Determination of Development Precedence for Drawpoints in Block-Cave Mining

Firouz Khodayari and Yashar Pourrahimian
Mining Optimization Laboratory (MOL)
University of Alberta, Edmonton, Canada

Abstract

High rate of production, low operational cost, and automated systems have made block caving attractive to mine owners and mining engineers. Two of the key steps in block-caving operation scheduling are the development direction and the drawpoints' precedence determination. An optimum direction for cave development and precedence for drawpoint extraction can add remarkably to the net present value of the mining project. In this paper, a methodology is introduced in order to find the best direction for development and the best precedence of extraction based on the development direction. In the first step, drawpoints are evaluated using the adjacent concept to find the best direction of development; the selection is based on the draw economic value (DEV). In the next step, the best precedence for all drawpoints is determined. Results show that this methodology can lead the decision makers to more realistic and near-optimum options in short- and long-term scheduling.

1. Introduction

As the mineral resources near the surface are being exploited, the mining operation goes deeper into the ground, waste removal rates increase, capital and operation costs become higher, and environmental impacts are more evident. In such a situation, underground mining with lower waste removal and less environmental impact are becoming more attractive. Usually the main problem with underground mining is the low rate of production and high operation costs that make the undertaking less practical. Among underground methods, block-cave mining with its high rate of production, low operational cost, and automated systems can be one of the best choices instead of surface mining or block-cave mining can be considered as part of production after surface mining during the life of mine.

In block-cave mining, gravity plays the main role for production. After creating drawpoints (production level) and developing an empty space as the undercut level (the gap between the rock mass and drawpoints), the rock is fractured because of the weight of rock mass above it and then the crushed rock is exploited using drawpoints. The whole procedure seems to be easy, but there are actually many factors involved with the operations. In particular, production scheduling in block-cave mining is a multi-criteria decision making problem with related constraints. In this paper, we

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model one of the most important steps in the production scheduling of block caving in order to improve the profitability of the mining project.

2. Production scheduling in block-cave mining

Production scheduling in block-cave mining is the determination of the amount of ore extraction from each drawpoint in each period of production in order to achieve the maximum net present value (NPV) regarding the project's constraints. Production scheduling is one of the most challenging problems in both open-pit and underground mining. Many researchers have focused on solving production scheduling problems using different methods of mathematical programing, such as Linear Programming (LP), Mixed-Integer Linear Programming (MILP), and Quadratic Programming (QP). Some mathematical programming models have been proposed to optimize the production scheduling for a block-cave mining operation: LP (Winkler 1996, Guest, Van Hout et al. 2000, Hannweg and Van Hout 2001), MILP (Song 1989, Chanda 1990, Winkler 1996, Guest, Van Hout et al. 2000, Rubio 2002, Rahal, Smith et al. 2003, Rubio and Diering 2004, Rahal 2008, Rahal, Dudley et al. 2008, Weintraub, Pereira et al. 2008, Smoljanovic, Rubio et al. 2011, Epstein, Goic et al. 2012, Parkinson 2012, Pourrahimian 2013, Alonso-Ayuso, Carvallo et al. 2014, Khodayari and Pourrahimian 2014), and QP (Rubio and Diering 2004, Diering 2012).

The first step of the production scheduling is the determination of the mining advancement direction. The second step is finding the precedence of extraction based on the defined direction. Reviewing the literature, we see that the proposed production scheduling models are based on a manual direction selection. In the other words, the mining direction is selected manually and then the production schedule is generated for the defined direction at the first step. Since the first step of the optimization is manual, there is no guarantee that the resulting production schedules are optimal. Also, some researchers have applied the optimization for different directions (Pourrahimian 2013). Our research, however, proposes a methodology to find the best mining direction in block-caving operations using an automated mathematical method.

3. Mining direction determination

In block-cave mining, the production starts from one part of the ore-body and then continues to the other side(s) of the ore-body. Fig 1 indicates that the mining started at the north-east side of the layout (A to B). Mining direction is determined according to different factors, such as the geotechnical parameters of the ore-body and overburden, grade distribution in different parts of the ore-body, commodity price, and available equipment.

