A model for determining optimal transition depth over from open-pit to underground mining

E.Bakhtavar Amirkabir University of Technology, Iran
K.Shahriar Amirkabir University of Technology, Iran
K.Oraee University of Stirling, UK

Abstract

In this paper, the authors consider to the deposits which have potential for exploiting initially by Open Pit (OP) method, and as it is proved to greater depths, the pit is planned to transfer to Underground (Ug) mining methods. The most significant problem connecting to the deposits is determination of optimal Transition Depth (TD) from OP to Ug mining. Here, a heuristic algorithm as a basic model based on Block Economic Value (BEVs) of OP and Ug was represented. Initial part in the model is, recognizing mineable main blocks of 50*50 m due to both mining methods and comparison between sum of OP and Ug main block values in each main level from upper to lower, respectively. To increase accuracy and capacity of the model, the final main level of OP is imperative to separate to sub-levels and related sub-blocks of 12.5*12.5 m. The performed stages of the algorithm for main levels and blocks must be supplied for the sub-levels and sub-blocks, too. To state the model in detail, it was employed as a tool for determining the optimal transition depth and total profit in the combined method of OP and Ug for a hypothetical deposit.

1 Introduction

Selection of the mining method is one of the most important decisions in the design stage of mine. Open Pit (OP), underground (Ug) methods or both of them are selected depending on the geometry properties of the deposit, its position with respect to the surface and so on (Camus, 1992). In a choice between Op and Ug methods, the other most significant factors to be taken into account, are: a) size, shape, and depth of deposit; b) rock conditions; c) productivities and machinery capacities; d) capital requirements and operating costs, discount rate, investments, amortization, and depreciation; e) ore recoveries and revenues; f) safety and injuries; g) environmental aspects (Hartman, 1992), (Nilsson, 1997). Surface mining is generally considered to be more advantageous than Ug in recovery, grade control, economics, flexibility, safety, and working environments (Chen, 2001). There are many near surface deposits that have considerable vertical extent. Although they are initially exploited by OP mining, there is often a point where decisions have to be made to either continue deepening the pit or mining the same deposits by Ug methods (Flores, 2004).

In figure 1, a general schematic and the components of the transition from OP to Ug are demonstrated.

Figure 1 A general Schematic of the transition from OP to Ug mining

Some of the biggest OP mines worldwide will be achieving their final pit limits during the next 10 to 15 years (Fuentes, 2004). As well as, there are many mines planning to transfer from OP to Ug mining due to
increasing the extraction depth and environmental requirements (Chen, 2003). In this way, block/panel caving will likely enable the operations as an Ug method to continue achieving a high production rate and low costs (Fuentes, 2004).

The aim of this paper is a means of determining optimal transition depth from OP to Ug mining. This paper demonstrates a heuristic model based on a two dimensional block model with two values (OP and Ug) to solve this problem. For statement of the present model in detail, it was employed for a hypothetical deposit as a tool of determining the optimal transition depth and total profit in vertical combined method of OP and Ug.

2 Model description

In the paper, a basic heuristic methodology based on each block economic values of OP and Ug mining for a certain ore deposit was introduced. The authors seek to find an optimal transition depth including the maximum profit via both OP and Ug. In the present model, we focused on ore deposits have potential for exploiting initially by OP method, and as it is proved to greater depths, the pit is planned to transfer to Ug mining method, meaning, mining in initial levels is done by OP and in the middle levels transition process from OP to Ug can be happen. The main idea in the new model is comparison between OP and Ug block values in each level and starting from level 4 (it is assumed that the initial three levels are extracted using OP) to level m (which is identified as final economical level for OP using the algorithms of optimization final pit limit without consider to Ug alternative).

In the present study, the following assumptions were made:

**Assumption 1:** Initial three levels are selected for OP method

**Assumption 2:** A level can be mined at most once and via at most one method (OP or Ug)

**Assumption 3:** Sequencing constraints of OP

**Assumption 4:** No simultaneous mining of OP and Ug above and below ground (initially exploitation by OP mining)

**Assumption 5:** Definition of crown pillar height considering the selected underground mining method and geotechnical investigations

**Assumption 6:** Allow at most one uniform crown pillar

**Assumption 7:** Definition of the final underground working depth

**Assumption 8:** At most once Ug mining method can be employed

**Assumption 9:** The most suitable Ug mining method is known

**Assumption 10:** All OP levels are contiguous, and also all Ug levels are contiguous

**Assumption 11:** Unmined level (levels) can occur via a crown pillar between OP and Ug contiguous levels

A general schematic of the model algorithm is entirely detailed step by step as figure 2. The mentioned model must be served as a step by step (as follow) tool for obtaining the objectives of the study.

