tr>
<tr>
<td>No. of ramps</td>
<td>No.</td>
<td>1</td>
</tr>
<tr>
<td>Ramp width</td>
<td>m</td>
<td>24</td>
</tr>
<tr>
<td>Ramp gradient</td>
<td>1:n</td>
<td>1:10</td>
</tr>
<tr>
<td>Pit width</td>
<td>m</td>
<td>650</td>
</tr>
<tr>
<td>Pit length</td>
<td>m</td>
<td>700</td>
</tr>
<tr>
<td>Pit depth</td>
<td>m</td>
<td>250</td>
</tr>
</tbody>
</table>

The starter pit mines the least amount of waste to produce the largest amount of ore, and this allows more waste from the next pushback to be stripped while still satisfying the feed requirements for the plant. The ultimate pit with subsequent pushbacks is shown in Figure 3 and Figure 4.
Figure 3 – Plan view of ultimate pit (in brown) with two pushbacks (green and blue)

Figure 4 – Cross-section of ultimate pit (in brown) with two pushbacks (green and blue)
**Ore production**

The open pit is scheduled to produce about 2 Mt of ore and 10 Mt of waste from year 2 onwards, with an estimated mine life of 9 years. Figure 5 shows a comparison of reported mineable ore and grades between standard and pushback approaches. Figure 6 shows the minimized stripping ratio in the early years, which influences the capital costs associated with main mining equipment purchases.

![Figure 5](image1.png)

*Figure 5 – Material movement using the standard and pushback approaches*

![Figure 6](image2.png)

*Figure 6 – Stripping ratio using standard and pushback approaches*
Cash flows
A summary of cumulative cash flows for the life of mine from the standard and pushback approaches is presented in Figure 7. Using the pushback approach, the reduction in capital expenditure early in the mine life shows results in an increased NPV. Table II shows an NPV comparison between the standard and pushback approaches. Table II shows that NPV for the pushback approach is US$7 million higher than when using the standard approach, while the capital payback period is about one year shorter than for the standard approach. The internal rate of return (IRR) is 24% and 27% for the standard and pushback approaches, respectively.

Table II. NPV and IRR using standard and pushback approaches

<table>
<thead>
<tr>
<th>Name</th>
<th>Unit</th>
<th>Standard</th>
<th>Pushback</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV at 10% discount rate</td>
<td>US$ million</td>
<td>69.3</td>
<td>76.2</td>
</tr>
<tr>
<td>IRR</td>
<td>%</td>
<td>24</td>
<td>27</td>
</tr>
<tr>
<td>Payback period of capital (discount)</td>
<td>Years</td>
<td>5 years 6 months</td>
<td>4 years 7 months</td>
</tr>
</tbody>
</table>

Conclusions
The results of the study show that using the pushback approach can increase the project NPV by minimizing the stripping ratio in the early years and deferring some of the equipment purchase until later in the mine life. The reduction in capital expenditure early in the mine life has been shown to improve project economics.

For this study, the pushback approach showed increase in NPV of US$7 million in comparison with the standard approach.
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Dr Sergei Sabanov is a chartered engineer and a professional Member of Institute of Mining Materials & Metallurgy (CEng MIMMM) with 23 years of experience in the energy, metals & mining, oil & gas industries. Dr Sabanov supported a number of Business Improvement, Internal Investment Decision, Resource and Reserves Audit projects. For those he completed technical due diligence work, including Competent Person Reports (CPR) for stock exchange listings, financial analysis, risk assessment etc. His expertise lies in strategy planning, organisation, managing and working on technical studies (International and CIS standards). Dr Sabanov is experienced in a wide range of commodities areas including oil shale, coal, gold and silver, iron ore, diamonds, zinc, bauxite, potash and rare earth elements. Dr Sabanov has also specialised on Mining Method/Design,