A Guideline to Block-Cave Production Scheduling Graphical user Interface

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Abstract

This paper introduces the open-source software application with a graphical user interface called drawpoint scheduling in block-caving (DSBC). This appendix explains how the sequence of extraction in a block cave mine can be optimized using the mixed-integer linear programming (MILP) formulations in the DSBC. This appendix presents the workflow and documentation on how to use DSBC software. The prototype software helps transfer knowledge and optimization technology developed in this research to practitioners and end-users in the field of block-cave production scheduling.

1. Introduction

The developed prototype software helps transfer knowledge and optimization technology developed in our research to practitioners and end-users in the field of block-cave production scheduling.

In this paper, an open-source software application with a graphical user interface called drawpoint scheduling in block-caving (DSBC) is introduced. The paper also explains how the sequence of extraction in a block-cave mine can be optimized using the MILP formulations in the DSBC.

All stages before scheduling, from creating a block model to converting a slice file, are done using GEMS and PCBC (Geovia, 2014). These stages include:

1. Creating a block model using GEMS.
2. Importing drawpoints data such as coordinates, dip, and azimuth.
3. Creating a slice file using PCBC.
4. Calculating the best height of draw (BHOD).

After creating the slice file, all the clustering and optimization steps are done using the DSBC. These steps are as follows:

1. Importing the slice file, the BHOD file, and coordinates of drawpoints into DSBC.
2. Creating all required databases and sets to use in the developed MILP models.
3. Clustering the draw columns based on the similarity of the draw column's tonnage, average grade, and physical location.

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4. Defining the scheduling parameters.
5. Creating the objective function and constraints for three levels of resolution: cluster level, drawpoint level, and drawpoint-and-slice level.
6. Solving the problem using one of the methods: either single-step or multi-step.
7. Plotting the results.

2. Required Software to Run the DSBC

To run the DSBC, at the beginning MATLAB and TOMLAB/CPLEX must be installed on the computer. MATLAB is a high-level language and interactive environment for numerical computation, visualization, and programming. Using MATLAB, the user can analyze data, develop algorithms, and create models and applications. The language, tools, and built-in math functions enable users to explore multiple approaches and reach a solution faster than with spreadsheets or traditional programming languages, such as C/C++ or Java. TOMLAB is a general-purpose development and modeling environment in MATLAB for research, teaching, and finding practical solutions to optimization problems. TOMLAB/CPLEX integrates the solver package CPLEX with MATLAB and TOMLAB.

3. Experiments Framework for the MILP Models

The methodology applied to the block-cave production scheduling problem in the MILP framework includes a solution scheme that is based on the branch-and-cut optimization algorithm (Horst and Hoang, 1996) implemented in TOMLAB/CPLEX (Holmstrom, 2011). To be able to obtain reliable experimental results, the solution scheme employed in solving the problem should be able to capture the complete definition of the block-cave production scheduling problem. The assumptions are based on the framework for applying operations research methods in mining. Fig 1 shows the general workflow of database creation in the DSBC. After creating the database, based on the selected level of resolution, the problem is solved. These levels include the cluster level, drawpoint level, and drawpoint-and-slice level.

The three MILP formulations for three levels of problem resolution -- cluster level, drawpoint level, and drawpoint-and-slice level -- can be used in two ways: (i) single-step, in which each formulations is used independently; and (ii) multi-step, in which each step's solution is used to reduce the number of variables in the next level and consequently generate a practical block-cave schedule in a reasonable CPU runtime for large-scale problems. Fig 2 and Fig 3 show the general workflow for single-step and multi-step methods, respectively. It should be mentioned that the MILP formulations use a solver developed based on exact solution methods for optimization. In this solver, an optimization termination criterion is set up to stop the algorithm when an integer feasible solution has been proved to be within a specific percentage of optimality, subject to the practical and technical mining constraints.

4. Input Data

To solve the problem we use the PCBC's slice file. Three Excel files with the following information have to be prepared:

- *Coordinates*: This file contains two sheets titled "Drawpoints" and "Tunnels." Fig 4 shows the order of these Excel sheets. The order of columns in the sheet titled Drawpoints is record, drawpoint's name, X, Y, and depth. In the sheet titled Tunnels, the coordinates of the start point and endpoint of each tunnel are defined.

- *Slice info:* This file contains information about slices within each draw column. These data include dilution, density, tonnage, dollar value, and percentage of the elements within each slice. Fig 5 shows the order of parameters in this file.
- *BHOD:* This file contains the BHOD information for draw columns and other economic information. Fig 6 shows the order of this file.

