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A SHORT-TERM PRODUCTION PLANNING MODEL FOR DIMENSION STONE QUARRIES

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ABSTRACT

In this paper, problem of short-term production planning for dimension stone quarries was mathematically modeled using a binary integer programming. The model includes an objective function, which was founded as the minimization of the costs due to the total cutting planes of the blocks. This objective may cause to maximization of the net present value (NPV) in dimension stone quarries. During the mathematical modeling the essential constraints are dimension stone quarry capacities and the market demand, block accessibility for the equipment and the reserve constraints. As a base, an optimal size and shape of extractable blocks should be first assigned according to the available extraction technique and the market demand, in order to create a geological block model. Then an economical block model is provided by assignment of a value of “one” for ore blocks and “zero” for waste. Maximum profitability and minimum amount of the ore wastage can be gained using this plan and modeling.

INTRODUCTION

Providing the amount of dimension stones that is needed for the processing factories (market) can be optimally achieved by means of a short-term production planning. Numerous studies to the problem of short and long term production planning and scheduling in “open pit mining” have been appeared by using the operation research methods in the literatures. But, for such planning in “dimension stone quarrying” industry, there is no considerable study.

The production operation and concepts of dimension stone quarrying are partly different than other metal and non-metal open-pit mining. Unlike to the open-pit mining operation which produces ore in form of fragmented materials by bench blasting, in the dimension stone quarrying only the blocks with marketable size and shapes are desired. These blocks can be appropriately provided using the mechanized techniques such as diamond wire cutting and armed-chained cutting machines.

A production planning should be shortly set for the blocks extraction with the objective of maximizing net present value (NPV) or profit considering the maximum efficiency, minimum wastage, maximum recovery of the reserves.

A certain stone quality was found as the best decision variable for planning dimension stones [1]. A method was also presented for determination of amount of the marketable blocks before extraction operation.

PRODUCTION PLANNING

There are typically three time ranges of production planning: short-term, medium-term and long-term. Although short-term production planning usually ranges from one month to one year, it can also define as daily and weekly sub-periods. A medium-term production planning may commonly range 1-5 years. This period can divide into 1-6 month sub-periods which are needed for a detailed scheduling. Long-term planning often varies between 20 and 30 years. It can also divide into 1-5 years sub-periods.

Totally, a long-term plan can make an operating and mining strategy including some objectives as below [2]:

- Maximization of output (profit or NPV) for investors
- Minimization of risk to investors
- Maximization of mine life.

In dimension stone industry, a certain amount of blocks, which may extracted during a short-term period, are usually ordered by the market. Furthermore, if a quarry includes a non-homogeneous dimension stone reserve, it is necessary to establish a short-term production plan in order to supply the homogeneous materials according to the market demand.

There are a great number of parameters which control the blocks production plan are [3]:

- Mode of occurrence of the deposit (in the forms of flat, tabular, inclined, orientation, rough, etc.)
- Geological and geotechnical characteristics
- Quarry configuration such as its dimensions, number of working faces and etc.
- Extraction technique (mechanized or manual) and capacities of the available equipment
- Block size and shape according to the market demand

In this case, “characteristics of the waste and ore blocks” and “enough working space for the extraction, splitting and transportation” play a major role in the process.

FORMULATION OF THE SHORT-TERM PRODUCTION PLANNING

Problem definition

Production planning over a period of time is known as planning horizon. During the short-term production planning typically annual plans should be performed on a planning horizon as an operational guide, in order to provide the production planning requirements.

As it was found in the literatures, both binary and mixed integer mathematical programming can be effectively used for optimal open-pit production planning and scheduling subject to the required crucial constraints.

Total NPV should be maximized in production planning optimization. The most sensitive parameters controlling the NPV are:

- Product price
- Discount rate
- Time sequence of the schedule
- Production cost

In planning a dimension stone quarry or any mining industry, cost is clearly a controlling factor. As a case, in hard-rock stone quarrying by means of a diamond wire cutting machine, the costs are mostly influenced by erosion on the diamond [3]. On the other hand, in dimension stone quarries, NPV is mostly depends on cost of the blocks extraction using the available cutting machines. Therefore, the extraction cost for a dimension stone quarry should be minimized to a possible value. For this purpose, the minimum possible amount of the blocks cutting planes must be performed. It means that the minimization of the total area of the extractable blocks planes, which must be cut, can be directly caused to the maximization of the NPV.

In case a mathematical model minimizes the lateral cutting planes, the optimal production planning is given. Hence, the most appropriate size and shape must be considered for the extractable blocks according to the market demand. Number of cutting planes per unit volume of dimension stones can be minimized if the optimal size and shape is selected for the blocks. Upside and downside cutting planes of the blocks are not considered. Because they do not have any influence on optimization of short-term production planning [3].

Production planning in dimension stone quarrying can be defined on an economical block model as the same of open-pit mining. In this case, an optimal sequence of blocks extraction should be obtained with the objective of maximizing the NPV. There are some economical and technical constraints that should be considered in this process.

Accessibility of block for the quarry equipment is one of the constraints during short-term production planning. It means that all extractable blocks must be accessible to the equipment on a planning horizon.