**Step 0:** Start

**Step 1:** Generation of separate OP and Ug block economic model based on 50*50 m size of blocks

**Step 2:** Determining optimal ultimate pit limit due to OP Block Economic Value (BEV) in respect to extraction sequences using one of the related optimization algorithms such as Korobov or Lerchs&Grossmann. As well as, finding the optimum Ug layout and consequently the mineable 50*50 m blocks using one of the related algorithms such as Floating Stope Optimizer

**Step 3:** Identification of mineable blocks in each level and the dependent blocks in the upper levels by OP. In addition, Identification of mineable blocks in each level by Ug

Assessment of the previous steps can be done using the mining optimization softwares such Datamine and the results can import to the model.
Step 4: Economical comparison between the two methods from level 4 to level \(m\) which is identified as the final profitable level of pit (this step is generally the main process of the presented model). In this economical analysis and comparison process, the total BEV of OP mining in level \(i\) is \(BEV_{opi}\) and the total BEV of OP mining in the same level is \(BEV_{ui}\). The components and the steps of this main process are summarized as following and the implemented algorithm focused on level 4 are shown in figure 3.

Step 5: Determination of transition depth from OP to Ug based on 50*50 m blocks size

Step 6: Save results

Step 7: Dividing the 50*50 m blocks located just in the final level selected for OP into 12.5*12.5 m smaller blocks

Step 8: Repeat the previous steps just for the 12.5*12.5 m blocks in final OP working level. In this step, the first sub-level (constructing from the blocks size of 12.5*12.5 m) is mined by OP, and investigation process must be started from the second sub-level namely \((m-y, 2)\) to final sub-level \((m-y, 4)\), and \((y\) can be 0,1,2, or more levels)

Step 9: Determination of optimal transition depth from OP to Ug basis on the 12.5*12.5 m blocks size. In this case, if one or more sub-level/sub-levels consider to be mined using Ug, it is necessary to refer to the remained sub-levels and investigate them economically.

Step 10: Save results

Step 11: Between the remained levels below the optimal transition depth, one or more level (levels) from level \(m-y\) to \(m+x\) can be considered as a crown pillar \((x\) can be 1,2, or more level). The mentioned levels selected as a crown pillar may be profitable due to Ug mining method.

Step 12: The remained levels below the crown pillar are focused and considered just for extraction utilizing Ug mining method (from level \(m+x\) to \(n\)).

Step 13: Calculation of the total profit from the identified levels due to both OP and Ug, as the following comparison relation (equation 1):

\[
BEV_{(op&u)t} = \sum_{i=1}^{m-y} (BEV_{opi}) + \sum_{i=m+x}^{n} (BEV_{ui}), \quad y \in \{0,1,2,\ldots\}, \quad x \in \{\ldots,-2,-1,0,1,2,\ldots\}
\]

Where:

\[
BEV_{(op&u)t} = \text{total profit (BEV) obtaining from whole levels (i to n) extracted by both of OP and Ug (vertical combined mining}).
\]

\[
BEV_{opi} = \text{total profit (BEV) obtaining from whole levels (1 to m-y) and sub-levels extracted just using OP}.
\]

\[
BEV_{ui} = \text{total profit (BEV) obtaining from whole levels (m+x to n) and sub-levels extracted just using Ug}.
\]

Step 14: End
Figure 2  A general schematic chart of the algorithm
2 Hypothetical case

The following example is a hypothetical case that explains how the optimum transition depth from OP to Ug by the presented model is determined. The exercise is based on a two dimensional block model, demonstrating 108 blocks of 50*50 meters in 9 levels and 12 columns. Let us assume that the hypothetical ore deposit length is 413 m with an average width of 185 m. The extension of deposit is from level of 37 m below the ground surface to 450 m.

In Step 1, it is necessary to generate the separate OP and Ug block economic model based on 50*50 m size of blocks as shown in figures 4 and 5, respectively.