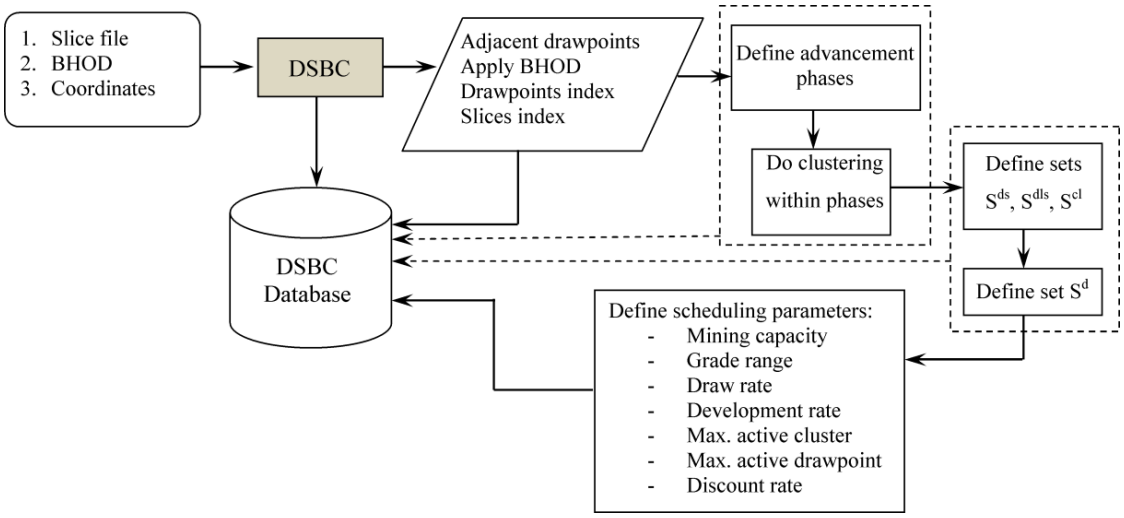


Fig 1. Database creation in the DSBC

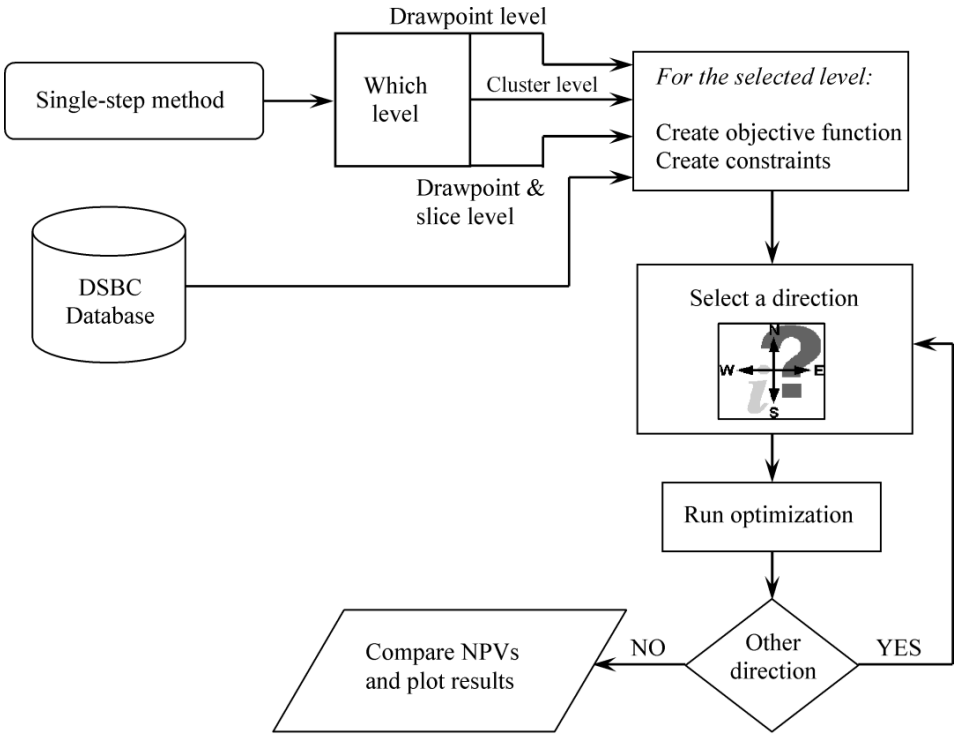


Fig 2. General workflow for single-step method

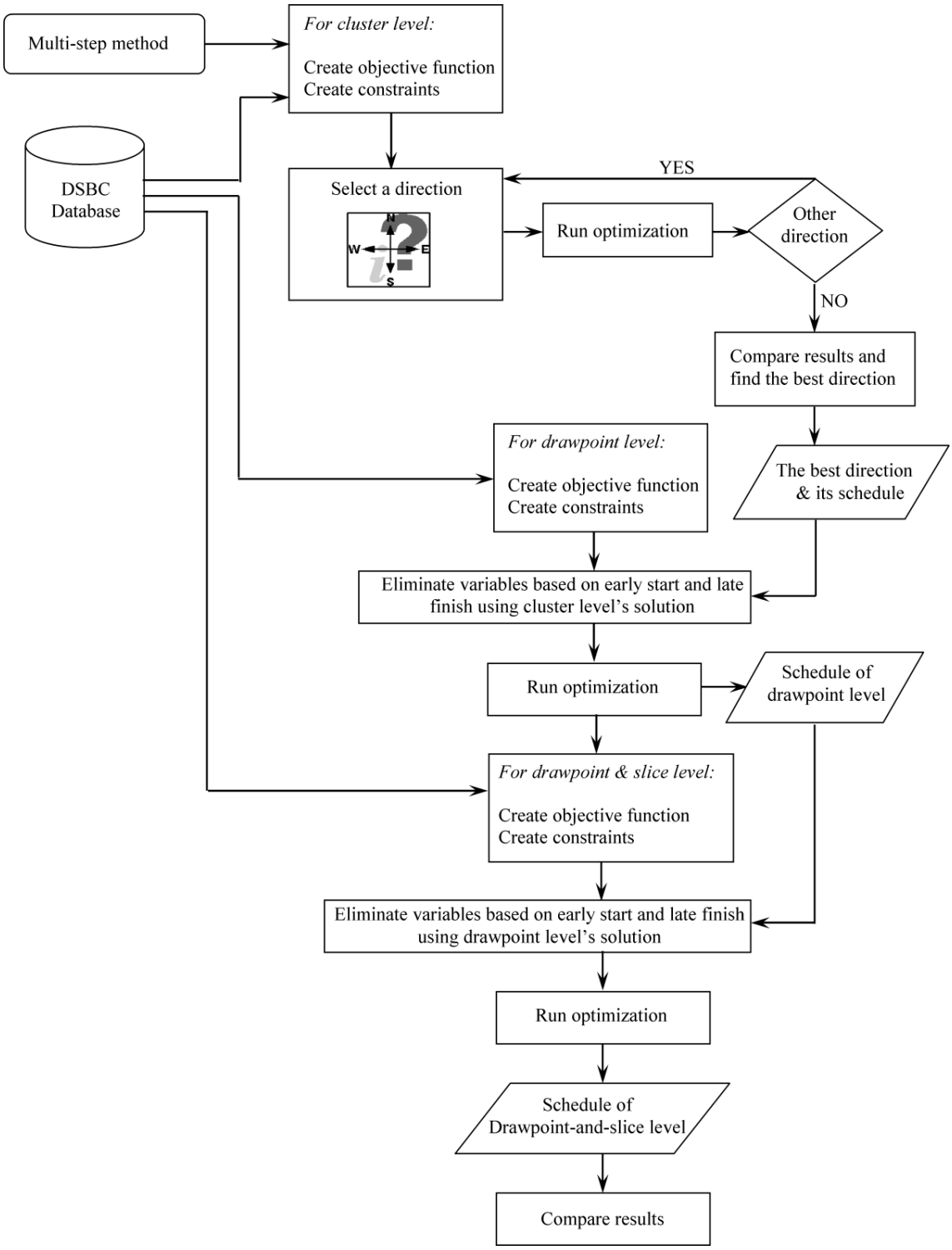
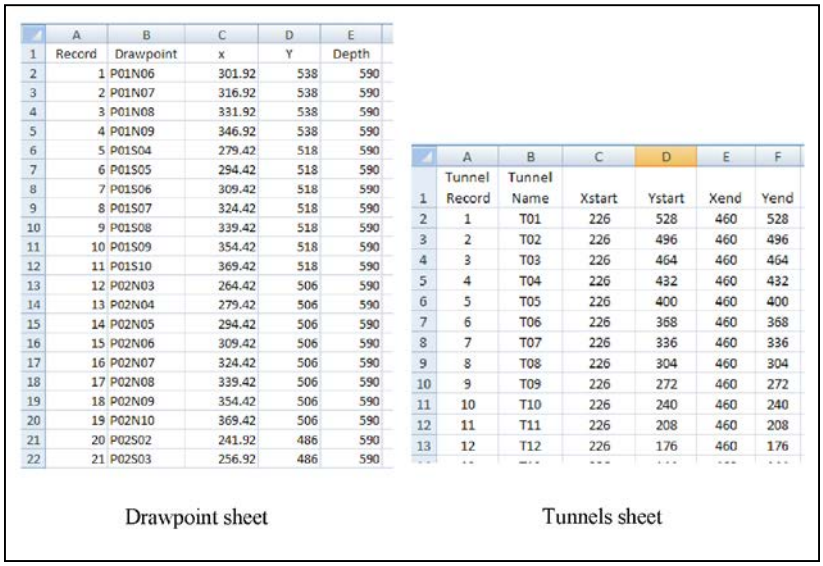


Fig 3. General workflow for multi-step method



	A	B	C	D	E
1	Record	Drawpoint	x	Y	Depth
2	1	P01N06	301.92	538	590
3	2	P01N07	316.92	538	590
4	3	P01N08	331.92	538	590
5	4	P01N09	346.92	538	590
6	5	P01S04	279.42	518	590
7	6	P01S05	294.42	518	590
8	7	P01S06	309.42	518	590
9	8	P01S07	324.42	518	590
10	9	P01S08	339.42	518	590
11	10	P01S09	354.42	518	590
12	11	P01S10	369.42	518	590
13	12	P02N03	264.42	506	590
14	13	P02N04	279.42	506	590
15	14	P02N05	294.42	506	590
16	15	P02N06	309.42	506	590
17	16	P02N07	324.42	506	590
18	17	P02N08	339.42	506	590
19	18	P02N09	354.42	506	590
20	19	P02N10	369.42	506	590
21	20	P02S02	241.92	486	590
22	21	P02S03	256.92	486	590

Drawpoint sheet

	A	B	C	D	E	F
1	Tunnel Record	Tunnel Name	Xstart	Ystart	Xend	Yend
2	1	T01	226	528	460	528
3	2	T02	226	496	460	496
4	3	T03	226	464	460	464
5	4	T04	226	432	460	432
6	5	T05	226	400	460	400
7	6	T06	226	368	460	368
8	7	T07	226	336	460	336
9	8	T08	226	304	460	304
10	9	T09	226	272	460	272
11	10	T10	226	240	460	240
12	11	T11	226	208	460	208
13	12	T12	226	176	460	176

Tunnels sheet

Fig 4. Structure of drawpoints and tunnels sheets in the Excel file

	A	B	C	D	E	F	G	H	I	J
1	Record	Slice Name	Descriptic	Height	Dil %	Density	Tons	$val	CU	AU
2	1	P07S03	... Vmix10	10.00	0	2.80	3,007.59	25.95	1.48	0.50
3				20.00	1	2.80	5,790.37	24.73	1.47	0.43
4				30.00	4	2.80	6,438.14	22.97	1.42	0.41
5				40.00	8	2.79	6,702.38	20.89	1.36	0.38
6				50.00	13	2.79	6,676.88	18.16	1.27	0.35
7				60.00	20	2.78	6,675.91	14.94	1.17	0.32
8				70.00	26	2.77	6,639.00	11.39	1.06	0.28
9				80.00	33	2.77	6,696.08	7.68	0.94	0.25
10				90.00	41	2.76	6,731.95	3.84	0.82	0.22
11				100.00	49	2.75	6,605.59	(0.09)	0.70	0.18
12				110.00	57	2.74	6,491.40	(3.86)	0.58	0.15
13				120.00	65	2.73	6,414.18	(7.30)	0.47	0.12
14				130.00	72	2.73	6,396.01	(10.30)	0.37	0.10
15				140.00	78	2.72	6,417.30	(12.85)	0.29	0.08
16				150.00	83	2.72	6,406.64	(15.00)	0.22	0.06
17				160.00	87	2.71	6,390.34	(16.77)	0.17	0.04
18				170.00	91	2.71	6,390.87	(18.18)	0.12	0.03
19				180.00	94	2.71	6,409.45	(19.27)	0.09	0.02
20				190.00	96	2.70	6,380.00	(20.10)	0.06	0.02
21				200.00	97	2.70	6,428.43	(20.70)	0.04	0.01
22				210.00	98	2.70	6,493.94	(21.12)	0.03	0.01
23				220.00	99	2.69	6,513.13	(21.41)	0.02	0.00
24				230.00	99	2.68	6,472.15	(21.60)	0.01	0.00
25				240.00	99	2.67	6,478.63	(21.72)	0.01	0.00
26				250.00	100	2.66	6,507.08	(21.79)	0.01	0.00
27				260.00	100	2.65	6,520.76	(21.83)	0.01	0.00
28				270.00	100	2.63	6,482.01	(21.84)	0.01	0.00
29				280.00	100	2.61	6,505.49	(21.84)	0.01	0.00
30				290.00	100	2.59	6,062.47	(21.83)	0.01	0.00
31				300.00	100	2.57	6,069.73	(21.81)	0.01	0.00
32				310.00	100	2.55	6,071.42	(21.79)	0.01	0.00
33				320.00	100	2.54	6,071.42	(21.77)	0.01	0.00
34				330.00	100	2.54	6,071.42	(21.77)	0.01	0.00
35				334.50	100	2.50	2,439.55	(21.86)	0.00	0.00
36										
37	2	P08N03	... Vmix10	10.00	1	2.80	3,007.59	27.37	1.57	0.42
38				20.00	3	2.80	5,790.37	24.71	1.48	0.40

