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Arch. Min. Sci., Vol. 60 (2015), No 3, p. 687–695

Electronic version (in color) of this paper is available: http://mining.archives.pl

DOI 10.1515/amsc-2015-0045

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OP-UG TD OPTIMIZER TOOL BASED ON MATLAB CODE TO FIND TRANSITION DEPTH FROM OPEN PIT TO BLOCK CAVING

NARZĘDZIE OPTYMALIZACYJNE OPARTE O KOD MATLAB WYKORZYSTANE DO OKREŚLANIA GŁĘBOKOŚCI PRZEJŚCIOWEJ OD WYDOBYCIA ODKRYWKOWEGO DO WYBIERANIA KOMORAMI

In this study, transition from open pit to block caving has been considered as a challenging problem. For this purpose, the linear integer programing code of Matlab was initially developed on the basis of the binary integer model proposed by Bakhtavar et al (2012). Then a program based on graphical user interface (GUI) was set up and named "Op-Ug TD Optimizer". It is a beneficial tool for simple application of the model in all situations where open pit is considered together with block caving method for mining an ore deposit. Finally, Op-Ug TD Optimizer has been explained step by step through solving the transition from open pit to block caving problem of a case ore deposit.

Keywords: Transition, open pit to block caving, Op-Ug TD Optimizer, program, Matlab

W pracy tej rozważano skomplikowane zagadnienie przejścia od wybierania odkrywkowego do komorowego. W tym celu opracowano kod programowania liniowego w środowisku MATLAB w oparciu o model liczb binarnych zaproponowany przez Bakhtavara (2012). Następnie opracowano program z wykorzystujący graficzny interfejs użytkownika o nazwie Optymalizator Op-Ug TD. Jest to niezwykle cenne narzędzie umożliwiające stosowanie modelu dla wszystkich warunków w sytuacjach gdy rozważamy prowadzenie wydobycia metodą odkrywkową oraz wydobycie komorowe przy eksploatacji złóż rud żelaza. W końcowej części pracy podano szczegółową instrukcję stosowanie programu Optymalizator na przedstawionym przykładzie przejścia od wydobycia rud żelaza metodami odkrywkowymi poprzez wydobycie komorami.

Słowa kluczowe: Przejście, wydobycie metodami odkrywkowymi, wydobycie komorami, program Optymalizator Op-Ug TD, MATLAB

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1. The transition problem and the mathematical model overview

The problem of transition from open pit to underground mining is raised in case there is an outcrop or a near surface ore deposit continues to a high depth. This is mined by open pit from the beginning to an optimal depth where decision has to be made transition to an underground method. Block caving has been known as the only underground method that can be compared with open pit from the production rate and cost viewpoints.

Recently, a number of researches have been done in order to solve the problem of transition from open pit to underground mining. A complete literature was given in the study by Bakhtavar et al. (2012).

In this study, the author puts emphasis on the mathematical transition model (by Bakhtavar et al.. 2012). The model was introduced by the use of "zero" and "one" integer decision variables as given through Equations 1 to 9 which include the objective function together with the essential constraints. The indices, counters, sets, and all parameters are given in the *Appendix* at the end of this paper as they were defined in the model. In this model, the economical block models of open pit and block caving methods are the base for the modelling and solving.

$$Z = Max \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{2} \left(C_{i,j}^{k} \cdot Z_{i,j}^{k} \right) \tag{1}$$

$$Z_{i,j}^{1} + Z_{i,j}^{2} \leq 1 \qquad \forall i, j \tag{2}$$

$$\alpha \cdot Z_{i,j}^{1} - \sum_{l=-1}^{1} Z_{i-1,j+l}^{1} \leq 0 \qquad \forall i, j \tag{3}$$

