

# Whittle Four-D in the Undergraduate Mining Engineering Classroom

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## Introduction

Computer assisted mine planning and design applications are routinely used by many Australian mining companies. However, not many undergraduate students are properly trained in using these sophisticated mine design software. The department of mining engineering and mine surveying at Western Australian School of Mines is fortunate enough to train its graduates with a host of state-of-the-art contemporary software. The list includes DATAMINE, SURPAC, VULCAN and WHITTLE FOUR-D courtesy the software companies. This paper introduces the application of the WHITTLE FOUR-D optimisation software in the fourth year unit of mine design project.

The author is the principal instructor and coordinator of this final year mine design project unit and is instrumental in incorporating the major mine design software in the unit syllabus. An attempt is made to mimic the design process as practiced in the industry. The paper covers the procedures used in introducing the WHITTLE FOUR-D software to the students and incorporates some samples of the students' works. Recommendations for improvement in the parameter file editor for making it a very efficient training tool are also highlighted.

A detailed coverage on computer education at WASM was addressed by Golosinski (1996) in a presentation at the 26th APCOM meeting. The optimisation software is introduced in the fourth year unit Mine Design Project 492. The students are exposed to the optimisation theory in a second year subject of Surface Mining. The other mine design software, such as DATAMINE and SURPAC are introduced as third year units. This current paper provides details on how engineering design

principles are presented for consideration as the key elements of mine planning and design.

A typical mine design procedure is of cyclic nature. The unit Mine Design Project 492 captures a full cycle of the design process including Preliminary Feasibility, Engineering Design, and Financial Analysis combining the results of the prior two items.

## Details for the unit Mine Design Project 492

Tuition pattern included two (2) hours of lecture and four (4) hours of laboratory session for initial training for using the Whittle FOUR-D software and independent project work. **A complete feasibility study, detailed mine design and project evaluation were required to a professional standard.** The students were advised to stay with metalliferous mining and perform a detailed open pit mine design (feasibility study) to represent local mining practice. An orebody model was supplied and the students were asked to follow the design guidelines and specifications provided. There was only one orebody model used for the project work, but each group (two to four students per group) had the choice of selecting independent design objectives and parameters. This approach generated multiple design for one orebody.



**Text and references used were:**

- SME Mining Engineering Handbook (Vol. 1 and Vol. 2).
- Hustrulid, W. and Kuchta, M., 1995, Open Pit Mine Planning and Design, Balkema.
- Whittle FOUR-D Software Manual and published material on the use of the software.
- Datamine Training Manual (with new Guide 2.3.2 Software Manual).
- AusIMM Cost Estimation Handbook, 1994.
- Rensburg, P. W. V. (ed.), 1970, Planning Open Pit Mines, Proceedings of the Symposium on the theoretical background to the planning of open pit mines with special reference to slope stability, Johannesburg, South Africa, Aug. 29 - Sept. 4.
- Other software manuals and materials as suggested by guest lecturers from industry.

- Student project reports (1994, 1995), available from the unit coordinator.

**Assessment for the project work:**

- Reserve estimation and preliminary feasibility: **25 %**
- Feasibility study - Engineering design: **20 %**
- Final optimisation and economic analysis: **5 %**
- Perform open pit design using DATAMINE/GUIDE: **10 %**
- Final project report: **10 %**
- Mid term test (Based on reading assignments and material presented by guest lecturers): **20 %**
- Self and group evaluation: **10 %**

The following table shows details of the Practical/tutorial sessions:

Week No	Practical/tutorial session
1	Introduction to Whittle FOUR-D Tutorials/Parameter file.
2	Parameter/Model file from DATAMINE/Optimisation and Analysis.
3	Work on preliminary feasibility report.
4	Work on preliminary feasibility report.
5	Work on preliminary feasibility report.
6	Deadline for draft preliminary feasibility report (25 % of final grade).
7	Engineering Design: Geometrical and Geotechnical Design (Introduction to GALENA software, may use any other design tool).
8	Engineering Design: Production Planning and Scheduling, Blast design (Introduction to TALPAC software, may use any other design tool).
9	Training session for final optimisation, cost calculation, etc.
10	Work on Engineering Design.
11	Deadline for draft report on Engineering Design (20% of final grade).
12	Work on Final Project Report. <u>Optional training</u> -Mine Planning and Design using VULCAN/ENVISAGE.
13	Work on Final Project Report. <u>Optional training</u> -Mine Planning and Design using VULCAN/ENVISAGE.
14	Work on Final Project Report. <u>Optional training</u> -Mine Planning and Design using VULCAN/ENVISAGE.

## Design Guidelines and Specifications (Starting Week 3)

Following instructions were provided to the students for loading an orebody model and creating a model file for the optimisation process. The filenames used in this paper are project work specific and included here for completeness (refer to the Appendix for more details).

### Phase 1: Reserve Estimation, and Preliminary Feasibility Study

- Power on computer, login, and start DATAMINE. Using the DATAMINE process OPSYS copy **model.dm**, **airmodel.mac**, and **fddata.mac** files from Z:\public\dmdata directory.
- Run DATAMINE process MAKDIR (with options **merge=1** and **link=1**) to associate the model.dm file in your data directory. Run '**airmodel.mac**' to create air blocks (density =0) on top of the topography boundary of the 'MODEL (obtained from DATAMINE macro TRAIN.MAC)' file representing the geological model. A new model file '**airmodel.dm**' will be created. You may use GUIDE and view this airmodel file (use field DENS (density) to view it).
- This model uses default block size 12.5m x 20m x 10m. This is sufficient for project requirement, but you may change the block size and recreate the model.
- Run 'FDDATA.MAC' macro in DATAMINE to prepare the data to be transferred for optimisation. View the macro file to understand its function. This process will create an output file 'VALMOD'.
- Run DATAMINE process FDOUT and enter 'VALMOD' as file input. Use **Option B** for method and use prompt **no** (to keep integrity of individual parcels) in response for merging identical parcel type. Provide parameter file name (this parameter file will not be used) and model file name for optimisation use.

**Note:** that the parameter file has to be created using FDED in Whittle FOUR-D software. Use **air blocks option =1** and **air flag option = 3**

- Run FDUT utility in Whittle FOUR-D software to check correctness of your model. Moreover

this process may be used to perform a reserve estimation for an orebody model.

- Run FDRB to reblock and remove excess waste material. Run FDST to create structure arcs. Run optimisation and perform economic analysis as prescribed in step 3 using the FDAN process of the Whittle FOUR-D software.
- After optimisation, you may transfer a set of parameter file and results file to view the optimised model using DATAMINE and GUIDE. Use DATAMINE procedure FDIN to load the model in DATAMINE. Then view the model in GUIDE. Load the topography file to see how air blocks were used in optimisation.

### Components for Draft Preliminary Feasibility Report

This section was designed to make students familiar with sensitivity analyses. They perform these sensitivity analyses to obtain an initial knowledge of the orebody and design requirements. The following instructions cover this section:

- Discuss preliminary feasibility and its components. Address the role of optimisation using the Whittle FOUR-D software in determining preliminary feasibility (emphasis on flexibility of including all the design and cost information). Briefly describe the process of applying the software for preliminary study (do not need all the program details, one can get it from the users manual). Mention the approximations, if any, are being used. **5 %**
- Expand on results obtained from the FDAN process (you have to guess a mining cost at this stage). Provide a general report showing total reserve and grade, mine life, and cash flow (reference - print output file **.pra** from FDAN run). Comment on best case and worst case schedules.
  - Analyse and report the results for following cases: **15 %**
  - NPV (Total discounted cash flow) Vs Rock tonnage or Pit Number for both best and worst case schedule. Perform this analysis for a price range of AUD 400/oz - 600/oz at an interval of AUD 50/oz
  - Grade - Tonnage information (effect of cutoff, use your own judgment).