Then, in Step 2, first, the optimal ultimate pit limit due to OP Block Economic Value (BEV)s in respect to extraction sequences using Korabov algorithm (Korabov, 2003) was determined (figure 4). then, the optimum Ug layout and consequently the mineable 50*50 m blocks by Floating Stope Optimizer (Alford,1995) was determined (figure 5).

During Step 3, the mineable blocks in each level and the dependent blocks in the upper levels by OP are identified (as figure 4). In addition, this process relating to Ug method is done and the mineable blocks in each level by Ug are identified (as figure 5).

![Figure 3](image) A schematic chart of the main process of the model, focused on level 4

| Level 1 | -1 | -1 | -1 | -1 | 0 | 0 | 0 | -1 | -1 |
| Level 2 | -1 | -2 | -1 | -1 | 2 | 1 | 4 | 3 | 1 | -1 | -1 | -2 |
| Level 3 | -2 | -2 | -2 | -1 | -2 | 0 | 3 | 3 | 0 | -2 | -2 | -2 |
| Level 4 | -2 | -3 | -3 | -3 | -3 | 3 | 6 | 4 | 0 | -3 | -3 | -3 |
| Level 5 | -3 | -4 | -4 | -4 | 1 | 4 | 5 | 3 | -4 | -3 | -4 | -3 |
| Level 6 | -3 | -4 | -5 | -4 | 1 | 3 | 5 | -3 | -6 | -5 | -5 | -5 |
| Level 7 | -4 | -5 | -6 | -3 | 3 | 1 | -1 | -2 | -6 | -5 | -6 | -5 |
| Level 8 | -6 | -7 | -7 | 0 | 2 | -1 | -1 | -5 | -6 | -7 | -5 | -7 |
| Level 9 | -7 | -7 | -3 | 1 | -1 | -1 | -6 | -1 | -6 | -8 | -7 | -7 |

![Figure 4](image) OP block values, optimal final pit limit and final working depth

Figure 4 is represented that without take into account the effectiveness of Ug mining in the future, the final profitable level is the sixth.
Figure 5  Ug block values, optimum underground layout and final working depth

According to the main process of the presented model, the three initial levels are selected for OP. During investigation of level 4, it is resulted that the OP mining method is more profitable than Ug, thus OP is selected also for the level. The components and the steps of this main process for level 4, 5 and 6 are summarized in figure 6.

Figure 6  A general vision of the main process for the levels 4, 5 and 6

According to the previous economical analysis, and based on the 50*50 size blocks, transition depth from OP to Ug is determined as figure 7.

Figure 7  Transition depth from OP to Ug based 50*50 m size of blocks without any crown pillar

Now, it is necessity to divide the 50*50 m mineable blocks located in level 4 as the final level selected for OP into 12.5*12.5 m smaller blocks and repeat all the previous steps.
But with this difference that in the step the main process is achieved, in stead of selection of the initial three levels (with 50*50 m size of blocks) for OP, just the first sub-level (constructing from the blocks size of 12.5*12.5 m) is considered and selected for OP, and now the economical comparison must be started from the sub-level \((m-y, 2)\) to \((m-y, 4)\), where \((y)\) can be 0,1,2, or more level. Here, sub-level \((4,1)\) is selected for OP and the comparison is started from sub-level \((4,2)\) to \((4,4)\). Figure 8 illustrates the mineable sub-levels and consequently blocks due to optimization algorithms of determining ultimate pit limit. The optimum Ug working layout, the sub-levels for Ug, and mineable blocks, are demonstrated in figure 9.

<table>
<thead>
<tr>
<th>Lev (4,1)</th>
<th>5</th>
<th>6</th>
<th>6</th>
<th>5</th>
<th>6</th>
<th>6</th>
<th>11</th>
<th>8</th>
<th>8</th>
<th>10</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lev (4,2)</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>9</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Lev (4,3)</td>
<td>3</td>
<td>-1</td>
<td>2</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>-2</td>
</tr>
<tr>
<td>Lev (4,4)</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Figure 8**  
OP block values and optimal final pit limit for level 4

<table>
<thead>
<tr>
<th>Lev (4,1)</th>
<th>5</th>
<th>2</th>
<th>1</th>
<th>3</th>
<th>-1</th>
<th>0</th>
<th>2</th>
<th>1</th>
<th>2</th>
<th>1</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lev (4,2)</td>
<td>2</td>
<td>3</td>
<td>-3</td>
<td>4</td>
<td>2</td>
<td>-1</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Lev (4,3)</td>
<td>-1</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Lev (4,4)</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>-2</td>
<td>4</td>
</tr>
</tbody>
</table>

**Figure 9**  
Ug block values and optimum underground layout for level 4

Corresponding to the main process step, the initial sub-level is selected for OP. During investigation of sub-levels from \((4,2)\) to \((4,4)\), it is diagnosed that if sub-level \((4,2)\) and \((4,3)\) are selected for mining by OP, in relation to Ug method more profit can be obtained, except sub-level \((4,4)\) is imparted to Ug mining method.

