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SLO - A Program for Stope Limit Optimisation Using A Heuristic Algorithm

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ABSTRACT: Tlie heuristic *"Maximum Value Neighbourhood" (MVN)* algorithm is proposed to optimise stope boundaries. The algorithm provides a 3D analysis and can be applied to any underground mining method. The *MVN* algorithm uses a 3D economic block model to locate the best neighbourhood of a block, whtch guarantees the maximum net value. Neighbourhoods are restricted by the mine geometry constraints. A *Fortran 90* program, the *"Stope Limit Optimiser" (SLO),* has been developed to implement the algorithm. *SLO* integrates the *Fortran 90* code of the algorithm with the *Winteracter* user interlace features, to provide a Windows based interactive environment for defining the model specifications, stope constraints and mine economic factors and displaying the results as 2D plans/sections in a text mode view. Intermediate results are reported for each block and an on screen summary report is provided.

1 INTRODUCTION

Few algorithms have been developed for optimisation of the ultimate stope boundaries. The latest one, termed *"Maximum Value Neighbourhood" (MVN),* is based on a heuristic approach and benefits from its generality and simplicity (Ataee-pour & Baafi 1999). Few alternatives have been reported for the *MVN* algorithm including the Floating Slope Algorithm of Datamine (Alford 1995) and the Branch and Bound Technique (Ovanic and Young 1995). The *MVN* algorithm is implemented on a 3D economic block model, in which the problem of determining the best combination of blocks (for mining) that provides the maximum profit is formulated by Equation (I).

$$\left.\begin{array}{l}\text{Objective function :}\\ \qquad \textit{Maximise SEV} = \sum_{ijk} F_{ijk}\ BEV_{ijk}\\ \text{subject to :}\\ \qquad \textit{slope geometry constraints}\end{array}\right\} \quad (1)$$

where
SEV: total stope economic value,
BEV_{ijk}: the economic value of the block, B_{ijk}.
F_{ijk}: an indicator function showing whether the block, B_{ijk}, is mined or not. It is defined by Equation (2).

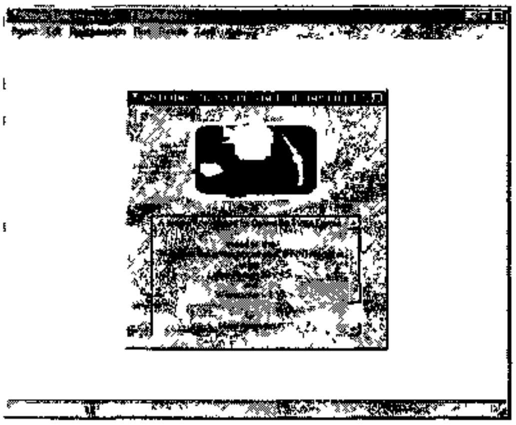
$$F_{ijk} = \begin{cases} 1 & \text{if } B_{ijk} \text{ is mined,} \\ 0 & \text{otherwise.} \end{cases} \quad (2)$$

Stope geometry constraint is formulated by the *neighbourhood (NB) concept*, which is based on the number of mining blocks equivalent to the minimum stope size. The size of (he *NB* in terms of the number of blocks is defined as the *order of neighbourhood (0„i,).* The *MVN* algorithm constructs the set of possible *neighbourhoods for* each block, calculates the dollar value of each *NB*, locates the *NB* with the maximum dollar value *(MVN)* and flags the corresponding blocks for inclusion in the final stope. The *MVN* algorithm has been implemented on small sized examples, using *Excel Visual Basic* modules (Ataee-pour and Baafi 2000).

An application program, the *"Stope Limit Optimiser" (SLO)* was developed to implement the *MVN* algorithm on actual mine data. *SLO* integrates *Fortran W* code of the algorithm with *Winteracter* user interface features. This paper introduces the procedure, capabilities and limitations of *SLO* and illustrates how a project is manipulated in *SLO* and how the optimisation results are displayed.