The direction can be defined as a straight line(s), curve(s), or triangles. In this paper, at the first step, adjacent drawpoints are defined using the distance between drawpoints so that the combination of each drawpoint with its adjacent drawpoints are called production block (PB). Based on the locations of drawpoints in the production layout, each drawpoint can appear in several production blocks with its different sets of adjacent drawpoints. Therefore, in a layout with "n" drawpoints, there are "n" production blocks.

Fig 2 shows the schematic view of the method. For the considered drawpoint (hatched block), the adjacent drawpoints are determined using the defined adjacent radius of R. Depending on the geometry of the production layout, there might be some production blocks with a smaller number of the drawpoints compared to the other production blocks (this situation happens in the boundaries of the layout). The adjacent radius as an input parameter is imported to the model and then the adjacent drawpoints for each drawpoint is determined. The adjacent radius depends on different factors, such as geotechnical parameters of the ore-body and its host rock(s), mining equipment, and operational constraints.

In the input model, the draw economic value (DEV) for each draw column has been calculated based on the ore tonnage of the draw column, which is the summation of the tonnage resulting from the block model according to the best height of draw (BHOD), grade distribution in the draw column, the ore price, mining cost, processing cost, and selling cost. The BHOD is the height that produces the best economic value and it is usually not discounted with time.

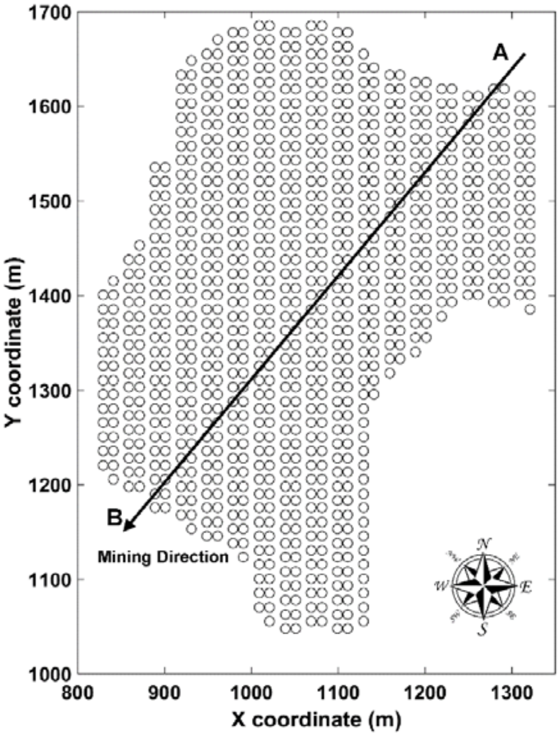

Fig 1. Mining direction for a block-cave mining layout (A to B)

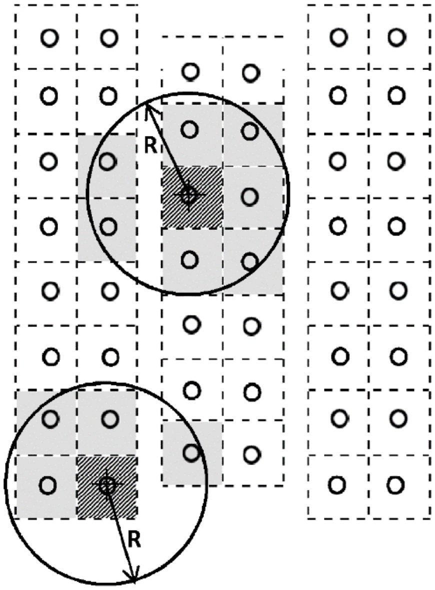

Fig 2. Adjacent drawpoints for the considered drawpoint with the adjacent radius of R (small circles represent the drawpoints)