- NPV (Total discounted cash flow) vs Slope Angle variation. Use only one sub-region and vary the slope angle (keeping bearing angle constant=0) between 45 deg. and 60 deg. at 5 deg. intervals. Use just one price value of AUD 500/oz.
- Investigate and comment on effect of mining rate and mill capacity (eg, effect of a constant mining rate and varying mill capacity and vice versa). Use metal price as AUD 500/oz.
- Ore and Waste tonnages, Strip ratio and grade vs Pit no. for price of AUD 525/oz.
- Prepare an Executive Summary from the above information. Assume the orebody is in typical geological setup of Kalgoorlie-Boulder area. You may use the student project reports (1994, 1995) for geological, geotechnical, mining and other information. In addition, you are encouraged to use data (with proper reference) from any relevant sources. **5 %**

### Phase 2: Detailed Engineering Design

Geotechnical design in open pit mine design is a high leverage area (Lye, 1996). Steepening of a pit slope by one degree may save a large amount of money. Therefore, it is planned to put emphasis in this section. Main objective of this design component of the current project is to help the students revisit some principles of slope stability analysis and design. Moreover, the design data is provided in such a way that two separate sub-regions are to be modelled in the final optimisation. This feature will provide experience in handling multiple sub-regions.

The students were asked to provide a sample blast design and prepare a tentative mining schedule. They were advised to use preliminary feasibility study (best case and worst case schedule) reports. The following set of instructions were provided. Moreover, a detailed geotechnical design scenario was presented (Basu, 1996) which is not included in this paper.

- **Geotechnical Design** - Pit geometry, haul road design and pit slope stability. **10 %**
- **Production planning and scheduling** - Provide a mining schedule using optimisation results (best and worst case). Discuss excavation and haulage procedures and equipment selection (fleet sizing). Provide sample blast designs for production and pit wall construction. Provide a

time-line schedule from start of mining to end of open pit life. **10 %**

### Phase 3: Final optimisation and Economic Analysis

- Use Whittle optimisation software incorporating the detailed engineering design for final economic analysis. You have to modify your parameter file to incorporate your geotechnical design and other mining and processing parameters. You have to incorporate your designed production figures (mining rate, milling rate) and cost of mining and processing cost ratio in proper places. **Run the FDAN module for only one price ie, AUD 525/oz.**
- Include results of the final analysis in the final report.