Fig 5. Structure of the slice file

	A	B	C	D	E	F	G	H	I	J
1	Record	Draw Point	OK?	Best HOD	Ave_Dol	Net_Dol	Tot_Dol	Tonnage	CU	AU
2	1	P07S03	OK	90	15.95049	882.9919	882.9919	55358.29	1.198847	0.337136
3	2	P08N03	OK	80	14.90038	723.4717	723.4717	48553.92	1.173203	0.311591
4	3	P07S04	OK	160	19.85667	2037.188	2037.188	102594.6	1.3276	0.360297
5	4	P08N04	OK	140	19.59518	1744.636	1744.636	89033.96	1.323794	0.348382
6	5	P07S05	OK	220	21.16943	3000.261	3000.261	141726.1	1.372936	0.363632
7	6	P08N05	OK	210	20.68158	2789.119	2789.119	134860.1	1.358006	0.358263
8	7	P07S09	OK	280	20.46782	3713.835	3713.835	181447.5	1.344116	0.371735
9	8	P08N09	OK	280	21.31608	3871.473	3871.473	181622.1	1.378115	0.363758
10	9	P07S10	OK	280	17.35229	3178.504	3178.504	183174.9	1.244121	0.347454
11	10	P08N10	OK	280	19.56856	3588.879	3588.879	183400.3	1.320371	0.353706
12	11	P07S11	OK	270	12.15976	2116.752	2116.752	174078.4	1.073345	0.315853
13	12	P08N11	OK	280	15.41513	2786.104	2786.104	180738.3	1.184623	0.326591
14	13	P08S04	OK	100	14.25443	879.1486	879.1486	61675.44	1.151218	0.309256

Fig 6. Structure of the file containing the BHODs

5. Guideline on Running DSBC

The DSBC folder contains sub-folders, .tif and .m files (see Table 1). Within the folder DSBC, right click on the *DSBC_Login.m*, and then open it in MATLAB. In MATLAB, run the opened text file. If you have been asked to change the directory, accept it and change the directory. In the opened login window, enter User name and Password. Then press **Login** (see Fig 7). The main window of DSBC comes up (see Fig 8).

Table 1. Existing sub-folders, photos and MATLAB files within the DSBC's folder

Folders	.tif files	.fig files	.m files
8. FUNCTION	16.BlockCave1	19.DSBC_Login	20.DSBC_Login
9. IMPORT	17.BlockCave2		
10.Input Data	18.BlockCave3		
11.MODELS			
12.REPORTS			
13.RESULTS			
14.TOMLAB Input			
15.TOMLAB Output			

Fig 7. DSBC's login window

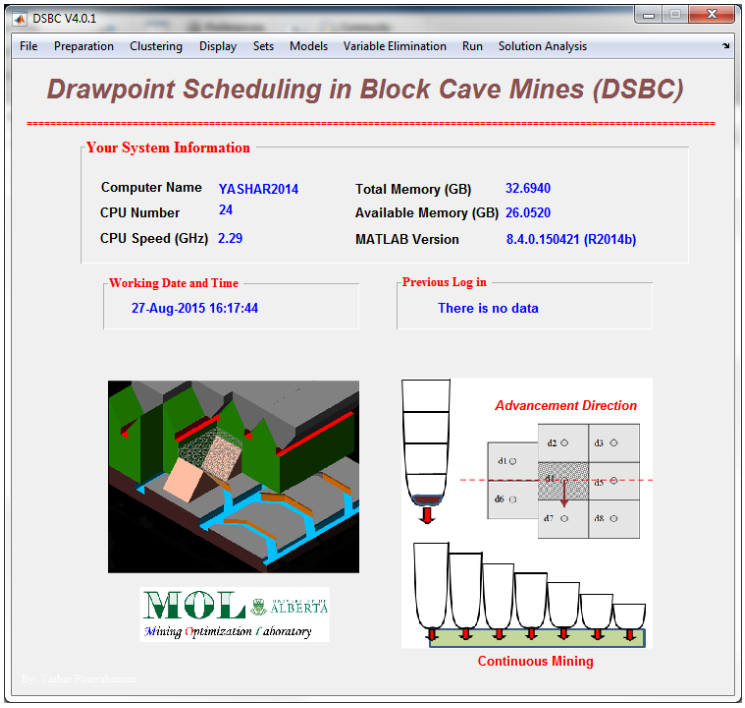


Fig 8. Main window of the DSBC

The components of the main window are menu bar, system information area, and date and time information area. The menu bar contains File, Preparation, Clustering, Display, Sets, Models, Variable Elimination, Run, and Solution Analysis.

In the system information area, useful information about the computer which the DSBC is running on that and version of the MATLAB are presented. Under the system information area, the date and time of the current and previous login is displayed.

5.1. Database Preparation

After executing the DSBC, to create a new project, go to:

File > Set New Problem

If there is another project, this option makes a backup from that project and then creates a new project. To import the three main Excel files into the DSBC, go to **File > import .xls to DSBC**. In the opened window, import the Excel files one by one. Then press **OK** (see Fig 9). After the Excel files are imported, they have to be converted to the MATLAB format. For this purpose, go to **File > Convert To .mat**.

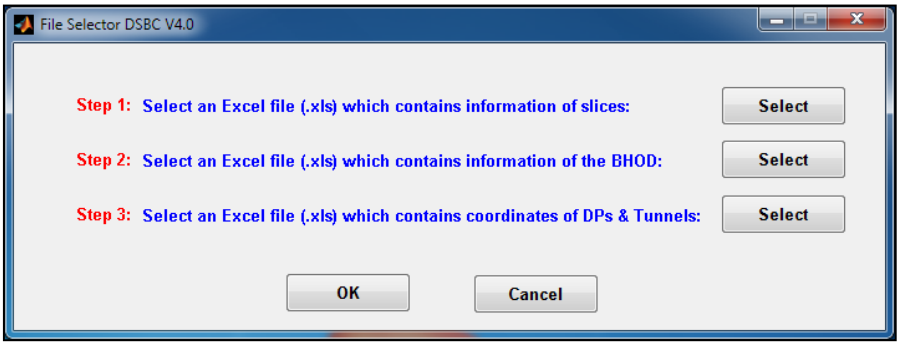


Fig 9. Import window

A window titled **Excel 2 MATLAB** comes up (see Fig 10). In this window you have to follow the steps. After each step the window is updated at the left bottom corner, and green lines appear.