2 GENERAL PROCEDURE

SLO considers jobs for optimisation as projects. A project is a collection of input files that specify the block model parameters, stope geometiy constiaints and economic factors An ınteıactıve environment is piovided tor the usei to define projects and import block data for the optimisation process Figure I shows the *SLO* welcome page with the main menu Using the "'Project" option ot the menu, the usei may create a new project or open an existing one, save the pioject and close it 01 exit from the *SLO* application



Fıguıe I The *SLO* welcome page

The general performance ot the *SLO* optimiser, tor any pioject, is divided into three stages, ı e the input, optimisation and output stages, as shown in Fıguıe 2 During the input stage, all input data, including the block model definition, stope constiaints, economic factors and the block data are edited and prepared using the "Edit" option Each input data type is saved in a separate file tor lurther use In cases where block data contain only grade values, block economic values *(BEV)* arc calculated tiom grade values by *SLO* through the data preparation phase ot the "Preoptımısatıon" option The final pioduct ot the input stage, however, is an economic-block model (a 3D array containing the economic values ot the blocks) together with the 3D order ot neighbourhood

The optimisation stage is the core ot the whole program Optimisation may be peilormed on the whole, or a sub-region ot, the block model Using the "Preoptımısatıon" and "Run" options, a (sub) region is specified, the corresponding block data are impoited and optimisation is performed in accordance with the oıder ot neıghbouıhood and based on the *MVN* algorithm The optimisation stage receives the 3D array ot block economic values, as well as the 01 dei of neıghbouıhood, and produces a 3D arıay of block flag data

The output stage includes all processes concerning the visualisation ot the optimisation results (using the "Results" option) At this stage, *SLO* receives the 3D array of block flag data, arranges them in a plan or section older, wiaps them in a table tormat with suitable annotations and finally displays the optimised stope layout in an ascn formatted file Alternatively, the *SLO* exports the flag data directly into an ascn formatted file, accessible to other computer packages, which have been developed tor 2D and 3D display ot lesults The output stage also includes the display of all the reports and intermediate results collected thioughout the optimisation stage

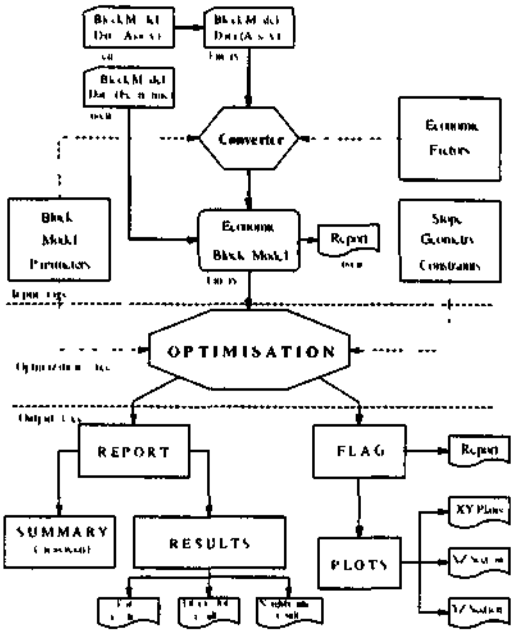


Figure 2 Geneial scheme of the *SLO* tlow-chart

3 PROJECT MANIPULATION

Projects are created, modified or deleted via three groups ot files, ı e model parameters files, stope constraints files and economic factors files

3 I Block Model Definition

The model parameters files contain information about the specifications ot the block model These include the co-oıdınates ot the origin and the maximum limit ot the block model, the extension and the numbei ot the blocks in X, Y and Z directions, as well as the definition ot possible sub-regions within the whole model Figure 3 shows the main dialog box tor the definition ot the block model

Block models may be defined in either the XYZ or UK mode In the XYZ mode, the model coordinates and the block dimensions are entered by the user The block volume, the number ot blocks in each direction and the total number of blocks within the model are automatically calculated. The UK mode requires that the user enter the number of blocks as well as the block's extensions in X, Y and Z dimensions. Then *SLO* calculates the minimum and maximum co-ordinates of the block model.

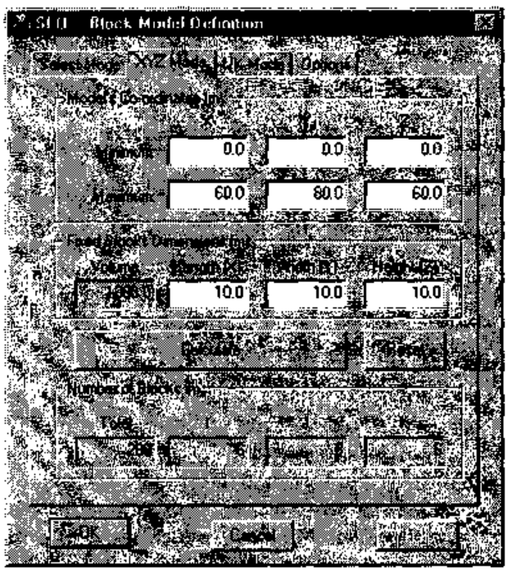


Figure 3. Defining the block model (XYZ mode)