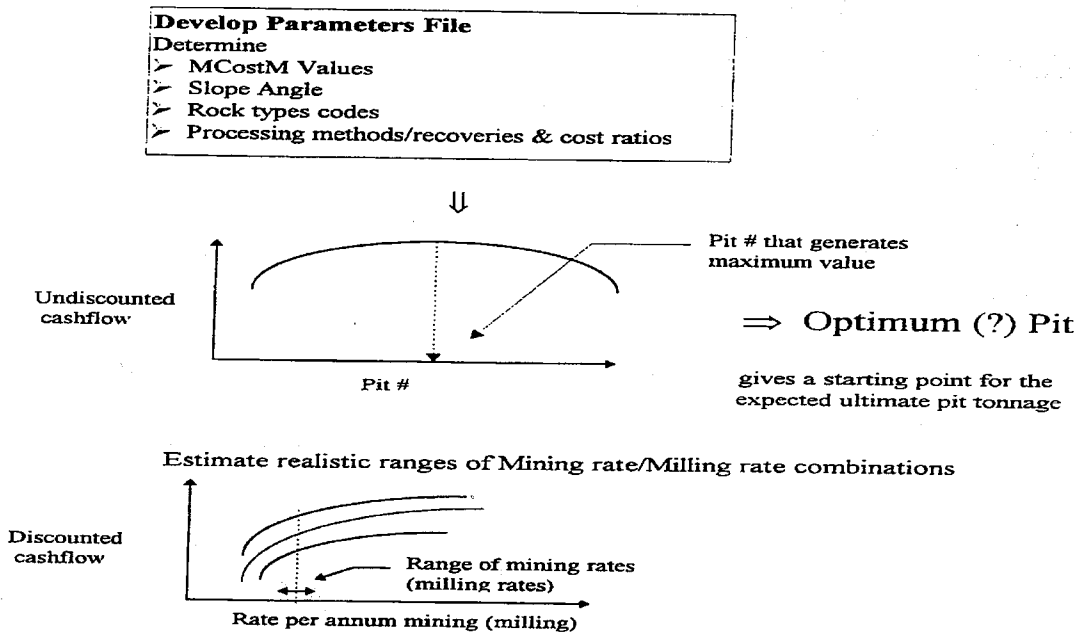
### Other Phases

- **Phase 4:** Transfer the optimisation results in DATAMINE/GUIDE and perform a pit design. Plot the final design a few representative sections (horizontal and vertical).
- **Phase 5:** Final Project Report.

### Examples of Students' Work

This section provides a few Figures illustrating the students' work (Belohlawek et al, 1996). Figure 1 provides a summary of optimisation procedure prepared by this student group (Belohlawek et al, 1996). This summary will be very useful to introduce the objective of optimisation using Whittle FOUR-D to the novice students. Figure 2 shows the nested pits for the orebody model created using the DATAMINE training dataset. Figure 3 shows a grade vs tonnage curve created using the FDUT module. Figure 4 through 6 shows results of the sensitivity analyses. Moreover, Figure 7 shows ore, waste tonnages and strip ratio. These figures demonstrate that students' project work covered the major aspects in open pit mine planning. They also created a mining schedule based on the FDAN output for the final analysis.

**Procedure for initialisation of an optimisation using Whittle 4D**



Re-run optimisation to investigate the effect of the above combinations on *discounted cashflow*.

A Optimum Pit is now defined by constraints of

- Mining Rate
- Milling Rate
- Capital Cost
- Discount Rate

These constraints allow the optimisation process to determine a *mine life* and thus enables the time dependent discounting of revenues and expenditures.

Further analysis would typically include evaluating sensitivities of

- Slope angle
- Inclusion/exclusion of ore types
- Variations in recoveries
- other

Figure 1. Summary of optimisation procedure using Whittle FOUR-D

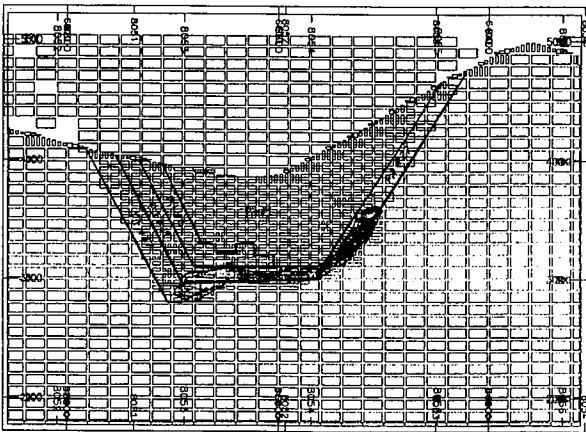
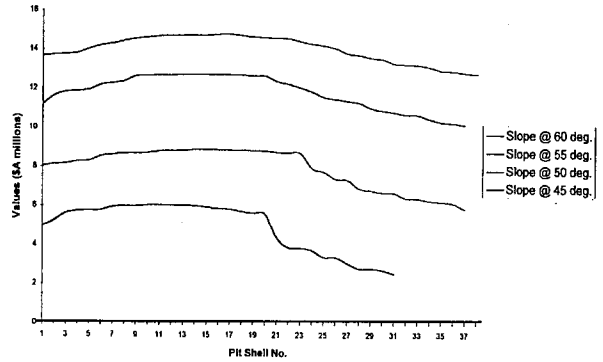