$$\left[\left(\beta * \gamma \right) - 1 \right] \cdot Z_{i,j}^{2} - \left[\sum_{\mu=1}^{(\gamma-1)} \sum_{q=1}^{\beta} Z_{i-\mu,q+j-1}^{2} + \sum_{q=1}^{(\beta-1)} Z_{i,q+j}^{2} \right] \leq 0$$
$$\forall i = \{m, m-1, m-2, \ldots, \gamma\}, \; j = \{1, 2, \ldots, n-\beta+1\} \tag{4}$$

$$\left(\delta - 1 \right) \cdot Z_{i,j}^{2} - \sum_{\lambda=1}^{(\delta-1)} Z_{i-\lambda,j}^{2} \geq 0 \qquad \forall i = \{m, m-1, m-2, \ldots, \delta\}, j \tag{5}$$

$$\left(\varepsilon - 1 \right) \cdot Z_{i,j}^{2} - \sum_{u=1}^{(\varepsilon-1)} Z_{i,u+j}^{2} \geq 0$$
$$\forall i = \{m, m-1, m-2, \ldots, \delta\}, \forall j = \{1, 2, \ldots, n-\varepsilon+1\} \tag{6}$$

$$Z_{i,j}^{1} - Y_{i}^{1} = 0 \qquad \forall i, j \tag{7}$$

$$\sum_{\eta=1}^{\theta} Z_{i+\eta,j}^{2} + Y_{i}^{1} \leq 1 \qquad \forall i, j \tag{8}$$

$$Y_{i}^{1} + Y_{i}^{2} \leq 1 \qquad \forall i \tag{9}$$

2. Op-Ug TD Optimizer program

In order to easily apply the transition mathematical model (by Bakhtavar et al., 2012), a visual computer-based program has been set up. The program is an extended form of the linear integer programming code which is available in the optimization toolbox of Matlab program. It is named "Op-Ug TD Optimizer".

2.1. Start with Op-Ug TD Optimizer

First, Matlab software must be installed on a computer system before a transition problem is started for solving by the use of Op-Ug TD Optimizer. Then user must click on "Op-Ug TD Optimizer" icon which is appeared on the system. In this case, a window titled "Op-Ug TD Optimizer1" will appear as shown in Fig. 1. There are two options on this window: the first for opening the last project which user previously worked on that; the second is assigned to create a new project. In spite of selecting the last or new workspace options, Fig. 2 as a new window "Project Name and Location" appears. The user can select the project's name and a directory as the location for saving. The project directory may be selected through the window as shown in Fig. 3. After that, the main stage of Op-Ug TD Optimizer is started.

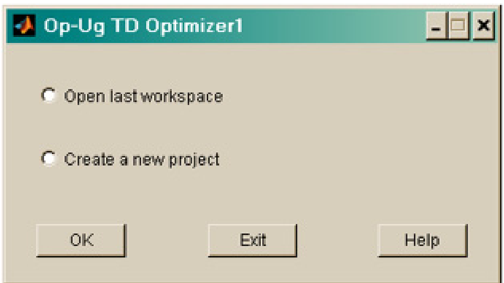

Fig. 1. Keeping on the last project or creation of a new project considered on the program

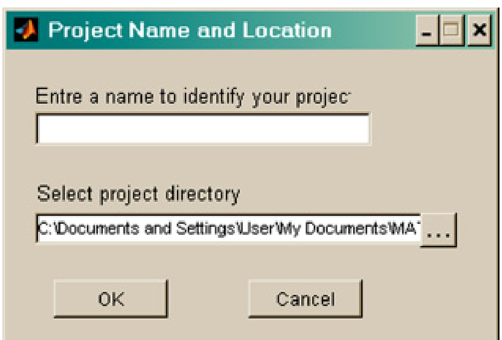

Fig. 2. Assigning a name and location on the system for a transition project

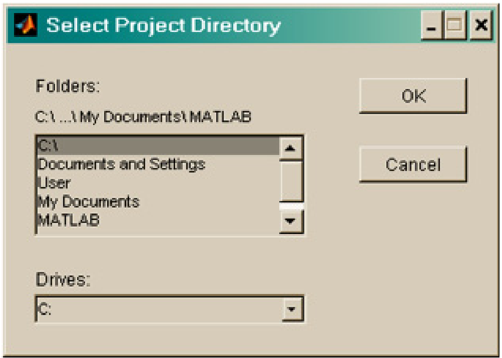

Fig. 3. Window for selecting a transition project directory

2.2. Inputs to Op-Ug TD Optimizer

Essential input data for solving a transition problem are entered to the main window of the program during three steps as illustrated in Fig. 4. The following items are included in the main window of the program:

– Input Block Values item (STEP 1): all block values based on the economic block models for open pit and block caving are separately entered after pressing "Import Data" icon (Figs. 5 and 6). The currency is considered to be Dollar for the block values (profits).

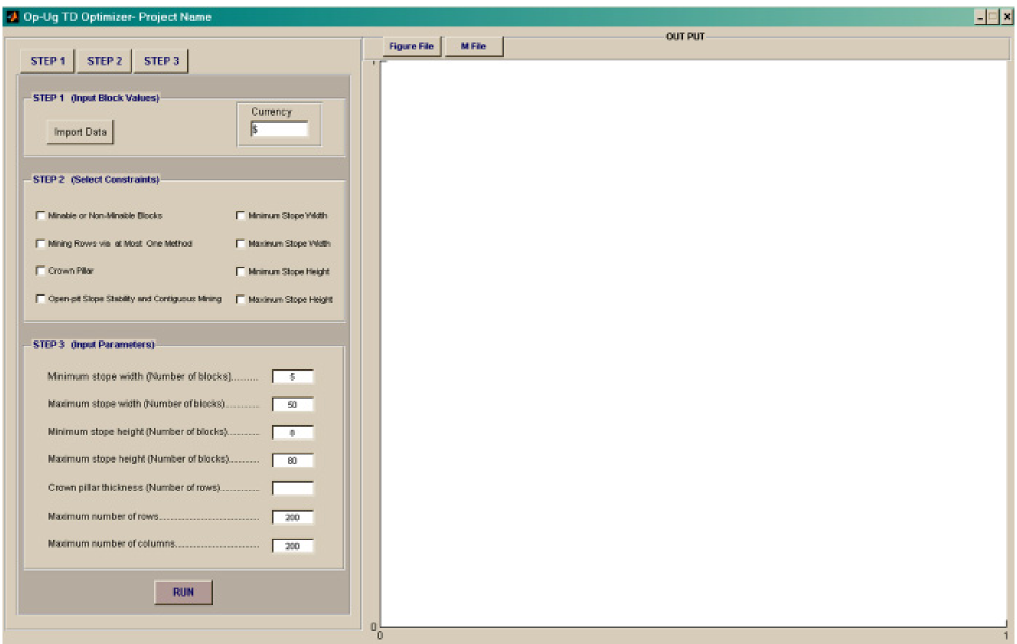

Fig. 4. Main window for entering the inputs and running the program

- Select Constraints item (STEP 2): the user can select some required constraints among the considered ones according to the conditions of a problem (Fig. 7).
- Input Parameters item (STEP 3): this item is used to consider the essential parameters associated with the mathematical transition model by Bakhtavar et al (2012). As shown in Fig. 8, the input parameters are regarded in relation to minimum and maximum stope width and height on the basis of the number of blocks, appropriate thickness of a crown pillar between open pit and block caving on the basis of the number of rows, maximum dimensions of a block model based on the number of rows and columns.
- RUN item: the user can execute the program to find a solution.
- OUT PUT item: after running the program, the output can be available in form of Figure File and M File.