It may be necessary to divide the block model due to geo-technical factors, different rock types or various mining methods. These impose different stope constraints to different parts of the block model. If this were to happen, various sub-regions may be defined to handle a variety of stope constraints and *orders of neighbourhood* within the model. When a deposit is too large and separate zones of mineralisation can be distinguished within the entire deposit, definition of various sub-regions may be helpful. In addition, the block model may contain either grade or economic values. *SLO* provides options to define both data types to a project. If economic values are used, the block data are directly used in optimisation. In cases where assay data are used, they should be converted into economic data before optimisation is performed. Through the "Options" sub-dialog in Figure 3, the user can state whether or not there are any sub-regions within the block model and specify the block data type.

3.2 Definition of the Stope Geometry Constraints

Information about the stope geometry constraints is collected in a separate file. The user should enter the minimum stope size, in terms of meters, for each of the three orthogonal directions. The stope block ratio *(SBR)* and the *order of neighbourhood* (O_{nh}), in each direction, is then calculated by *SLO,* based on the block size and the minimum stope size. O_{nh} is finally expressed in terms of the integer numbers, i.e. the number of blocks inside the minimum stope size in the X, Y and Z directions, respectively. The product of these three values indicates the total number of blocks within the minimum stope. It also indicates the total number of possible neighbourhoods for each block.

It is possible to define the stope constraints for the whole and/or sub-regions of the model. The existence of sub-regions often shows that there is not a consistent stope geometry constraint within the block model, so the constraints cannot be defined for the entire model but rather they should be defined for every sub-region. If the division of the model into sub-regions is not due to various stope constraints (e.g. it is because of a large deposit), then the stope constraints could be the same for all the sub-regions as well as for the entire model. This means that defining the stope constraints for sub-regions is not useful, unless the user is interested in performing the optimisation algorithm for a specified zone, instead of the entire model. *SLO* provides options to perform both cases. Figure 4 shows defining the slope constraints for a sub-region.

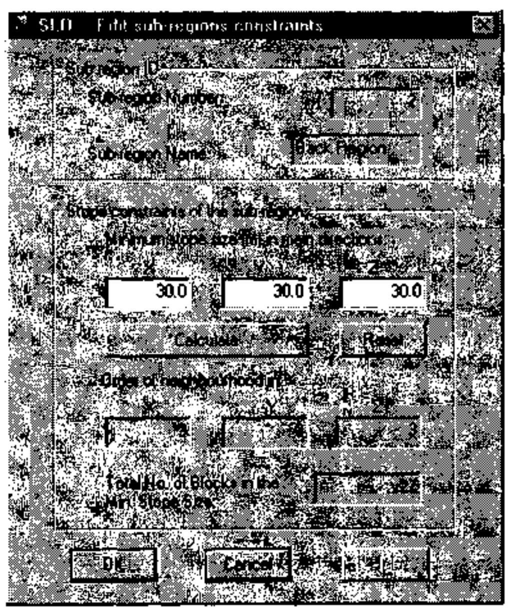


Figure 4. Defining the stope constraints (sub-regions)

3.3 Economic Factors

Another input to the system is information in respect of the economic parameters, which apply to mining the deposit. This information is used to help transloi m assay data into the dollar value of the blocks The tequired economic patametets include ınloıma-lion about the products of mining their puces, guides and price units costs of mining/processing of the pioducts, rates of recoveiy applied to products and the densities of the oie/waste Fıguıe 5 shows the economic paiameters dialog box thiough which pioducts ol the deposit may be defined Currently, *SLO* supports processing of economic factors tor multi product deposits containing up to tour by-products