In dimension stone quarrying contrary to open-pit mining, grade blending constraints may not important and also play no major role in the process.

The binary values of “zero” and “one” are assigned for the blocks in dimension stones economical block model. The values “one” and “zero” respectively indicate ore and waste blocks.

In this paper, the short-term production planning problem for dimension stone quarries is mathematically modeled for a part of the quarry according to the market demand. Maximum NPV and minimum amount of ore wastage can be obtained using this model.

During this model the following notes as the required assumptions and constraints are considered:

- The amount of market demand for a dimension stone can be provided from one level or one production horizon.
- Upside and downside cutting planes of extractable-blocks are ignored.
- Maximum tonnage of extractable-blocks can be about 25 tonnes in accord with the transportation regulation in Iran.
- The extractable-blocks height and bench height are similar.
- On-mine cutting planes should be minimized.
- Transportation cost for the extractable-blocks to processing plant (market) is not considered.

As the base of this study the following three steps must be respectively taken into account:

- Geological model creation.
- The most suitable size of extractable-blocks is assigned according to the market demand.
- Economical block model creation including zero and one as the block values.

Short-term production planning formulation

Geological block model with the certain blocks size according to the exploration drilling data should be first created. Dimensions of the blocks are assigned considering the market order and the maximum weight of transportable blocks. Then economical block model is made including zero and one values. The blocks with acceptable rock quality for the market are assigned as ore (one) and the bad quality and fully jointed (without the potential for being a block) rocks are named waste (zero).

For the problem mathematical modeling a binary integer programming is developed using the following symbols and their meanings.

t: Index for planning period, *t* = 1, 2,…, T;
T: Maximum number of periods in each planning horizon;
i,j: Indices for block number identification;
N,M: Total number of blocks to be planned in *X* and *Y* directions, respectively;
l: Block lateral cutting planes identification;
L: Maximum lateral planes area of blocks to be cut;

$x^t_{i,j}$: A binary decision variable, which is equal to “1” if the block *i* is to be extracted in period *t* and equal to “0” otherwise;
$C^t_{i,j}$: Cost due to the lateral planes cutting for block *i,j* in period *t*;
$E^l_{i,j}$: Total area of the lateral cutting planes (m^2) for block *i,j*;
$O_{i,j}$: Tonnage of ore block *i,j*;
$W_{i,j}$: Tonnage of waste block *i,j*;
$P_{\max}$: Maximum amount of the ore to be sent for the processing (maximum market demand) in period *t*;
$P_{\min}$: Minimum amount of the ore to be sent for the processing (minimum acceptable market demand) in period *t*;
$Q_{\max}$: Maximum amount of the ore to be extracted in period *t*; and
$Q_{\min}$: Minimum amount of the ore to be extracted in period *t*;

Mathematical programming approach to production planning objectives is to find the optimal sequence of extractable blocks. For the target of this study an objective function is considered as minimization of total area of the lateral cutting planes. This objective function may finally cause to maximize NPV. The objective function is formulated as given in Eq. 1.

$$Min\,Z = \sum_{t=1}^{T}\sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{l=1}^{L} C^t_{i,j} \cdot E^l_{i,j} \cdot x^t_{i,j} \qquad (1)$$

Constraints

A) Accessibility constraints. The blocks extraction operation in dimension stone quarries is usually started from a side of the ore reserve. In addition, it is assumed for setting up a cutting machine (like diamond wire cutting) for extraction of a new block, at-least eight contiguous blocks around the new block as Fig.1 should be extracted previously. Therefore, each extractable block has some neighbor blocks in a horizon that is considered for a short-term planning (Fig.1). For this purpose, only if at-least one of the four cases (as shown in Fig.1) have been accessed and their associated blocks extracted, block *i,j* can be selected for extraction through the cutting machines (according to Eq. 6). As it shown in Fig.1, block *i,j* can be accessed and then cut from four directions. As it mentioned above, block *i,j* is accessible if the blocks located in at-least one of the quadruplet areas are extracted prior to block *i,j*. Hence, the accessibility constraints are as Eqs. 2 to 6.

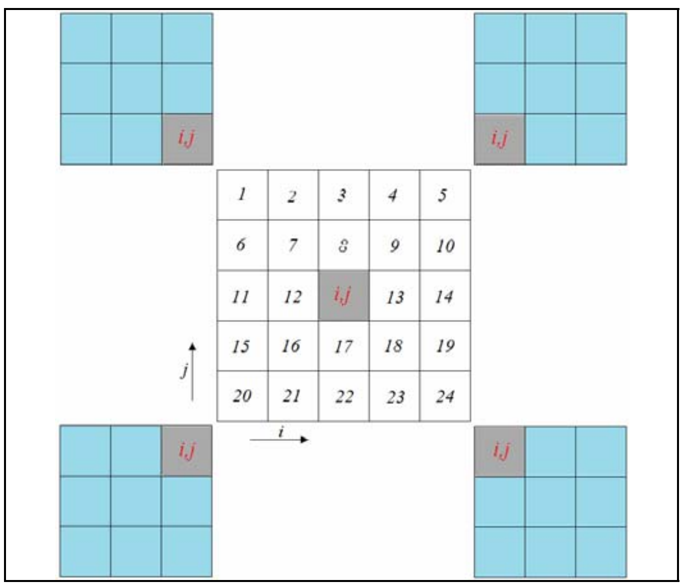

Figure 1. Accessibility blocks around the block *i,j* and the free faces directions.