Using draw economic values, the summation of DEV for each production block is calculated, and then the production block economic value (PBEV) profile is created.

$$PBEV_i = \sum_{j=1}^{J} DEV_j = \sum_{j=1}^{J}\sum_{n=1}^{N}[(p-s)*g_n*\rho*]-[c_m+c_p] \tag{1}$$

Where:

$PBEV_i$	is the i^{th} production block's economic value ($)
DEV_i	is the draw economic value for drawpoint j associated with draw column 'j' ($)
p	is the ore price per metric ton of product ($/t)
s	is the selling costs per metric ton of product ($/t)
g_n	is the grade for block 'n' in the block model (%)
ρ	is the processing recovery of ore in the processing plant (%)
c_m	is the mining cost per metric ton of ore ($/t)
c_p	is the processing cost per metric ton of ore ($/t)
J	is the number of defined production blocks in the block-caving layout using the adjacent concept
N	is the number of blocks (in the original block model) in draw column j according to the best height of draw (BHOD)

Using MATLAB (The MathWorks Inc. 2014), the adjacent drawpoints for each drawpoint are determined based on X and Y coordinates of the drawpoints and then the production block economic values are calculated. In the next step, the production block with the highest economic value is selected as the starting area for block-cave mining production. The production is started from the maximum economic value and then will continue to the area with lower economic value. During the production periods, the economic value of the current production block is equal or less than the previous one and greater or equal than the next one.

The methodology has been applied in two real case block-cave mining projects that will be discussed in this paper. The first case is a designed layout with 941 drawpoints (Fig 1). In total, 941 production blocks are defined for the production layout based on the 25 meter adjacent radius. The results show that the central area of the production layout is the best choice for starting the caving operation. Based on the proposed methodology, two major directions are suggested as the mining direction to move from the central part of the ore-body to the boundaries. The major mining direction is from the center to the east and the minor direction is to the south of the layout (Fig 3).

The second case is a block-cave mining layout with 1546 drawpoints (Fig 4). In this case, the adjacent radius of 30 meters and then the same methodology has been applied to find the best mining direction. Using the adjacent concept, 1546 production blocks were defined for this block-cave mine layout.

Results show that the best starting point is north-west and then the caving operation continues to the south-east of the deposit. The suggested direction is a triangle shape that is shown in Fig 5.