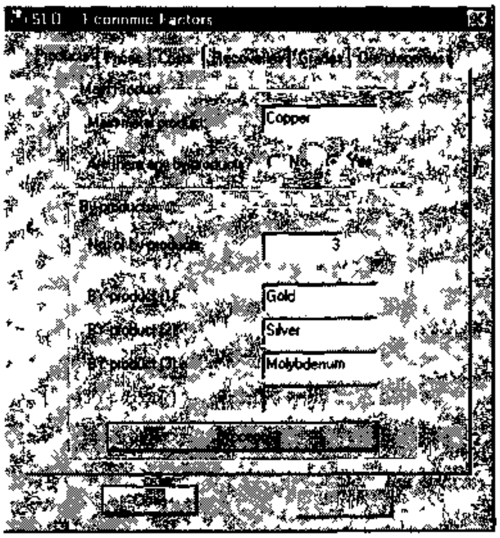


Figure 5 Defining the mine products

The puce and the price unit of each pioduct aie required The user may enter the price diieclly in a real field in the supplied dialog box A list of three price units is available to select via a drop down menu which include dollar per tonne dollar per ounce and cents pei kilo Figure 6 shows the corresponding dialog box in *SLO*

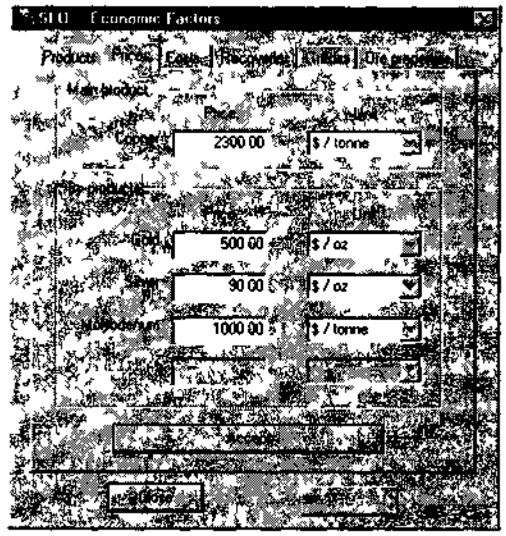


Figure 6 Defining prices and price units

There are two categories of costing applied in the optimisation of stope boundaries, ı e ore-based costs and metal-based costs Oie-based costs consist of all expenditures spent to extract the rock from the mine regaidless of whether it is ore or waste In order to obtain oie-based costs, all mining processes in eluding preparation, dulling blasting or haulage, should be consideied Then the average cost toi mining one tonne of rock (ore or waste) forms the ore-based costs Metal-based costs include all cx-pendituies to ıecover the metal pioduct from the mined ore Obtaining costs tor this category is by calculating the aveiage cost tor one tonne of the main product rather than the ore The metal-based costs may be broken down into a number of compo nents such as, the cost of smelting or pıocessıng, the cost ol letınıng, administration costs and other miscellaneous costs The user may enter these cost information thiough a dialog shown in Figure 7