Figure 2. Orebody model and nested pits

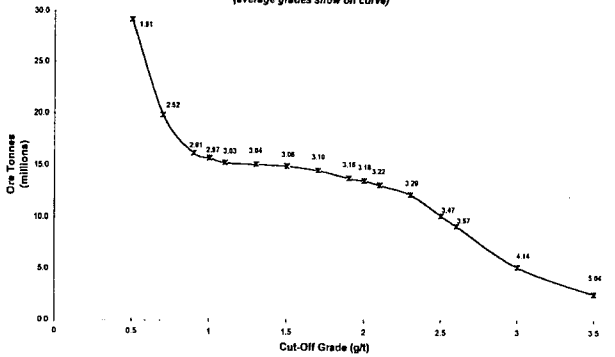
BEST CASE: NPV (Total discounted cash flow) vs Slope Angle Variation



\* BEST CASE Chart 2. 30/96

Figure 5. Slope Sensitivity

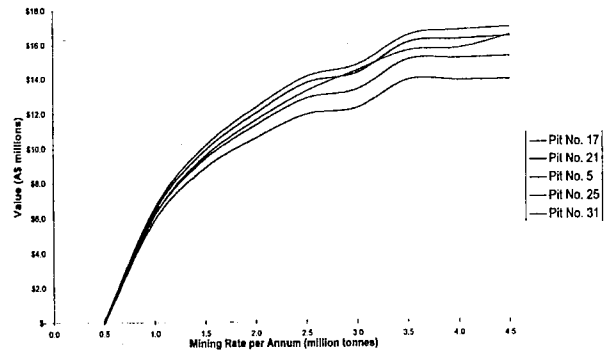
Ore Tonnage vs Cut-Off Grade  
(average grades show on curve)



\* Chart 1. 1/96

Figure 3. Grade-tonnage curve from FDUT

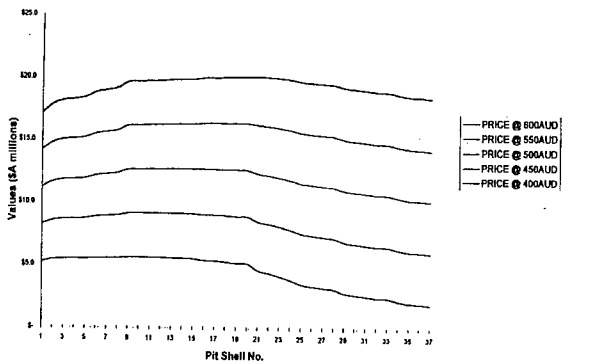
NPV vs Annual Mining Rate  
@ 0.5 MTPA milling rate



\* Chart 1. 1/96

Figure 6. Mining Rate Sensitivity

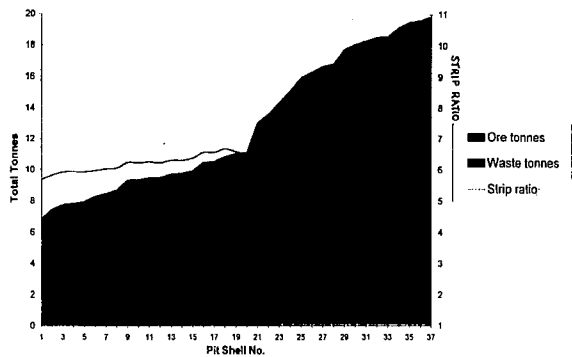
BEST CASE: NPV (Total discounted cash flow) vs Pit Number.



\* BEST CASE Chart 1. 30/96

Figure 4. Price Sensitivity

Ore, Waste and Strip Ratio vs Pit Shell Number  
(@ 626 AUD)



\* Pit 1. 1/96

Figure 7. Ore and Waste Tonnage, Strip Ratio

## Conclusion

The objective of this mine design project unit was to train the outgoing students with state-of-the-art mine design software and at the same time cover all the engineering design principles. That is why the orebody model was kept simple. A proven training model (DATAMINE) was used and optimisation run time on a standard PC was minimal (a few seconds). This feature allowed the students to concentrate on a variety of sensitivity analyses and evaluate a large number of economic scenarios.