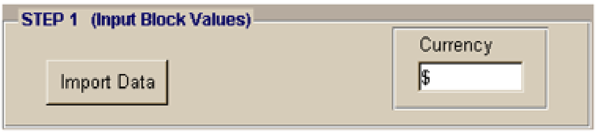

Fig. 5. Window for first step input data processing

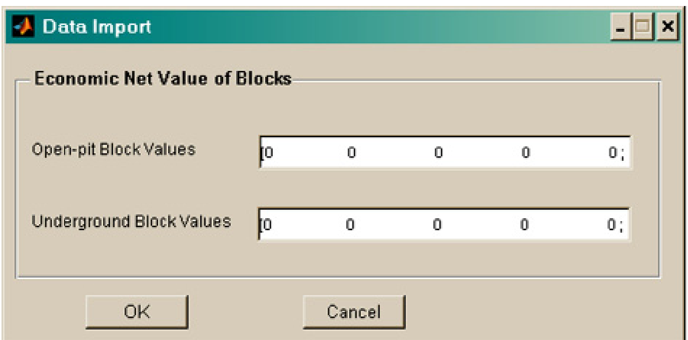

Fig. 6. Window for entering block values of open pit and block caving

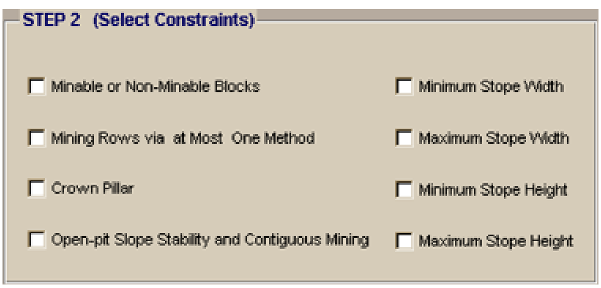

Fig. 7. Window for selecting the required constraints

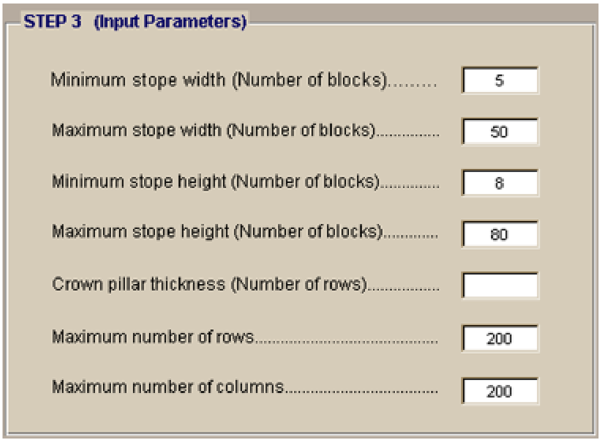

Fig. 8. Window for entering the parameters according to the selected constraints

3. Results and discussion

In order to provide a tool for simple utilization of the mathematical model proposed by Bakhtavar et al (2012) in transition from open pit to block caving, a computer program has been developed. To describe the program and the model in detail, a case ore deposit, which is proper for exploitation by the use of open pit and block caving together, is considered.

The main input parameters to the program are block values through both open pit and block caving methods. Therefore, the economic block models of the both mining methods are first created on the basis of a block size of 30*30 *m* as a multiple of open pit bench height of 15 *m*. It is notable that there is no limitation in assigning size of the blocks according to a typical bench height of an open pit mine such as 10 *m*, 12.5 *m*, and 15 *m*. For the purpose of creating the block models, some economical parameters such as production costs due to open pit and block caving, final product price, and etc. Originally, a block value is the achieved profit through extraction of that block by a mining method, and then, its sale.

After creating the block models, a section, which includes the maximum numbers of the ore blocks, is regarded as a base block model. Block values of open pit and block caving from the base model are prepared to enter to the program. According to block model created for the studied case ore deposit, the most representative section has been selected. As the first step of the program, the block values for both open pit and block caving are imported to the program. After that, all considered constraints are selected and therefore values for the associated parameters in third step are assigned. For example, two contiguous rows are assigned as a practical thickness of the crown pillar on the basis of geomechanical considerations. Finally, the program is executed. The outputs are shown in both form of Graphical and M File as Figs. 9 and 10. The results indicate a transition depth of 450 *m* (15 rows) and seven contiguous rows as a block caving stope beneath the crown pillar. Minable blocks through open pit and block caving methods are shown in white and block colours, respectively (Fig. 9).