$$8 \cdot x_{i,j}^t - \sum_{h=1}^{t} (x_{i,j+1}^h + x_{i,j+2}^h + x_{i-1,j}^h + x_{i-1,j+1}^h + x_{i-1,j+2}^h + x_{i-2,j}^h + x_{i-2,j+1}^h + x_{i-2,j+2}^h) \leq R \cdot y_1^t \quad (2)$$

$$8 \cdot x_{i,j}^t - \sum_{h=1}^{t} (x_{i,j+1}^h + x_{i,j+2}^h + x_{i+1,j}^h + x_{i+1,j+1}^h + x_{i+1,j+2}^h + x_{i+2,j}^h + x_{i+2,j+1}^h + x_{i+2,j+2}^h) \leq R \cdot y_2^t \quad (3)$$

$$8 \cdot x_{i,j}^t - \sum_{h=1}^{t} (x_{i,j-1}^h + x_{i,j-2}^h + x_{i-1,j}^h + x_{i-1,j-1}^h + x_{i-1,j-2}^h + x_{i-2,j}^h + x_{i-2,j-1}^h + x_{i-2,j-2}^h) \leq R \cdot y_3^t \quad (4)$$

$$8 \cdot x_{i,j}^t - \sum_{h=1}^{t} (x_{i,j-1}^h + x_{i,j-2}^h + x_{i+1,j}^h + x_{i+1,j-1}^h + x_{i+1,j-2}^h + x_{i+2,j}^h + x_{i+2,j-1}^h + x_{i+2,j-2}^h) \leq R \cdot y_4^t \quad (5)$$

$$y_1^t + y_2^t + y_3^t + y_4^t \leq 3 \quad (6)$$

In Eq. 2 to 6, R is a big value and y is a binary variable.

B) Reserve constraints. Each block can be only extracted once. The reserve constraints are formulated as below equation, which indicates that all blocks in the model can be extracted only once.

$$\sum_{t=1}^{T} x_{i,j}^t \leq 1 \quad (7)$$

C) Processing capacity (market demand) constraints. As the upper bound, the total amount of the ore to be extracted in period t (tonnage) cannot be more than the market demand or processing capacity (P_{max}) in any period, t.

$$\sum_{i=1}^{N} \sum_{j=1}^{M} (O_{i,j} \cdot x_{i,j}^t) \leq P_{\max} \quad (8)$$

As the lower bound, the total amount of the ore to be extracted in period t (tonnage) cannot be less than a certain amount (P_{min}) in any period, t.

$$\sum_{i=1}^{N} \sum_{j=1}^{M} (O_{i,j} \cdot x_{i,j}^t) \geq P_{\min} \quad (9)$$

D) Dimension stone quarrying capacity. As the upper bound, the total amount of dimension stones including ore and waste rocks to be extracted cannot be more than the total available equipment capacity (Q_{max}) for each period, t.

$$\sum_{i=1}^{N} \sum_{j=1}^{M} (O_{i,j} + W_{i,j}) \cdot x_{i,j}^t \leq Q_{\max} \quad (10)$$

The lower bound can be written as the following:

$$\sum_{i=1}^{N} \sum_{j=1}^{M} (O_{i,j} + W_{i,j}) \cdot x_{i,j}^t \geq Q_{\min} \quad (11)$$

CONCLUSION

In this study a binary integer programming model has been developed for the short-term production planning in dimension stone quarries. For the purpose, the most appropriate dimensions and shape of the extractable blocks should be first assigned for generation of the geological block model according to the market demand, the maximum transportable tonnage of the blocks and the cutting machines. After that an economical block model is made using the values “zero” and “one” for waste and ore blocks, respectively. The objective function was founded as the minimization of the costs due to the total cutting planes of the blocks which may finally cause to maximization of the net present value (NPV) in dimension stone quarries for a short-term. Some essential constraints associated with the short-term planning of dimension stone production were mathematically modeled. They are capacities and the market demand, block accessibility for the equipment and the reserve constraints. This short-term plan ensures that each block in a planning horizon has a free face for accessibility by extraction, loading and transportation equipment. Using this plan the maximum profitability and minimum amount of the ore wastage can be also obtained.

REFERENCES

1. Mutlutürk M. (2007), “Determining the amount of marketable blocks of dimesional stone before actual extraction”, *Journal of Mining Science*, 43 (1), pp. 67-72.
2. Steffen O.K.H. (1997), “Planning of open pit mines on a risk basis”, The Journal of The South African Institute of Mining and Metallurgy, pp. 47-56.
3. Abdollahisharif J. Bakhtavar E. (2009), "An intelligent algorithm of minimum cutting plane to find the optimal size of extractable-blocks in dimension stone quarries", Arch. Min. Sci., Vol. 54, No 4, pp. 641-656.