The author noticed that students mostly have problems in creating the parameter file and the concept of MCOSTM takes some time to drive in. A more elaborate help feature in line of expert systems may serve as a good training medium to introduce the parameter file to the novice users.

## Acknowledgments

The author acknowledges the donation of Whittle FOUR-D software by Whittle Programming Pty Limited for student training at WASM. Moreover, Whittle Programming also arranged the initial training. Mr. Tom Tulp provided the valuable training to the author who in turn is providing the training to WASM mining engineering students. DATAMINE AUSTRALIA also provided the DATAMINE software and training to the author for using the software in teaching mine design students. The author is also fortunate to have the support of SURPAC Software International in having the SURPAC software available at WASM. Moreover, MAPTEK Pty Limited and Hamersley Iron Pty Limited recently donated the VULCAN system and six Silicon Graphics Personal Iris workstations for student training and use. The future training plan would include an option for the students in using any of these three mine design software packages as all these software packages have Whittle FOUR-D interfaces.

Moreover, the author is also indebted to Mr. Kapila Karunaratna (Senior Mine Planning Engineer, KCGM) for proof reading this paper and some valuable suggestions.

## References

- Basu, A., 1996, Lecture Notes: Mine Design Project 492, WASM, Curtin University, Kalgoorlie, WA.
- Belohlawek, S., Smith, M, Foster, C., and Ngo, B., 1996, Project Report: Mine Design Project 492, WASM, Curtin University, Kalgoorlie, WA.
- Golosinski, T.S., 1996, "Computer Education in Mining Engineering at WASM", Proceedings, 26th APCOM, The Pennsylvania State University, State College, Pennsylvania, Sept.
- Lye, G., 1996, Lecture Notes: Geotechnical Engineering in Mine Design, Mine Design Project 492, WASM, Curtin University, Kalgoorlie, WA.

## Appendix

This section includes additional detailed instructions to the students in converting the DATAMINE orebody model for use with the optimisation process.

### Guidelines for using the DATAMINE to WHITTLE FOUR-D interface (FDOUT)

The DATAMINE process FDOUT creates an ASCII file (e.g. **test.mod**) for a block model (e.g. **valmod.dm** created using DATAMINE). The model file to be used by the optimisation software must have the following information:

- Block coordinates
- Number of parcels (e.g. no. of subcells per parent cell of ore blocks)
- Mining cost adjustment factor flag (0 to ignore it, 1 to use it)
- Processing cost adjustment factor flag (0 to ignore it, 1 to use it)
- Total tonnes of rock in the block.

If a block contains parcel(s) (subcells) then the information for parcel(s) follows. Each parcel has the following information:

- Block coordinates (IX,IY,IZ)
- Rock type code for the parcel (Alpha-numeric, 1-4 characters)
- Tonnage of the parcel
- Metal content (not grade) of the parcel.

In our current exercise, the **airmodel.mac** macro uses the DATAMINE model file **model.dm** (created using training macro **train.mac**) to add air blocks (blocks with density = 0) and creates another DATAMINE model file **airmodel.mac**.

#### Listing of the macro airmodel.mac:

```
!START AIRMODEL
!DDCOPY &IN(MODEL),&OUT(TMP1)
!PERFIL &PROTO(TMP1),&MODEL(TMP2),@MODE=0.0,@PLANE=1.3582E-19,
  @ZONE=0.0,@OPTIMISE=2.0,@FULLCELL=0.0,@XSUBCELL=1.0,
  @YSUBCELL=1.0,@ZSUBCELL=1.0,@RESOL=0.0,@OVCHECK=1.0
!GENTRA &IN(TMP2),&OUT(TMP3),@ECHO=0.0
SETC
DENS
0
END
Y
!GENTRA &IN(MODEL),&OUT(TMP4),@ECHO=0.0
SETC
DENS
2.7
END
Y
!ADDMOD &IN1(TMP3),&IN2(TMP4),&OUT(AIRMODEL),@TOLERNCE=0.001
!END
```