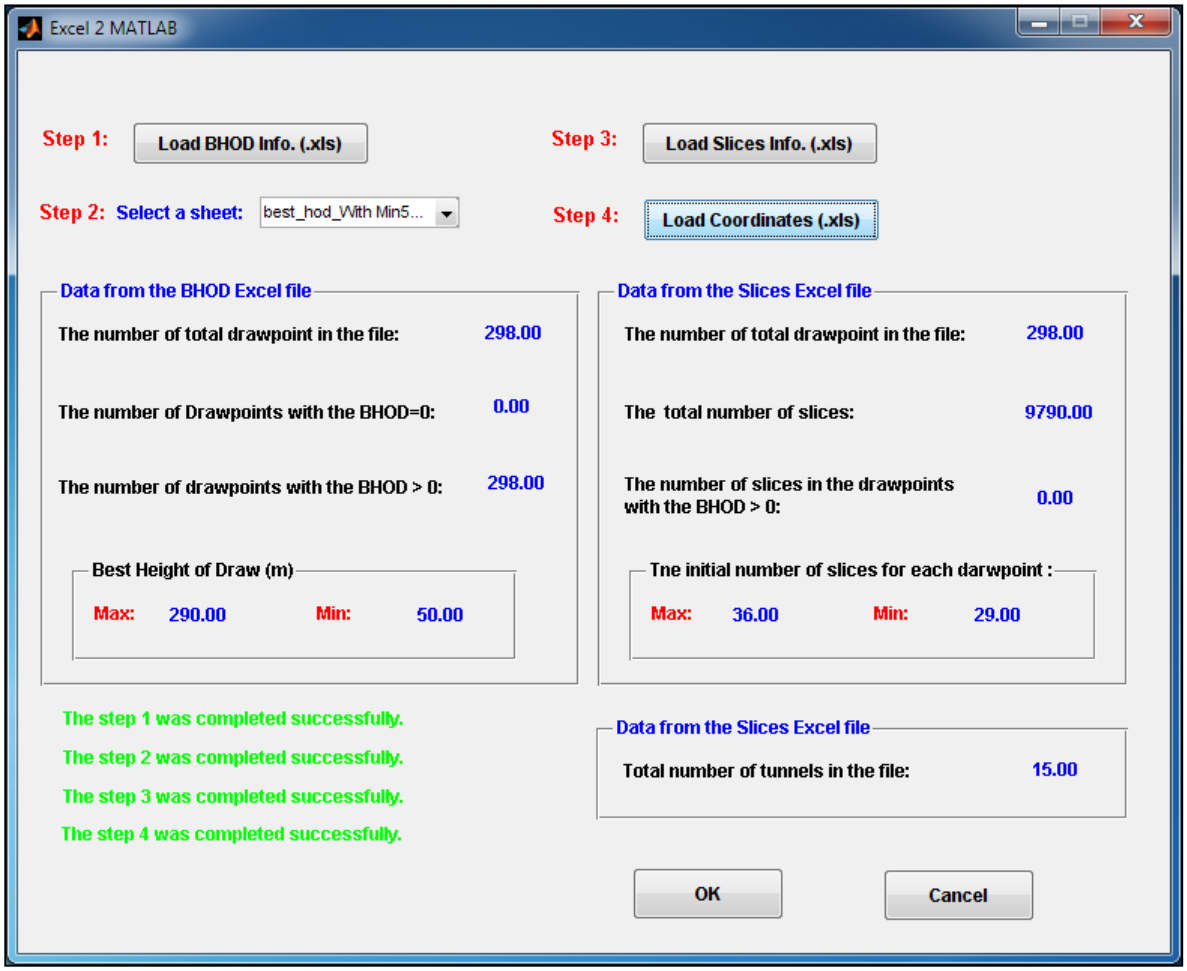


Fig 10. Excel 2 MATLAB window to convert .xls files to .mat

In the Excel 2 MATLAB window, Press **Load BHOD Info. (.xls)**. Then, from the pop-up menu in front of Step 2, select the sheet which contains the BHODs (see Fig 11).

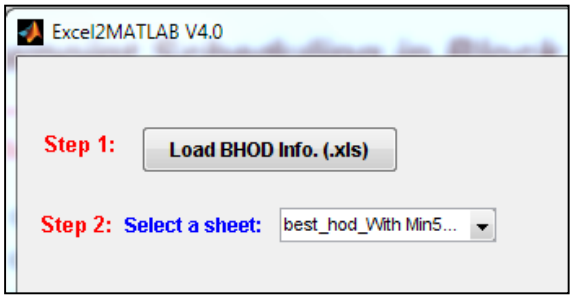


Fig 11. Selection of the sheet which contains the BHOD information

Press **Load Slice Info. (.xls)** to convert the slices info, and then Press **Load Coordinates (.xls)**. Check the data. Then press **OK**.

As the next step, the adjacent drawpoints and the drawpoints located between tunnels are recognized. Also, for each drawpoint-and-slice, an index is defined and the BHODs are applied on the initial draw columns. All this is done using the **Preparation** menu. Under this menu, there are five options. Select these options in the following order. After each step a dialog box is opened and displays useful information about the step.

1. **Preparation > Find Adjacent Drawpoints**
2. **Preparation > Create Index for Drawpoints**

In the opened window, enter the height of the slices.

3. **Preparation > Find Drawpoints Between Tunnels**
4. **Preparation > Apply BHOD on Slice file**
5. **Preparation > Create Index for Slices**

The **Display** menu allows a user to show the plan view of drawpoints, 3D view of draw columns, initial height of draw columns, and height of draw columns after applying the BHOD. To show these views, go to the **Display** menu and select the related option. If there is a draw column with BHOD = 0 in the data, it can be displayed using the last option under the **Display** menu.

5.2. Clustering and Creating the Sets

The next step is clustering. Before clustering, the advancement directions must be defined. For this purpose, go to **Clustering > Advancement Areas**. In the opened window, select a direction and press **APPLY**. This will display the plan view of the drawpoints and tunnels. Now, based on the advancement direction, the boundary of phases must be created in the following order:

- WE or EW: the lines should be created from left to right.
- NS or SN: the lines should be created from bottom to top.
- SWNE or NESW: the lines should be created from the left bottom corner to the right top corner.
- NWSE or SENW: the lines should be created from the right bottom corner to the left top corner.

Each line has two points. These points must be out of the black dash-line boundary. To pick the start and end points of the lines, use the LEFT click on the mouse. However, for the last line, the last point MUST be selected by the RIGHT click on the mouse. Fig 12 shows the advancement lines for the west to east (WE) and east to west (EW) directions. There are seven lines for the WE and EW directions. To define the phases boundaries for other directions, press **CLEAR** and then select another direction and press **APPLY**. Then, repeat the steps described in the previous sentence. Finally, press **OK**. The next step is the clustering of the draw columns within each phase. However, before clustering, the data must be prepared. For this purpose, go to **Clustering > Preparation**.

To cluster the draw columns within each phase using the hierarchical clustering method, go to **Clustering > Method > DPs Clustering Hierarchical**. Then, select a direction for clustering and press **Plot**.

Afterwards, the clustering parameters input window comes up; in this window type the required numbers (see Fig 13). If you press **OK**, the clusters in the selected direction appear. To find the best weights that create practical clusters, you have to repeat the clustering with different weights.

After clustering, you can analyze the clusters or display them. For this purpose, go to **Clustering > Display**.

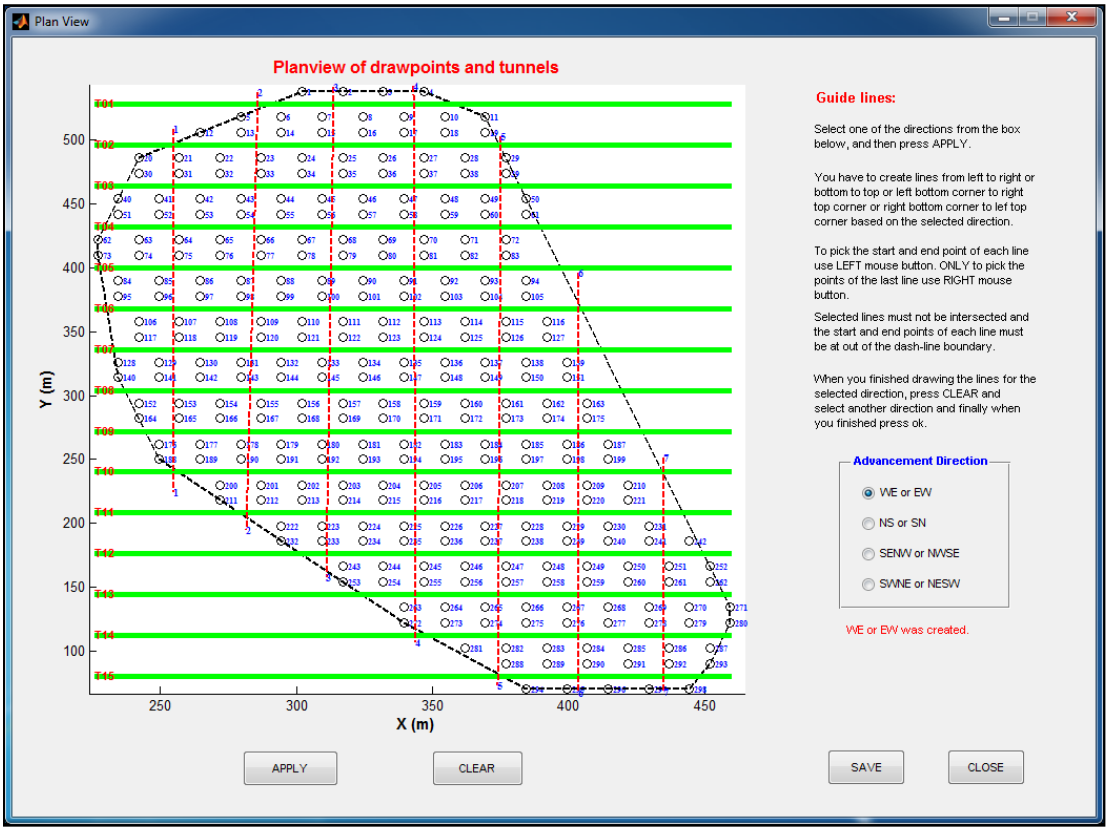


Fig 12. The window for advancement line selection with the phases boundaries for the WE or EW directions

Two options are available (see Fig 14). Using **DP Clusters**, you can display the clusters in the selected direction. Using **DP Clusters Analysts**, you can obtain useful information about the clusters and drawpoints within each cluster. This information includes tonnage, average grade, economic value, and number of drawpoints within each cluster. Go to **Clustering > Display > DP Clusters Analysts**.