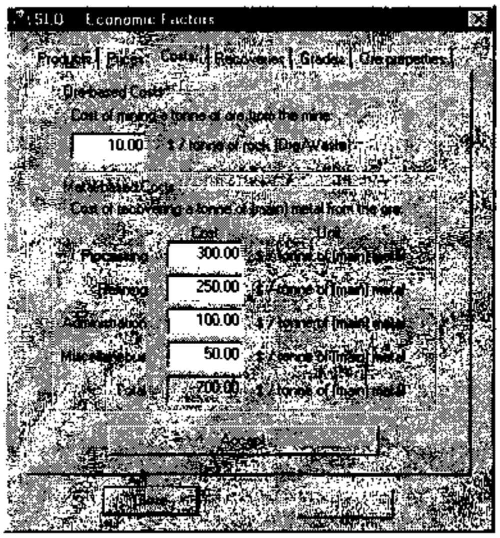


Figure 7. Defining various costs

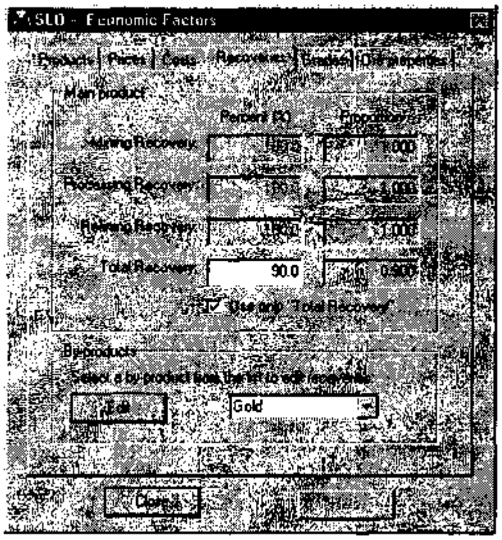


Figure 8. Defining various rates of recovery

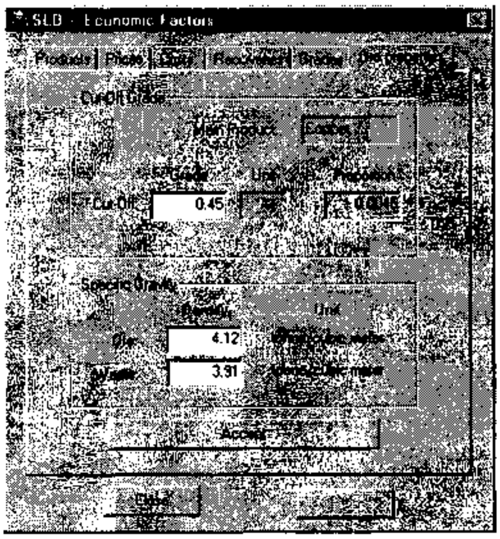


Figure 9. Defining ore properties

SLO provides definition of recovery of the metal contents in three stages, i.e. the mining, processing (smelting) and the refining stage. The user enters the rate of recovery at each stage, in terms of percentage, and *SLO* returns the total rale of recovery. However, the user may enter directly the total rate of recovery, if available, and ignore the sub recoveries. Figure 8 shows the dialog box for defining the various rates of recovery. If there are any by-products, the rates of recovery should be defined for each by-product using an additional dialog box.

The grade values are entered via the assay data file, however, the units of grades are defined through the project files. The grade units are defined for each by-product as well as the main product. A list of two items is available for the selection of grade units, i.e. the percentage (%) and grams per tonne (ppm). Ore properties are the last economic factor described in the project file. In order to obtain the weight of a block, the specific gravity of the rock is needed. Two distinct categories of density, i.e. the density of the ore and the density of the waste are supported. A cut-off grade should be defined for the main product lo discriminate between the ore and the waste. Figure 9 shows the *SLO* dialog box for defining the ore properties.

4 BLOCK DATA FILE

The main block inputs to the optimiser is the economic values of blocks stored in a data file. In cases, where economic values are not available, the data file may include the assay data of blocks. In either case, data files must contain information about the address and value of each block. For economic data files, the block value is a real number that represents the estimate of the dollar value of that block. Where the input is assay data, the block value consists of a group of, up to five, real numbers, which represent the estimated grade ot the main pioduct, as well as that ot a maximum ot torn possible by-products tor that block It is possible tor the usei to view and edit the data tiles in ascn format before peitoiming optimisation

In multi product projects where theie are multiple giade values tor each block, they are replaced by a single equivalent grade value, based on the main product giade In ordei to calculate the equivalent giade value, the prices grades and rates ot recovery tor each individual product are taken into consideration

5 OPTIMISATION AND RESULTS

After all data aie input in the îequired form, the usei may choose the entne model or select a sub-iegion to peitorm optimisation All required data corresponding to the blocks within the selected ıegıon aie then imported and optimisation is peiformed based on the *MVN* algorithm Finally, blocks ol the optimised stope aie flagged The flag data ot blocks are stoied in an output file

5 / *Plots*

The output tile may be impoited into other mine planning packages to display the end îesults in 2D and 3D views Howevei *SLO* provides utilities tor the usei to pioduce and view the plots ot the ultimate stope boundaries The usei may select the plot ling ol any ot the 2D views of the stope including X-Y plans X-Z sections and Y-Z sections, or all ot the plots It is also possible to specify a certain plan section, oi a range ot plans or sections ot the optimised slope tor plotting Figuie 10 shows the *SLO* dialog box tor specifying plans, or sections, ot the optimised slope to be plotted