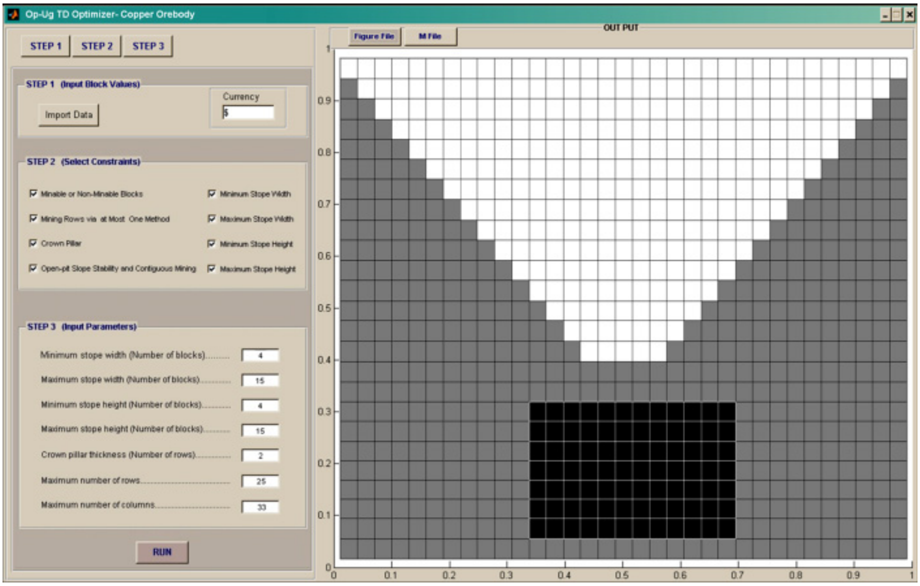

Fig. 9. Graphical file of the transition from open pit to block caving for the case ore deposit

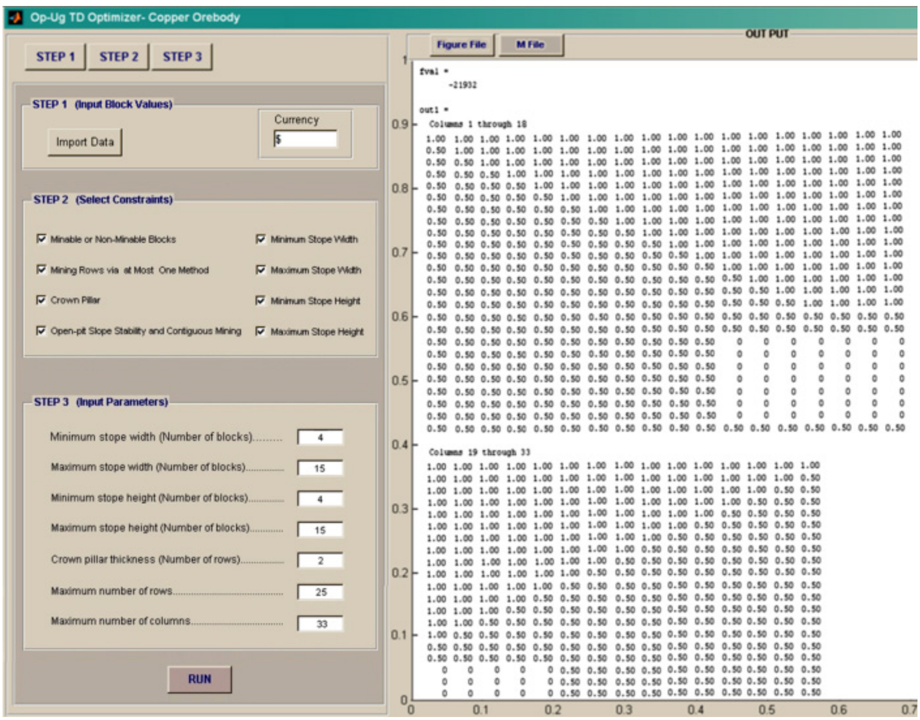

Fig. 10. M file of the transition from open pit to block caving for the case ore deposit