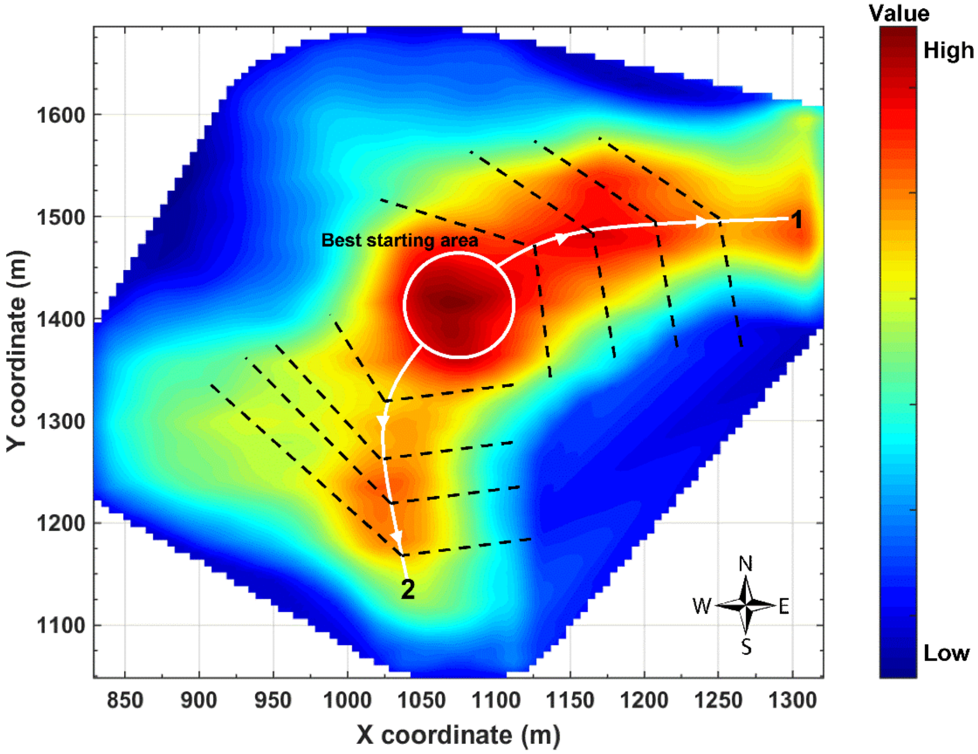

Fig 3. Mining direction determination for Case 1 based on the PBEV concept (1: major advancement direction, 2: minor advancement direction)

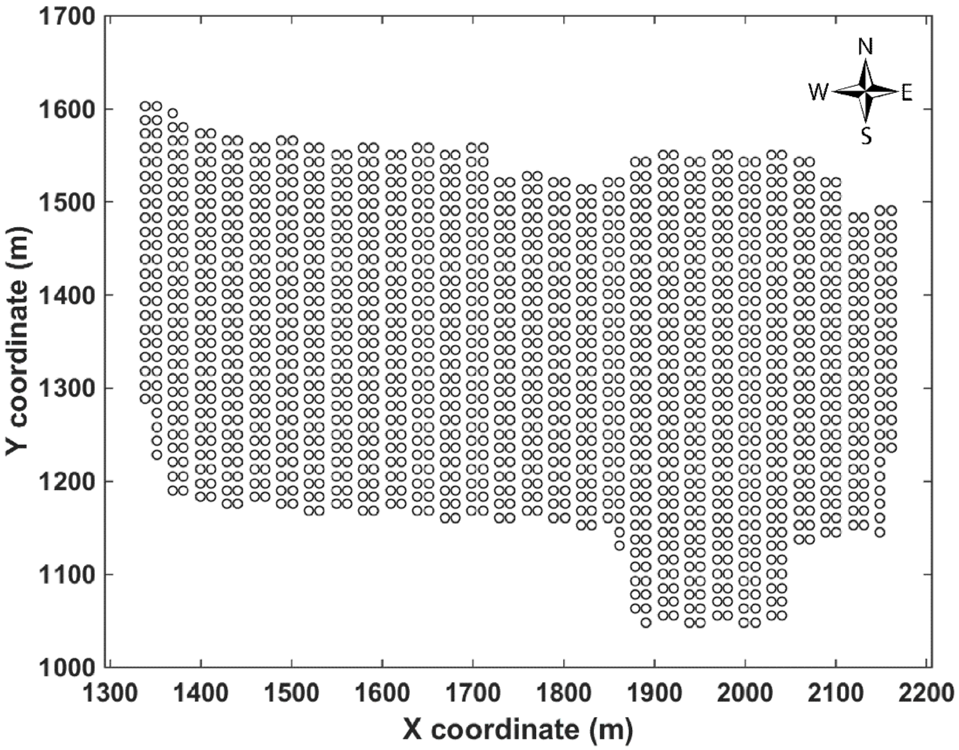

Fig 4. Production layout of the drawpoints for Case 2 (circles represent the drawpoints)