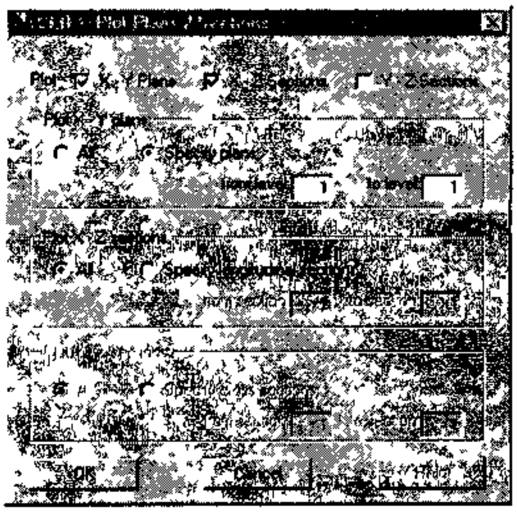


Figure 10 Spccılyıng plans/sections to plot

PLAN h 12

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28	*	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	*	28
21	*	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	*	27
26	*	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	*	26
25	*	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	*	25
24	*	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	1	1	0	*	24
23	_	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	*	23
22	*	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	*	22
21	≫	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	*	21
20	*	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	*	20
IS	*	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	*	19
İS	*	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	*	18
17	*	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	*	n
16	*	0	0	0	0	0	i	1	1	1	1	1	1	1	1	1	0	0	0	0	*	16
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14	*	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	*	14
13	*	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	*	13
12	*	0	0	0	0	0	0	1	1	1	1	i	1	1	1	1	1	1	0	0	*	12
11	*	0	0	0	0	0	0	1	1	1	1	i	1	1	1	1	1	0	0	0	*	11
10	*	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	*	10
3	*	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	*	9
8	*	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	*	8
7	*	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	*	7
S	*	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	*	6
5	*	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	*	5
4	*	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	*	4
3	*	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	*	3
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1 2 3 4 5 6 7 S 9 10 11 12 13 14 15 16 17 18 19

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Figuie 11 An example of the plans/sections plotted in *SLO*

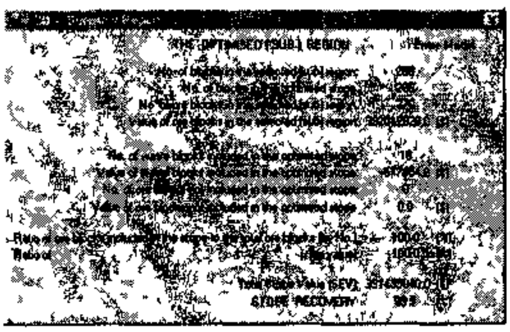
An example ot such plotted plans/sections is shown in Figure 11 Cunently, the plots of *SLO* are in text mode It is envisaged to modify the application to plot in giaphics mode

5 2 Results Files

SLO reports the intoimation obtained lor the optimised blocks at each stage This intoimation is updated as the optimisation progresses and is finally saved in some report files These include reports on the intermediate lesults, the neighbouihood results and a final on scieen summaiy report Information about the set ot possible neighbourhoods ot each block and their dollai values are saved in the specified file The intermediate results obtained tor each block contain the *neighbouihood (NB)* numbei within the set ot neıghbouıhoods ot that block, which piovides the maximum value, the maximum neighbourhood value, the maiginal value obtained fioin the *MVN* of the block, and finally the updated stope value These results obtained duiing the optimisation will help the user to see the vanation of the stope after the optimiser examines each block

5 3 Summen ^ Repoı t

Atteı the optimisation is completed, a summary leport ot the optimisation lesults is provided and appended to the end of the intermediate results file The summary report includes information such as the total number ot blocks within the region, number ot negative and non-negative valued blocks in the region numbei ot negative valued blocks included in the final slope, and then total values, numbei ot non-negative valued blocks excluded from the final stope and their total values, total stope value, and the percentage of the block values included in the ultimate stope Fıguıe 12 shows a typical on scieen summary leport



Fıguıe 12 A typical on scieen summaiy lepoit

6 CONCLUDING REMARKS

SLO is a Windows based application program which may be used to interactively optimise stope boundaries, implementing the *MVN* algonthm The major options available in *SLO* include XYZ and UK modes, defining sub-regions, accepting assay/economic value modes and supporting multi-product deposits (up to toui by-products) It is possible to produce nested stopes by changing the economic paiameters such as prices, costs, recoveries and cut-olt grades and multiple running ol *SLO* This parametensation is helpful in any decision making about the ore deposit including the feasibility study, prchminaiy mine evaluation and the mine closuie The variation in stope geometry constraints may also pioduce nested stopes which may help in mining method selection since different mining methods impose ditterent stope geomctiy constraints Running *SLO* tor alternative mining methods will help in the selection ot the method with the highest stope net value

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