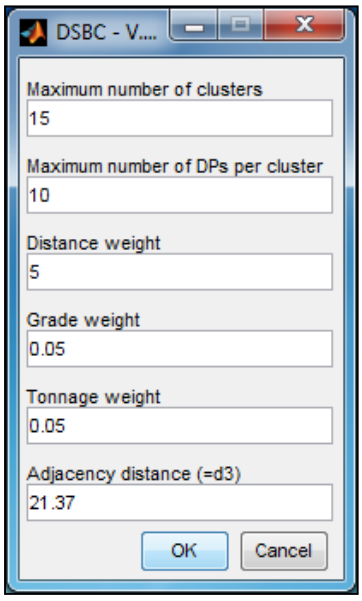


Fig 13. The clustering parameters input window

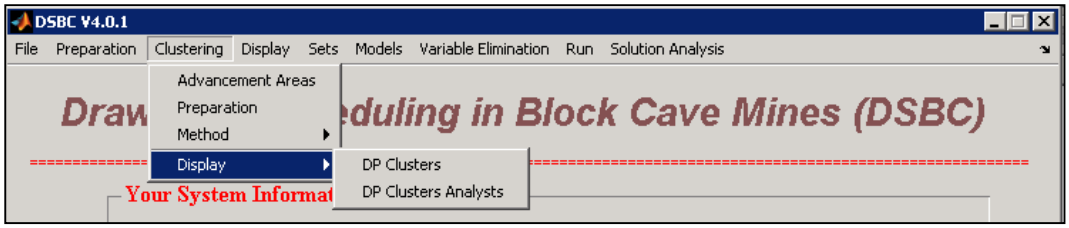


Fig 14. Available options for cluster displaying and analyzing in the DSBC

The DP Cluster Analysts window comes up. Select one of the existing directions and then press **PLOT**. The window on the left will display clusters from the selected direction. The window on the right will display tonnage, average grade, economic value, and number of draw columns for each cluster. At the bottom of the main window, each cluster can be analyzed based on tonnage, grade, and the economic value of the draw columns within the cluster. Fig 15 illustrates the DP Cluster Analysts window.

All the required sets explained in Chapter 3 are created through the **Sets** menu. To create sets S^{ds}, S^{dls}, S^{adj}, S^{CL}, and S^{d}, go to the menu called **Sets** (see Fig 16) and then select the options in the following order:

Sets > Create Sds, Sdls, Sadj

Sets > Create SCL

Sets > Create Sd

Fig 15. Cluster analysts window

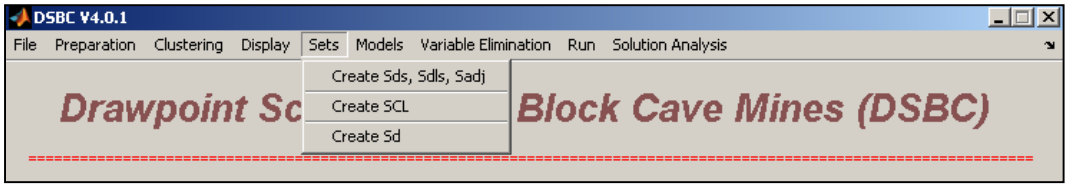


Fig 16. Sets menu to create all the required sets

5.3. MILP Models Preparation

To create the MILP models, the first step is to define of all the scheduling parameters based on the considered model. For this purpose there are two options. To define the scheduling parameters for the clustering-level model, go to

Models > Scheduling Parameters > Model With Cluster

In the opened window, select a direction and then press the **Schedule** button. A window will come up in which to enter the scheduling parameters for the clustering-level model (see Fig 17).

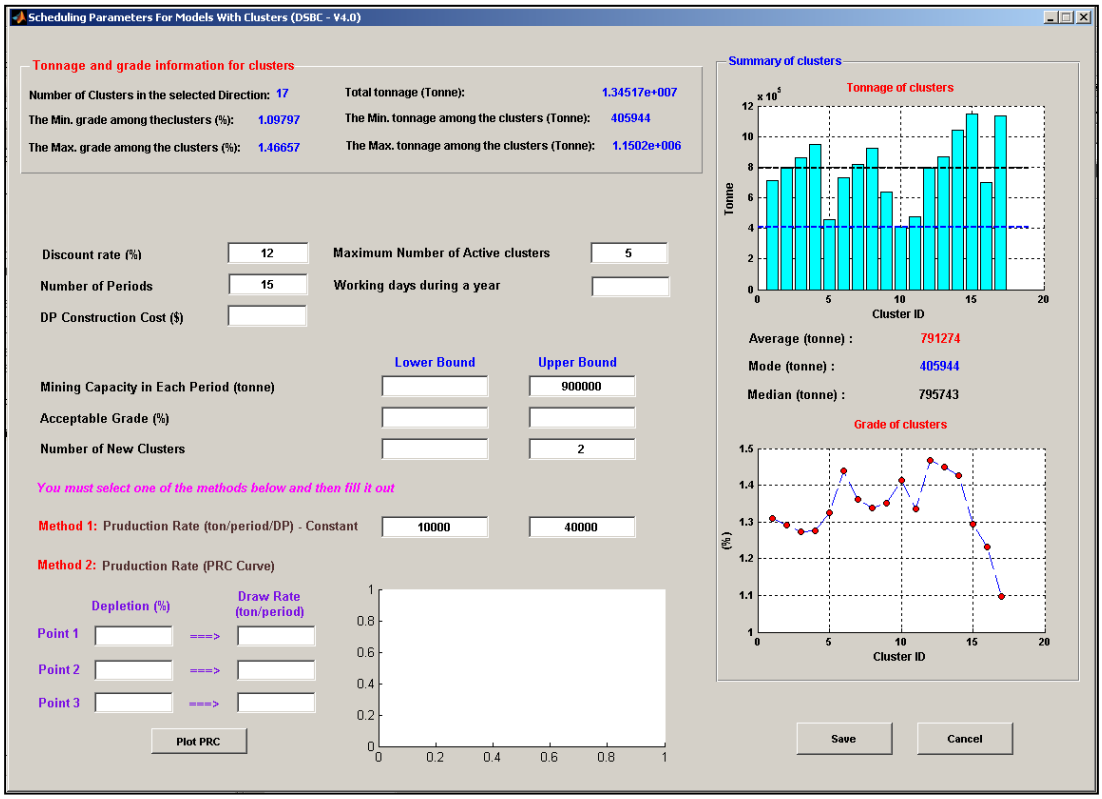


Fig 17. Scheduling parameters definition window for the cluster-level model

At the top part of this window, there is a summary about the minimum and maximum grade and tonnage among the clusters. Displayed on the right side of the window are the average grade of each cluster and its tonnage with the average, mode, and median lines. Fill out the blank boxes based on the project requirements. At the cluster-level model, user does not need to define the acceptable grade. For the draw rate, two different methods can be applied: (i) constant range, and (ii) production rate curve (PRC). Enter the drawpoint production rate in method 1. It will be automatically calculated for each cluster. Finally press the **SAVE** button. The summary of the entered data will appear; review the summary. If it is correct, press **OK**.

To define the scheduling parameters for the other models, go to

Models > Scheduling Parameters > Model Without Cluster

At the top of the open window, a summary of the useful data about the drawpoints and slices is presented. The right-hand side of the window displays the histograms related to the mentioned data (see Fig 18).