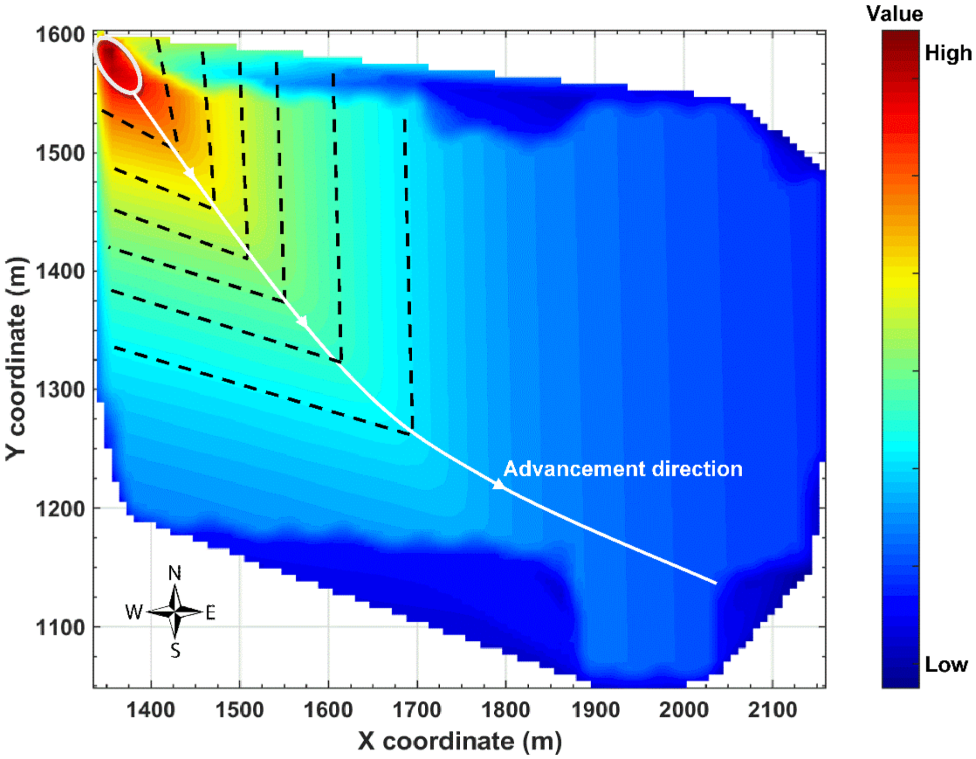

Fig 5. Mining direction determination for Case 2 based on the PBEV concept

4. Precedence determination of the drawpoints

Using the determined mining direction in the previous step, the appropriate precedence for each drawpoint can be defined. The precedence of drawpoints is considered as a production constraint in order to optimize the production scheduling of the block-cave mining operation. According to the advancement direction, for each drawpoint there is a set which defines the predecessor drawpoints among adjacent drawpoints that must be started before the considered drawpoint is extracted.

The proposed mining direction in the previous section (Fig 5) has been applied to find the best mining precedence for drawpoints in Case 2. In Fig 6, it can be seen that the production priority starts from the north-west and it continues to the south-east of the deposit, with drawpoints obtaining their precedence numbers based on the defined direction. For instance, the arrows show that extraction form drawpoint 47 must be started before drawpoints 45, 48, and 46. On the other hand, all four drawpoints 45, 46, 47, and 48 must be opened before drawpoints 41, 42, 43, 44, 97, 98, 99, 100, 101, and 103.

5. Conclusion

The first step of production scheduling in block caving is the determination of the mining direction in which the caving operation starts from an area of the ore-body and then expands to the other parts. For a block-caving layout, there are infinite numbers of directions in which the ore-body can be mined but not all of them will generate an optimal production schedule. Different methodologies have been proposed for production scheduling optimization in block-cave mining operation, but one of the shortcomings is the mining direction, which has been determined manually. In this paper, we have proposed a methodology in order to find the best mining direction and production precedence based on the economic value of the draw columns. The input block model of the ore-body was used for calculating the draw economic value of draw columns based on the tonnage, grade, price, operational costs (mining, processing and selling), processing recovery, and the best height of draw (BHOD). Then the production blocks were defined using the adjacent concept. Afterwards, the best starting area and mining direction among all possible directions were determined based on the PBEV. In the second step, the best production precedence was generated based on the best mining direction proposed in step 1. The application of an automated procedure for mining direction determination can generate a more accurate input compared to the manual methods for production scheduling models in block-cave mining.