Another macro **fddata.mac** is used to create the necessary fields (required by the optimisation software Whittle FOUR-D) for rock tonnage (**RTON**), tonnage of parcels (**PTON**), metal content (**METAL**), mining and processing cost adjustment factor flags (**MCAF** and **PCAF**). Moreover, the rock type codes 6 and 8 are converted from numeric to alphanumeric (this conversion of data type is required in this case, because numeric type was used in the initial modelling). This macro **fddata.mac** uses the file **airmodel.dm** as the input file and creates an output file **valmod.dm** with necessary fields. **You may change the relevant input and output file names if you want to, but be careful in making proper changes.**

Listing of fddata.mac macro:

```
!START begin
!GENTRA &IN(airmodel),&OUT(valmod),@ECHO=0.0
MUL VOL XINC YINC
MUL VOL VOL ZINC
MUL RTON VOL DENS
THIS PTON RTON
MUL METAL AU RTON
SETC MCAF 1
SETC PCAF 1
ENCN AROCK 1 1 ROCK 0
END
Y
!END
```

To run the FDOUT process, follow the following steps:

- Start DATAMINE if you are not already in DATAMINE
- Type in the process name FDOUT to start this process
- Enter **VALMOD** as input file name
- Do not change the parameter TOLTON (default = 0.5). This value controls parcel output. A parcel output is written if only the parcel tonnage is more than the parameter TOLTON.
- Change the parameter FORMAT to use value of **1.0**. This change will write the output model file (ASCII) in comma separated format (this process saves valuable storage space)
- Start the process. The following prompts will appear (example responses are shown in *italics*):

Enter FOUR-D parameter file name:

**SYSFILE> *test.par*** Note: This file is written in C:\DMDATA directory and contains only two lines providing block and model size information. Do not use this file as a parameter file for optimisation. View it only to get information on block and model size information.

Enter FOUR-D model file name:

**SYSFILE> *test.mod*** Note: This file is also written in C:\DMDATA directory. Copy this file to the FOUR-D working directory C:\4D\TUTOR after this process is completed. This file is used as the model file for the optimisation process.

There are two methods of specifying parcel fields:

**Method A:** A parcel type code and two numeric fields, for tonnes and metal content, are specified for each possible parcel type.

**Method B:** Three fields are specified. One contains the parcel type. The other two are numeric and contain the tonnes and metal content.

Product parcel specification method A/B [B]>B

Maximum number parcels [50]>50

Merge identical product parcel types Y/N [N]>N (This is default option, you may use option Y)

The fields available for selection are:

ROCK	AU	NO.SAMP	ZONE	DENS	VOL
RTON	PTON	METAL	MCAF	PCAF	

Field for ROCK tonnes >RTON

The fields available for selection are:

ROCK	AU	NO.SAMP	ZONE	DENS	VOL
PTON	METAL	MCAF	PCAF		

Mining cost adjustment field >MCAF

The fields available for selection are:

ROCK	AU	NO.SAMP	ZONE	DENS	VOL
PTON	METAL	PCAF			

Processing cost adjustment field >PCAF

The fields available for selection are:

ROCK	AU	NO.SAMP	ZONE	DENS	VOL
PTON	METAL				

Field for tonnes >PTON (This is parcel tonnage)

Field for metal content >METAL

The fields available for selection are:

AROCK

Field for product parcel type >AROCK

The fields used are as follows:

ROCK field = RTON (Note: Do not get confused by an existing field ROCK. In this case the left hand side item ROCK field is the field store rock tonnage in a block)

Type = AROCK

Tonnes = PTON

Metal = METAL

Accept this data specification Y/N [Y] >Y

Reading the blocks and writing the FOUR-D model file:

```
>>> 80,500 RECORDS WRITTEN:          TIME  . . . . :
      80,900 records read
      70,000 blocks written
      1,016 product parcels written
```

The maximum number of product parcels in a block was 50 (Note: At this point FDOUT process is completed and **Press enter to return to DATAMINE menu**)

- Quit DATAMINE, and copy the ASCII model file (eg. test.mod) to C:\4D\TUTOR directory.