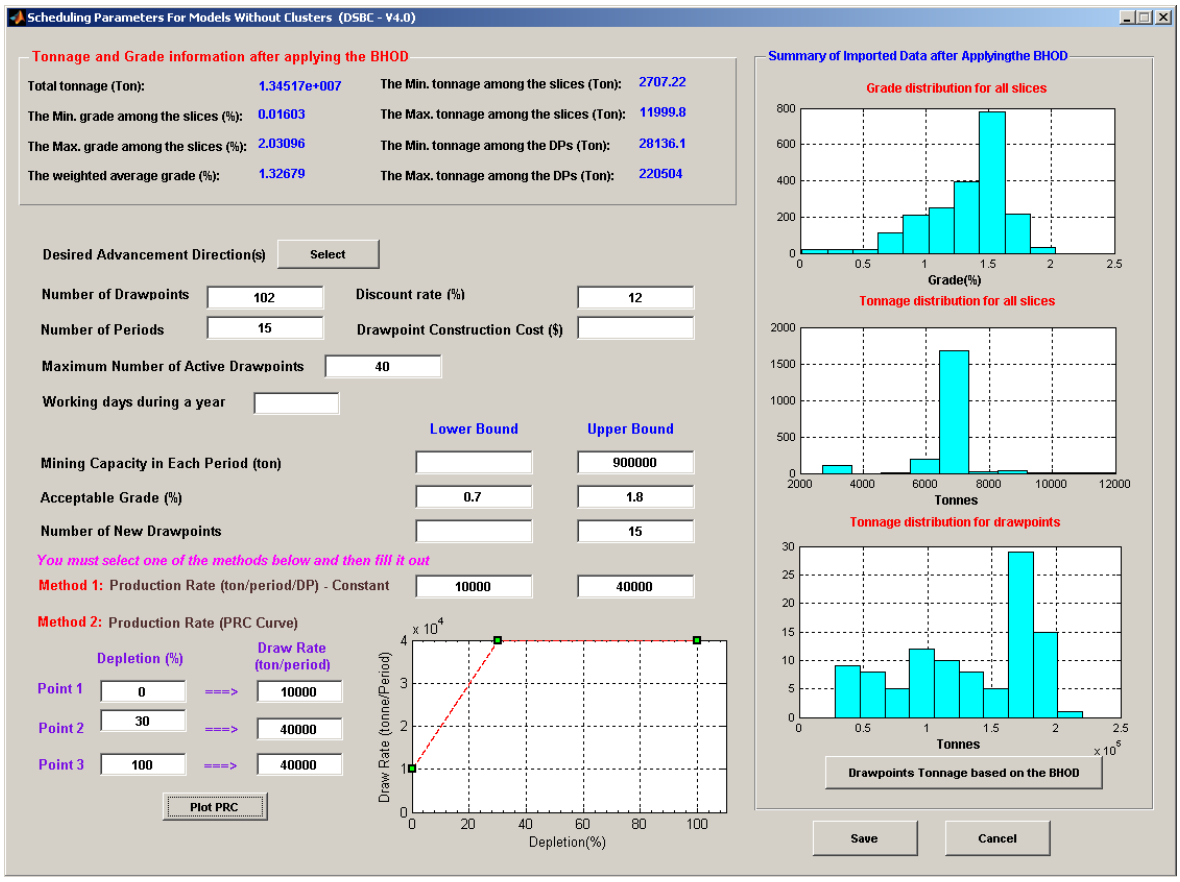


Fig 18. Scheduling parameters definition window for the drawpoint level and drawpoint-and-slice level models

Press the **Select** button in front of Desired Advancement Direction(s) and then select the scheduling directions. Then, press **OK** (see Fig 19). Fill out the blank boxes according to the project requirements. This time the acceptable grade must be defined. Finally, press the **SAVE** button. The summary of the entered data will appear. Check for accuracy. If everything is correct, press **OK**.

After defining the scheduling parameters and in order to create the models go to **Models > Create** and select the level of resolution needed to solve the problem. For example, to solve the problem at the cluster level, go to **Models > Create > Clustered DPs**. A mathematical model creator window will appear (see Fig 20). To see the formulation in detail, press the **Display Model** button. Create objective function and constraint in the order that has been appeared.

To create the draw rate constraint, select the **Lower and Upper Bounds option**. For the mining precedence, at the cluster level select **Set_SCL.mat** from the folder **SetSCL**. At the drawpoint level, select **Set_Sd.mat** from the folder **SetSd**. Finally, press **OK**.

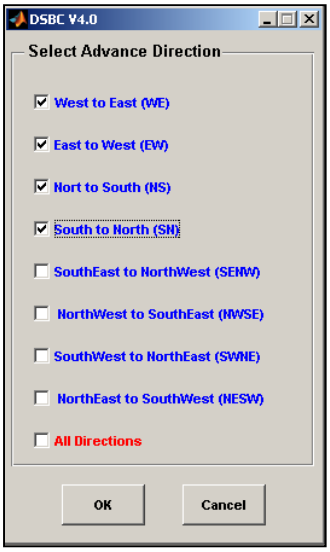


Fig 19. Direction selection window

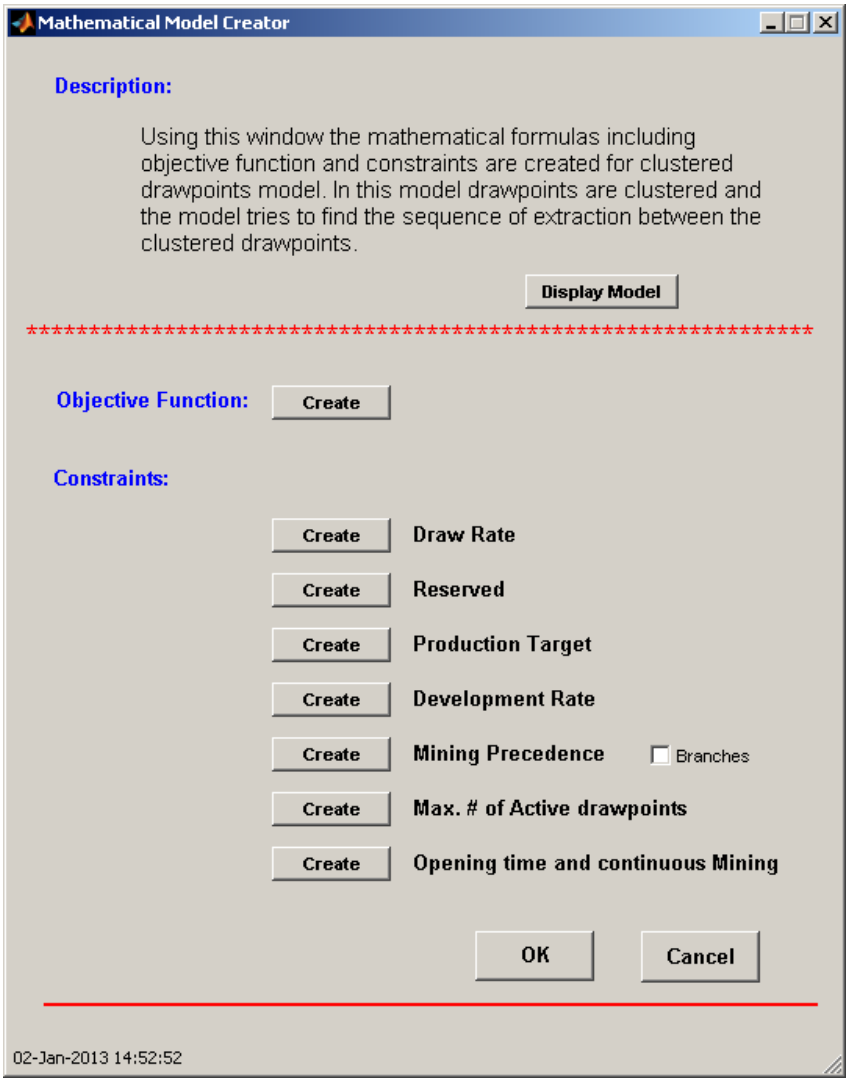


Fig 20. Mathematical model creator window for the cluster-level model

5.4. Scheduling Optimization

The MILP formulations presented for three levels of problem resolution -- cluster level, drawpoint level, and drawpoint-and-slice level -- can be used in two ways: (i) a single-step method in which each of the formulations is used independently, and (ii) a multi-step method in which each step's solution is used to reduce the number of variables in the next level and consequently generate a practical block-cave schedule in a reasonable CPU runtime for large-scale problems.

- **Single-Step Method**

After the model for each level of resolution has been created, it can be solved using the **Run** menu. For this purpose, go to **Run > Export to TOMLAB**. Select the model that you have created, and press the **Export** button. Then go to **Run > Solve the Model**.

TOMLAB/CPLEX is executed automatically. Then, a window comes up (see Fig 21). In this window, select the model and the advancement direction for optimization. Then enter the relative tolerance on the gap between the best integer objective and the objective of the best node remaining. For example, for the EPGAP of 1%, type 1 in the box. Finally, based on the number of available CPUs on your computer, enter the number of required CPUs to solve the selected model and press **Solve**.

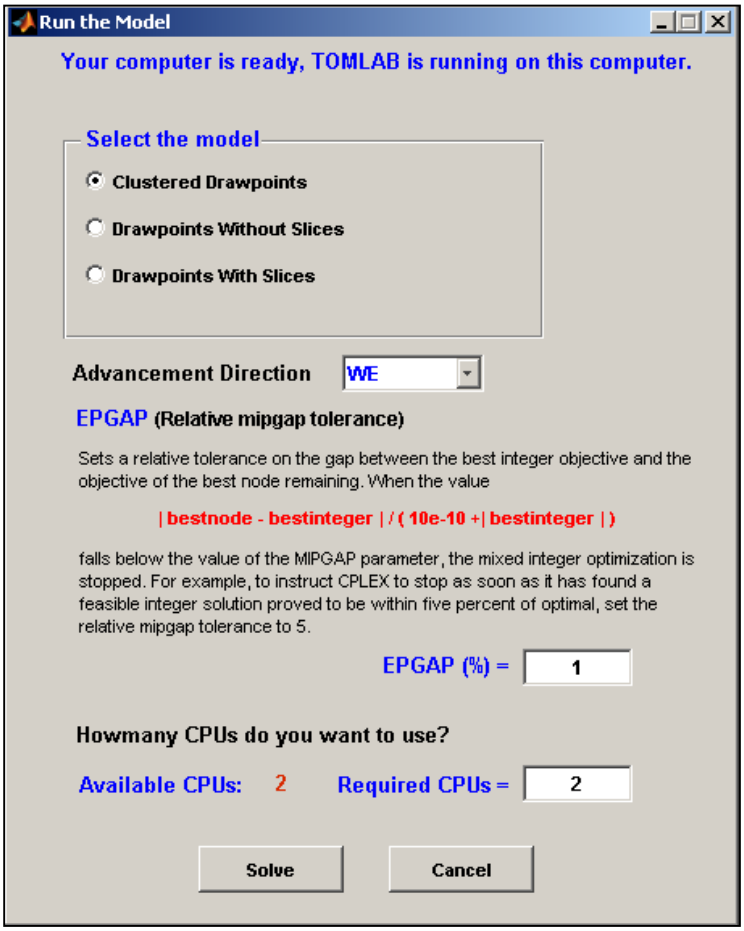


Fig 21. The window for defining the optimization criteria

After solving the problem in the selected advancement direction, to display the obtained results, go to **Solution Analysis > Results Preparation** and then select the related model and prepare it. To plot the results, go to **Solution Analysis > Plot Results**.