There are the following limitations and specifications about the utilized mathematical model and the program introduced here:

- Economic block models including open pit and block caving block values are used as the base input parameters.
- The essential constraints for both open pit and block caving should be regarded.
- Possibility of assigning a crown pillar between open pit and block caving.
- The model should be only used in case non-simultaneous mining of open pit and block caving is considered to use.
- Optimization is taken into account on two dimensional sections of both open pit and block caving economic block models.
- The program can only cause an optimal solution if the mathematical model includes less than 10000 binary decision variables. It means that the maximum numbers of rows and columns should be less than 50 and 50.

4. Conclusion

Solving the problem of transition from open pit to block caving is a new challenge in the mining industry where there is potential of applying surface and underground methods together for exploitation of an ore deposit. The mathematical model which proposed by Bakhtavar et al. (2012) based on the binary linear integer programming has been regarded in this study to establish a tool for easier application of the model. For this purpose, a visual computer-based program was set up on the basis of the available codes in the optimization toolbox of Matlab software in order to solve the transition problem during a simple process. The program was introduced as "Op-Ug TD Optimizer" which can be used by mining engineers in all situations where a non-simultaneous mining of open pit together with block caving is considered. The base inputs are block values of open pit and block caving that are imported to the program. To use the program proposed here in detail, a case ore deposit was regarded. After the program was run in relation to the ore deposit, optimal transition depth was determined equals to 450 *m*. The program can be used only if the transition problem includes less than 10000 binary decision variables.

References

Bakhtavar E., Shahriar K., Mirhassani A., 2012. *Optimization of the transition from open-pit to underground operation in combined mining using (0-1) integer programming*, The Journal of the Southern African Institute of Mining and Metallurgy (SAIMM), 112, 1059-1064.

Received: 07 January 2014

APPENDIX
(based on Bakhtavar et al. (2012))

i – is index for rows (levels),
j – is index for columns,
i,j – is index for location of block i,j,
k – is index for possible mining by open pit or underground (block caving); 1 for open pit and 2 for underground,
l – is counter for blocks overlying block (i,j) to assign the slope constraint,
q – is counter for blocks in a row to set minimum width of an underground stope constraint,
u – is counter for blocks in a row to set maximum width of an underground stope constraint,
μ – is counter for blocks in a column to set minimum height of an underground stope constraint,
λ – is counter for blocks in a column to set maximum height of an underground stope constraint,
η – is counter for rows to set a crown pillar between open-pit and underground stope mining constraint,
α – is the number of blocks overlying ore-block (i,j),
β – is minimum number of blocks that should be successively mined in a row through underground method,
ε – is maximum number of blocks that should be successively mined in a row through underground method,
γ – is minimum number of blocks that should be successively mined in a column through underground method,
δ – is maximum number of blocks that should be successively mined in a column through underground method,
θ – is the number of rows that should be successively remained below the open-pit mining
m – is the number of rows,
n – is the number of columns,
$C_{i,j}{}^k$ – is economic net value of block (i,j), which $C_{i,j}{}^1$ is considered for open-pit and $C_{i,j}{}^2$ is for underground mining,
$Z_{i,j}{}^1$ – is a binary variable representing block (i,j) mined through open-pit; it is assigned 1 if block (i,j) is mined through open-pit and assigned 0 otherwise,
$Z_{i,j}{}^2$ – is a binary variable representing block (i,j) mined through underground; it is assigned 1 if block (i,j) is mined through underground and assigned 0 otherwise,
Y_i^1 – is a binary variable representing row i mined through open-pit; it is assigned 1 if $w_{i,1}$ is one and assigned 0 otherwise,
Y_i^2 – is a binary variable representing row i mined through underground; it is assigned 1 if $w_{i,2}$ is one and assigned 0 otherwise.