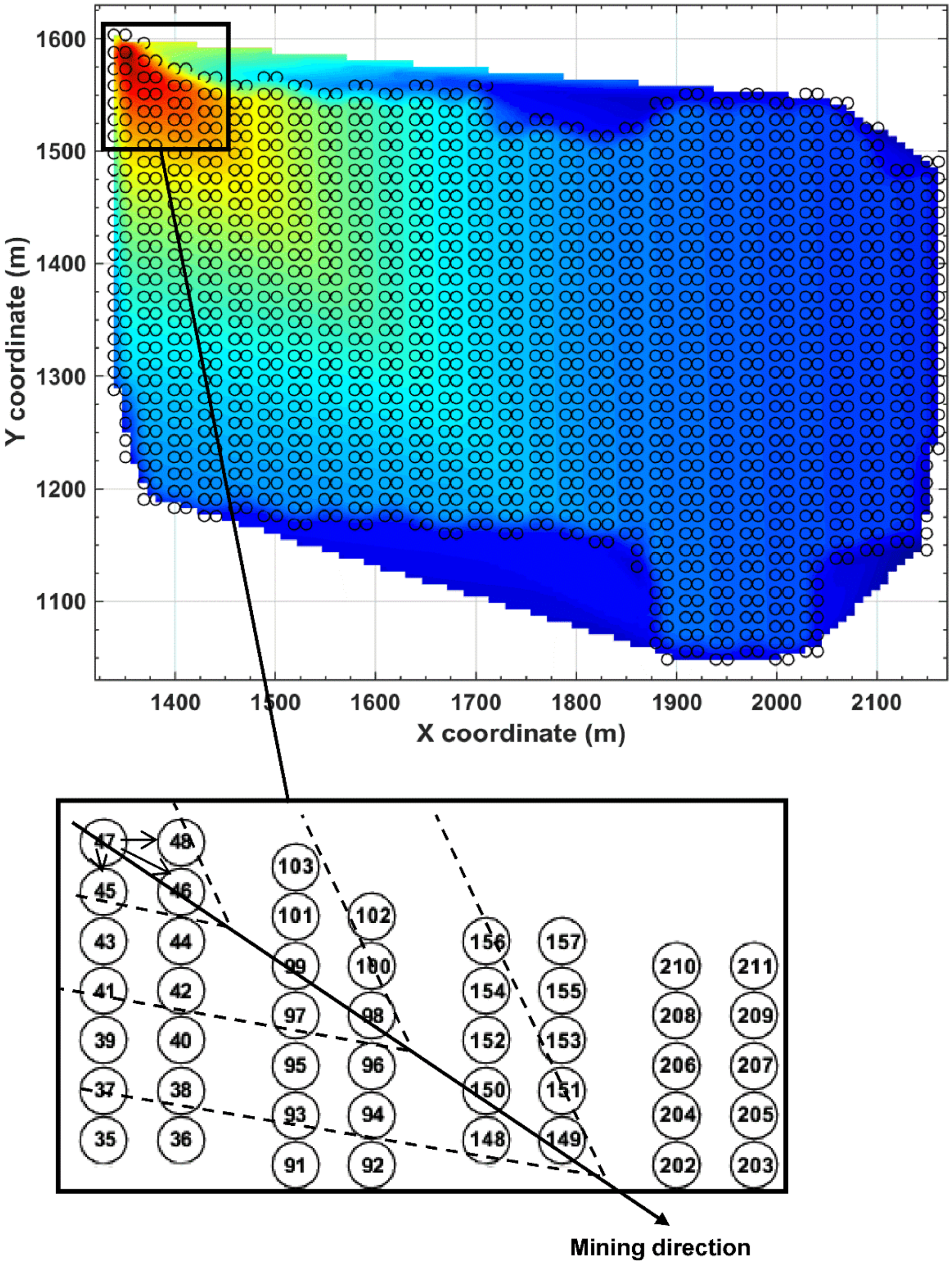

Fig 6. Production precedence for drawpoints in Case 2 based on the determined mining direction

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