For the present hypothetical example, it is assumed that one level plus one sub-level are required as a crown pillar. For this target sub-level \((4,4)\) and level 5 are more relevant (figure 10).

The remained levels below the crown pillar are focused and considered for extracting by Ug mining method. The general results achieved using the new model for determining optimal transition depth from OP to Ug due to the hypothetical case are illustrated in figure 10.

**Figure 10**  
The components of transition from OP to Ug for the hypothetical case

Finally, the total optimum profit of vertical combined mining obtaining from the identified levels due to both OP and Ug, using relation 1 are calculated, and results are summarized in table 1.
Table 1  The economical results utilizing the present model due to the hypothetical example

<table>
<thead>
<tr>
<th>Levels and sub-levels</th>
<th>Profit from OP</th>
<th>Profit from Ug</th>
<th>Selected method</th>
<th>Obtained profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>-3</td>
<td>-</td>
<td>OP</td>
<td>-3</td>
</tr>
<tr>
<td>Level 2</td>
<td>11</td>
<td>4</td>
<td>OP</td>
<td>11</td>
</tr>
<tr>
<td>Level 3</td>
<td>6</td>
<td>3</td>
<td>OP</td>
<td>6</td>
</tr>
<tr>
<td>(4,1)</td>
<td>5</td>
<td>0.94</td>
<td>OP</td>
<td>5</td>
</tr>
<tr>
<td>Level 4</td>
<td>3.56</td>
<td>1.31</td>
<td>OP</td>
<td>3.56</td>
</tr>
<tr>
<td>(4,2)</td>
<td>2.25</td>
<td>1.5</td>
<td>OP</td>
<td>2.25</td>
</tr>
<tr>
<td>(4,3)</td>
<td>1.125</td>
<td>2.375</td>
<td>Crown pillar</td>
<td>0</td>
</tr>
<tr>
<td>Level 5</td>
<td>2</td>
<td>7</td>
<td>Crown pillar</td>
<td>0</td>
</tr>
<tr>
<td>Level 6</td>
<td>5</td>
<td>6</td>
<td>Ug</td>
<td>6</td>
</tr>
<tr>
<td>Level 7</td>
<td>-</td>
<td>10</td>
<td>Ug</td>
<td>10</td>
</tr>
<tr>
<td>Level 8</td>
<td>-</td>
<td>8</td>
<td>Ug</td>
<td>8</td>
</tr>
<tr>
<td>Level 9</td>
<td>-</td>
<td>15</td>
<td>Ug</td>
<td>15</td>
</tr>
<tr>
<td>Total profit</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>63.81</td>
</tr>
</tbody>
</table>

As it shown in figure 10, the optimal depth of 162.5 meters for transition from OP to Ug is determined. Consequently, based on the new model, the related total profit was determined equal to 63.81.

3 Conclusion

Due to the significance of determining the optimal transition depth from OP to Ug, a model based on BEV of OP and Ug was represented. For description of the model in detail a hypothetical example was used. Through using the model for the hypothetical ore deposit, the optimal transition depth from OP to Ug was determined equal to 162.5 meters. Between levels 1 to 9, the three initial levels (1,2 and 3) were entirely selected for OP, as well as, levels 6 to 9 for Ug. Level 4 as the final extracting level for OP was divided into four sub-levels. Via implementation of the model, it was elicited that sub-levels (4,1), (4,2), and (4,3) are economically more relevant for mining by OP than Ug, except sub-level (4,4) which was selected for Ug mining method. In respect to the importance of a crown pillar consideration between the two methods and referring to the assumption of the example, levels 5 and sub-level (4,4) were imparted to the safety crown pillar. Finally, the maximum total profit of the vertical combination mining was determined equal to 63.81.

References