- **Multi-Step Method**

To solve the problem using the multi-step method, create all models. After creating the models, go to **Run > Export to TOMLAB**.

Select the cluster level model and export it. Then go to **Run > Solve the Model**. Select **Clustered Drawpoints** as a model and a direction to run the optimization. Enter the proper numbers for the EPGAP and the number of required CPUs. When the problem was solved, select another direction and solve the problem in that direction. Using **Plot Wizard**, recognize the best advancement direction for the obtained solutions in the selected directions. For this purpose, go to **Solution Analysis > Results Preparation** and then select the cluster-level model and prepare it. Afterwards, go to **Solution Analysis > Plot Results** and analyze the results to find the best advancement direction.

Then, go to **Variable Elimination > Cluster to Drawpoint Level**. Afterwards, go to **Run > Export to TOMLAB**. Select **Drawpoint Without Slices** and export it. Then, go to **Run > Solve the Model**. Select **Drawpoint Without Slices** as the model. The advancement direction must be the direction which had the maximum net present (NPV) value at the cluster level. Enter the proper numbers for EPGAP and the number of required CPUs and then solve the problem. After solving the problem at the drawpoint level, in order to solve it at the drawpoint-and-slice level, go to **Solution Analysis > Results Preparation** and select **Drawpoint Without Slices** and prepare it. Afterwards, go to **Variable Elimination > Drawpoint to Slice Level**. Select the solution of the drawpoint level as the starting period. Then, go to **Run > Export to TOMLAB**. Select **Drawpoint With Slices** and export it. Solve the problem at the drawpoint-and-slice level. The advancement direction must be that direction which had the maximum NPV at the cluster level. Enter the proper numbers for EPGAP and the number of required CPUs and then solve the problem.

After solving the problem, using the **Plot Wizard** you can analyze the results and compare different models.

5.5. Result Analysis

After solving the problem, results must be prepared for display. For this purpose, go to **Solution Analysis > Results Preparation** and select the related model and prepare it. Next, to plot the results, go to **Solution Analysis > Plot Results**. The **Plot Wizard** window will appear (see Fig 22). Select a model and then plot the results based on available options.

Fig 23 to Fig 28 illustrate the example of plots generate through DSBC's plot wizard.

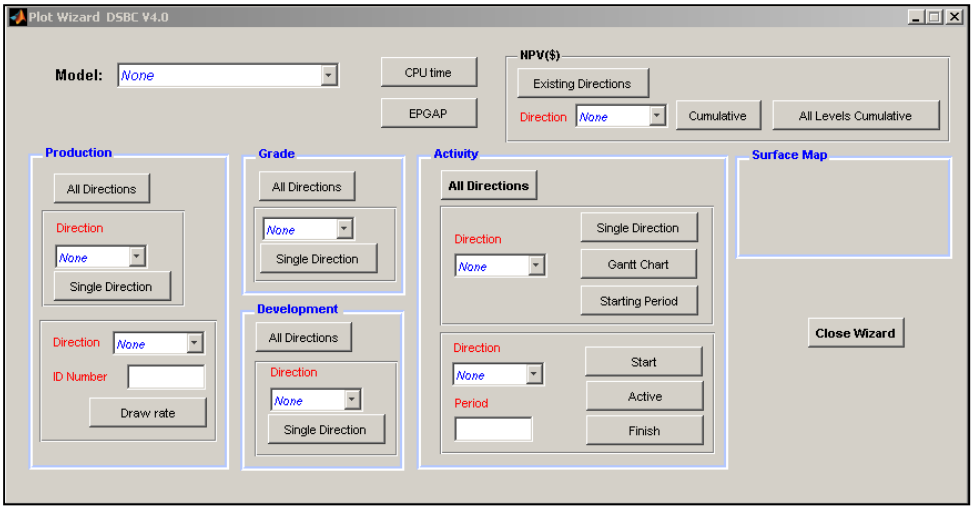


Fig 22. Plot wizard window

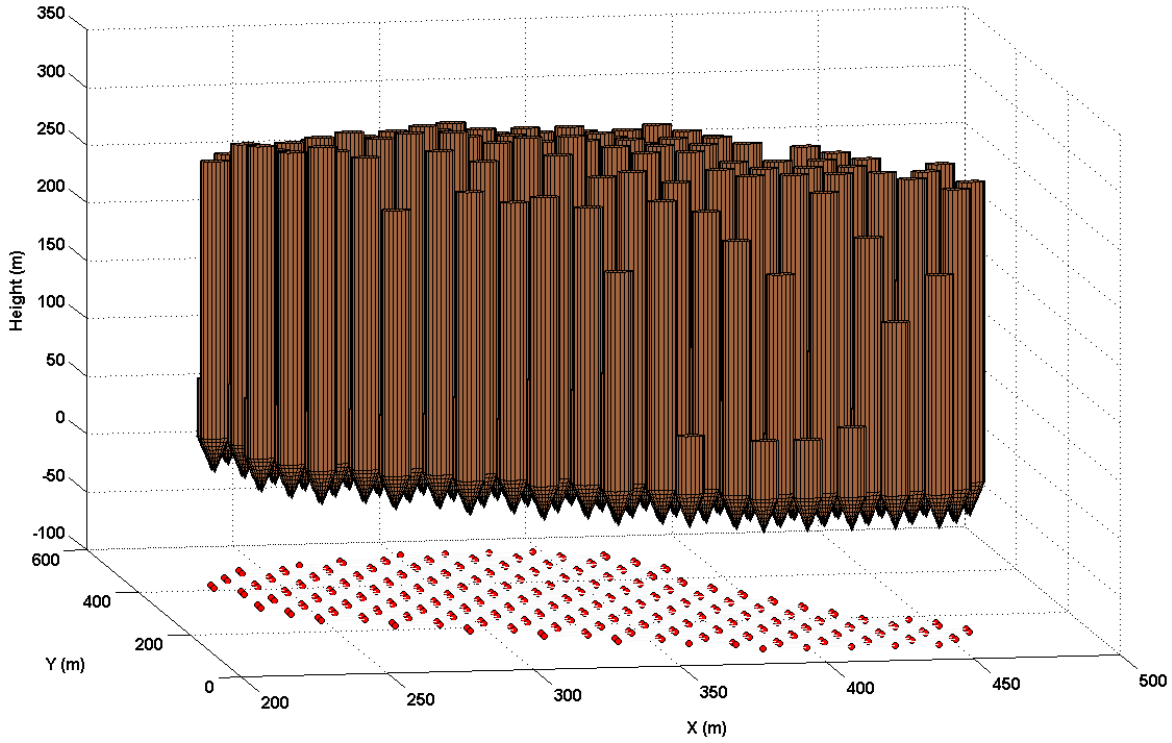


Fig 23. Example of plot for 3D view of the draw columns

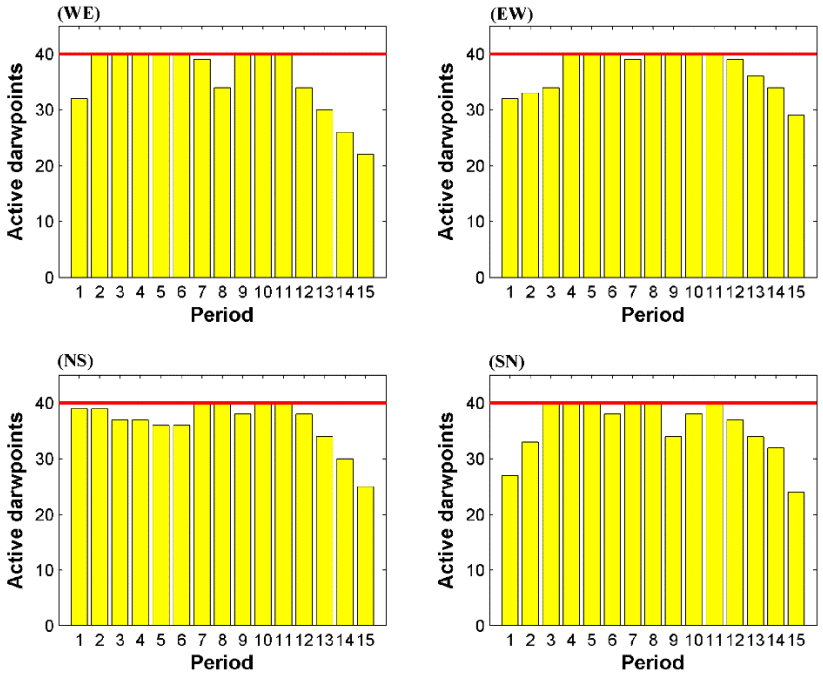


Fig 24. Example of plot for number of active drawpoints for different directions at the drawpoint level over the mine life