### Checking the model file using utility routine FDUT

- Start FOUR-D software. Go to the utility routine to run FDUT program. The following prompts will appear:

Please enter a name for the print file

[fdtut.pru]: test (Note: This process creates a text file test.pru)

SELECT MAIN OPTION

- Summarise a data file
- Show block value calculation
- Show FOUR-D system limits

Your choice: 1 (Note: Also use option 3 to check limits of FOUR-D)

SELECT FILE TYPE

- Use Model File
- Use Results File
- Use Mining Sequence File

Your choice: 1

Please input the name of the model file

[fdtut.mod]: test (Note: This is the model file you created using the DATAMINE process FDOUT)

SELECT TYPE OF FILE SUMMARY

- Counts only
- Distribution graph only
- Both counts and graphs

Your choice: 3

Rock types may be excluded from the summary.

Enter a list of rock type codes to exclude (separated by a space)

or leave blank for no exclusions: **Press enter**

Cut-off grade below which parcels are to be ignored

[0.0]: **Press enter** to accept default. You may also play with this parameter.

Try to see what happens if you use cut-off grade 1.0 g/t

Do you want to output data for spreadsheet use (Y/N) [Y] ? N (You may also use Y option and enter a spreadsheet file name. Then you will be able to import it to a spreadsheet (e.g., EXCEL)

A grade distribution will be produced for the ENTIRE ore body. Do you also wish to produce distributions by

Each Rock Type (Y/N) [Y] ? Y

Each Bench .... (Y/N) [Y] ? Y

Do you wish to use constant histogram scaling (Y/N) ? Y (May use option N and see what happens).

At this time the FDUT process will read the model file and create an output file **test.pru**. View or print this file (Note: all the files created in FOUR-D are in the working directory C:\4D\TUTOR). Report on information available from this file. Reserve information obtained from FDUT should also be checked against reserve estimation obtained from DATAMINE before proceeding with optimisation.

### Create a Parameter file for the orebody model

- View the parameter file created during the FDOUT process (the file is in C:\DMDATA directory). This file contains block size and model dimensions. Use this information to create a parameter file as outlined and demonstrated in the tutorial session of August 8, 1996. Slope information should match with the assignment requirements as listed in the unit outline.
- This parameter file contains 50 blocks in Z direction and it is obvious from the FDUT output of the model that the benches 1 to 25 are waste only. Therefore, the reblocking process of FOUR-D software should be used to delete these waste cells.

### Reblocking of the model file using FDRB program

The Reblocking process allows you to change model geometry and create a new pair of model and parameter files. Moreover, this module is also used to add positional mining cost adjustment factors. Study the tutorial 4 - rearranging a model section very carefully.

- Start Reblocking option from the main menu. Enter print file name and parameter file name. Respond yes (y) at the prompt for changing the size or position of the model. Next prompt will

be for new model framework. Accept defaults for X and Y directions and enter 25 for Z direction (new model will have only 25 benches as benches 1 - 25 will be deleted).

- Enter model file name at next prompt. You will be asked to provide offset information and accept defaults for X and Y direction and - 25 for Z directions (deleting of benches 1 - 25).
- Accept defaults for all following prompts until a prompt for new model file name appears. Supply a file for the revised model. Respond yes for the new parameter file and enter a new name. The program will stop at point and a new set of model file and parameter file will be available. View the parameter file and note the revisions.

### Optimisation and Analysis

You need to create structure arcs, optimise and run analysis routines to complete the preliminary feasibility assignment. The steps are very similar to Tutorials 1 and 2 of the user manual.

#### Some useful tips:

- Remember to run structure arc and reoptimise every time you change the slope information in the parameter file.
- You have to run the structure arc program prior to the optimisation run. Note the slope error reported (view **.prs** file). Revise the number of benches for structure arc generation to keep this error within 2%.



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