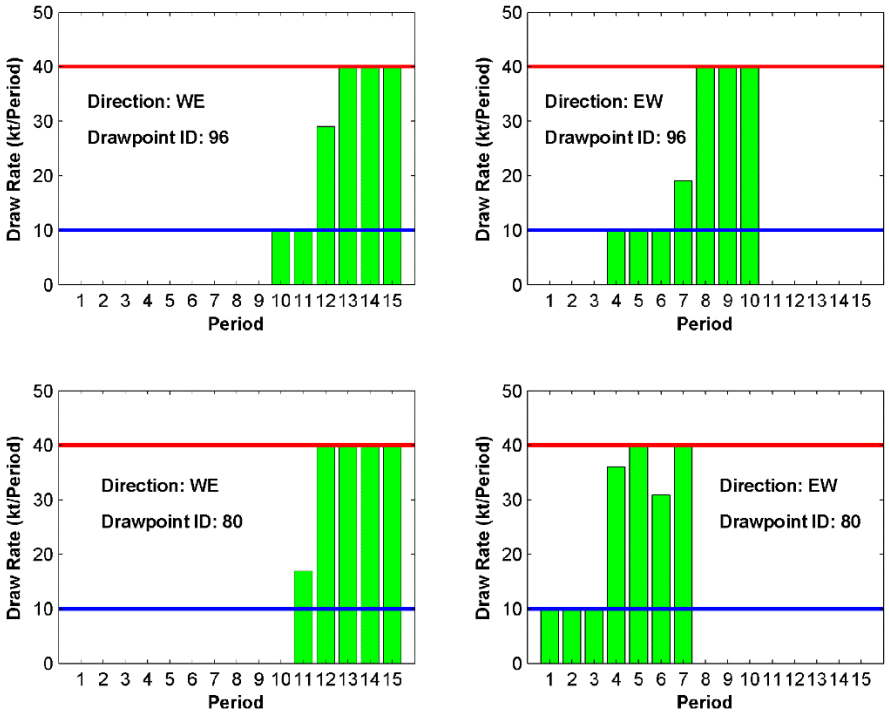


Fig 25. Example of plots for amount of depletion from drawpoints in different directions

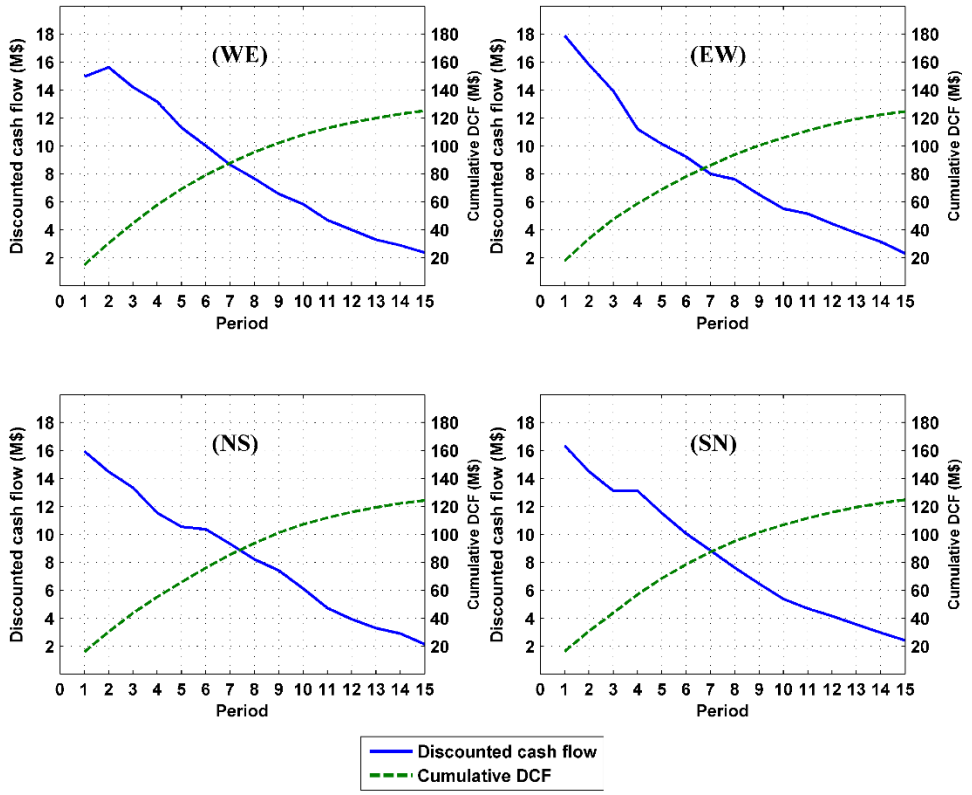


Fig 26. Example of discounted cash flow and cumulative DCF for different directions at the drawpoint level over the mine life

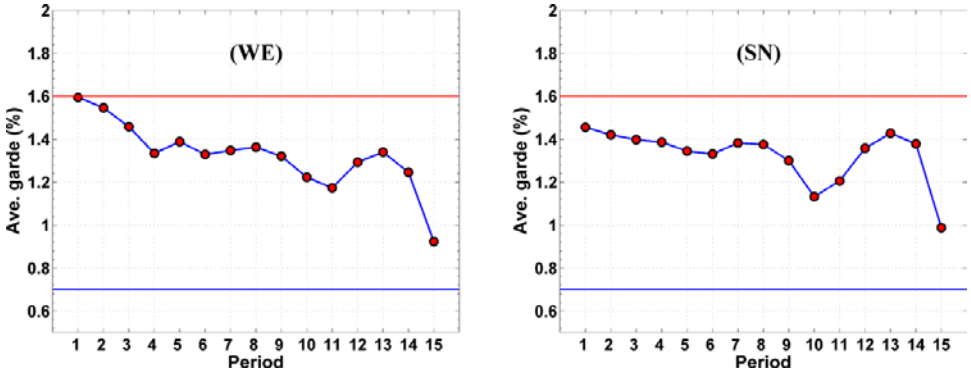


Fig 27. Example of plot for average grade of production in the different advancement directions at the drawpoint- and-slice level over the mine life

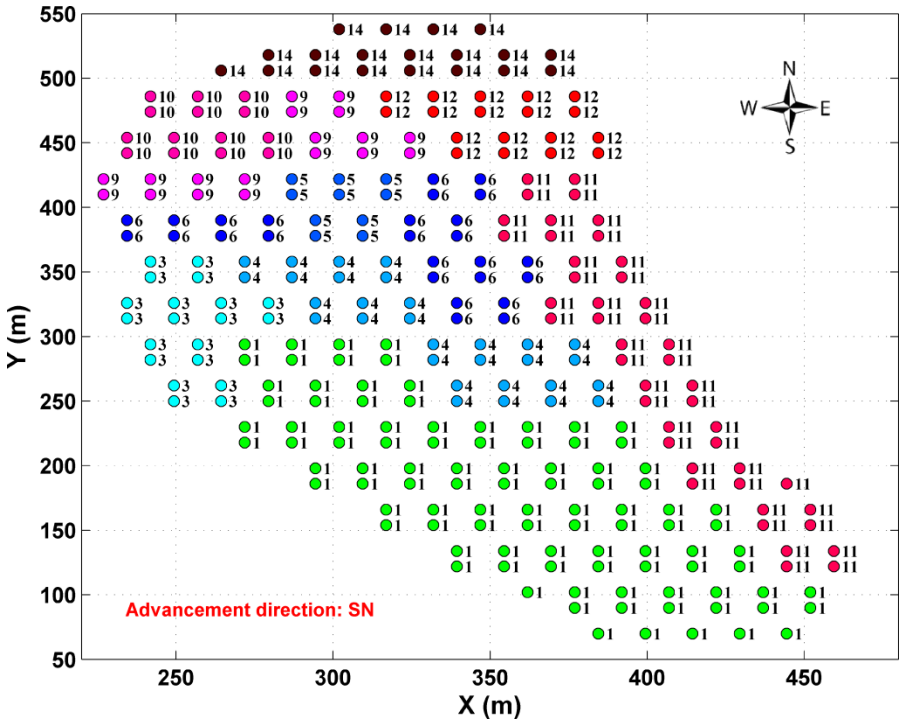


Fig 28. Example of plot for opening pattern using the cluster level formulation in the selected direction

6. References

[1] Geovia (2014). GEMS and PCBC. Ver. 6.5, Vancouver, BC, Canada.

[2] Holmstrom, K. (2011). TOMLAB/CPLEX, ver. 11.2. Ver. Pullman, WA, USA: Tomlab Optimization

[3] Horst, R. and Hoang, T. (1996). *Global optimization : deterministic approaches.* Springer, New York, 3rd ed,xviii, 727 p.