Planning and Forecasting Stope Production

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SYNOPSIS

In this paper a discussion is presented of a program designed to produce a 40-day production forecast for an underground stoping system.

The program is intended to be a tool for the operations department in an underground mine, and is designed to utilize data readily available from production reports. Brevity of data input, ability to revise stope conditions easily and the accuracy of starting stope status are stressed. Applicability of the program to a wide variety of stoping methods makes the program potentially useful in a large number of mines.

The general functions of the program subroutines, and input and output lists are discussed. An example is also given of a stope in operation for a three-day period, which shows how the program can handle production irregularities as they arise.

INTRODUCTION

In only a few instances have computers been utilized efficiently as operating tools in underground mining. This is due in part to an often justified suspicion on the part of mine operators of the accuracy of computer-aided scheduling. A more serious difficulty is that underground mine scheduling involves the consideration of a large number of non-routine problems, and to input all these to the computer often proves more difficult than doing the job manually. Nevertheless, a large number of mines do need to have some system to forecast and control stope grade and tonnage; for examples see Connell (1970), Parker (1969), Russell, *et al* (1970), Sloane (1969) and Thompson (1971). Planning is also necessary in mines which require stope support and which have a limited filling capacity.

There was, therefore, a need to provide a schedule created by a computer which would present, in a readable form, summaries of tonnage, grade and fill requirements. The schedule would allow for accurate update of the stope status at the beginning of the period and adjust to changes in stope activities during the period. Ordinarily, for a mine with a large number of operating stopes, this would require considerable manpower and the attention of production department personnel whose time is better spent on operating problems.

Keeping in mind these considerations, this program is designed to:

(i) utilize data generally available from shift boss reports,

(ii) accept these data in a form which can be extracted and prepared easily by clerical personnel,

(iii) allow for easy revisions of data defining the engineering efficiencies and geological conditions of the stope,

(iv) provide flexibility with respect to stope conditions and methods, and to

(v) provide forecasting and planning capability.

The program considers a 40-day production period for which it outputs the tons mucked or filled daily in each stope, along with a symbol indicating the operation in progress. The forecast period of 40 days was chosen to provide adequate time to cover a typical contract month. However, it can be lengthened or shortened according to need. In most cases the program will find its primary use in providing a short-term forecast of production bottlenecks. The program also provides a valid and rapid means for arriving at monthly production forecasts and for examining even longer-term production patterns. In these cases, it need not be run daily, since up-dating of stope status can be done on a weekly or monthly basis with the same one or two cards required on a daily basis.

Figure 1 shows the first 20-day segment of a typical output. Numbers in the body of the table indicate tons mucked or filled (followed by the letter F or M). Other letters in the table indicate that the stope was in another operation: Fill Preparation (FP), Downtime or other preparation (D), an 'M' without tonnage indicates that the entire shift was spent drilling or completing a preparation cycle, 'S' and 'H' indicate weekends and holidays. A summary in the lower part of the table shows total tons mucked and filled, and average grade of ore mucked (this could be expanded easily to include more than two metals). Stope No. 7 was a new stope which was not scheduled to come into operation until April 18, and stope No. 19 was shut down for most of the period.

PROGRAM LAYOUT

The program is written in Extended FORTRAN IV for the XDS Sigma 7 computer. It consists of a main subprogram and three subroutines. The main subprogram initializes all arrays to zero and then calls the three subroutines in order.

Subroutine calendar

The first subroutine, CALENDAR, generates a 40-day production calendar. In the array NUMDAY, it stores a value for each day, specifying whether it is a working day or holiday. In the array NOWDAY, it stores the calendar date of each of the next 40 days. Input variables include holidays during the year and working status of weekend days.

Subroutine status

The second subroutine, STATUS, performs three functions: it reads and checks for errors in daily production input data; it calculates a list of variables which indicate the up-to-date status of the stope at the beginning of the forecast period; it outputs a list of these status variables for visual verification.

The emphasis in STATUS has been placed on ease of data input by the production staff, and on correction of erroneous or contradictory data. Input from the production staff consists of only three items for each stope, which normally appear on shift boss reports. These are:

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(i) the task in progress at the end of the shift,

(ii) the hours remaining to complete this task or hours spent on the task during the shift, and

(iii) the tons or length of round blasted during the shift.

In addition, the mine department can input non-routine downtimes which are expected to occur during the forecast period.

To accomplish its task with this minimum of input data, the subroutine is required to maintain a status listing which it updates from the daily production input cards. Such a system could lead to discrepancies between the actual and calculated performance of the stope. To correct such discrepancy, STATUS notes deviations which occur near the end of each cut and updates itself accordingly. If there is a conflict between calculated stope status and mine department input, STATUS outputs a warning message and accepts the input of the mine department as valid. Mine department input for a typical day during which seven stopes are operating is shown in Fig. 2, along with several of the possible warning messages.

Subroutine forecast

The third subroutine, FORCAST, calculates a 40-day production schedule for each stope and tabulates the results showing total tons mucked, average daily grade and total tons filled (Fig. 1).

The subroutine functions by calculating stope operations on a daily basis (it is currently set up for one shift per day operation). At the start of each day, it determines:

(i) the operation in progress (drilling, mucking, fill, fill preparation, drill preparation, or downtime),

(ii) the time left to complete this operation, and

(iii) whether a cut will be completed or whether a change in operation will occur during the shift.

It then proceeds to calculate the time spent on each task during the shift. Up to two rounds per shift can be drilled and blasted and then mucked. Alternatively, one round could be spread over several days. If a cut, fill, or preparation cycle is completed during the shift, the next operation is started. At the end of the shift, tons mucked or tons filled are tabulated, and counters which indicate the time remaining to the current operation are set for the next day's run.

ADAPTABILITY OF THE PROGRAM

Thirteen variables are assigned to each cut within a stope. Standard values are assigned by default if specific inputs are not entered. Eleven of these variables are shown as the standard INDATA values in Fig. 3; the other two variables are cut length and cut width.

Another significant 'variable' which expands the use of the program is the definition of the word 'cut'. If the stope is uniform laterally, each cut would normally be a lift, followed by a fill prep and fill cycle. If significant lateral variations occur, such as changes in ore grade or size, lenses of waste, changes in production efficiencies, and so on, then each lift can be separated into two or more cuts.

Figure 5 shows a typical layout for a cut-and-fill stope, and shows one of the possible ways in which the cuts can be numbered. In the stope, a fill cycle has just been completed, and one round has been blasted from cut number 21.

The stope outlines are so variable that one cut, number 23, has not yet been entered. It will probably be formed by revising the size of cuts 22 and 24. Because the stope is so narrow at this point, cut 23 could easily be included as waste material, and would in that case have different mucking efficiencies and a grade of 0 per cent metal attached to it.

Note here that the fill line is being carried one lift below the back. The option can be changed to carry the fill flush with the back, which would be important, for instance, if the program were used to schedule an undercut-and-fill stope. This variable, along with many others, can be set differently for each stope in the mine and each cut in the stope so that different mining methods in different parts of the mine can all be forecast during the same scheduling run.

The combination of these factors allows direct application of the program to not only all variations of the cut-and-fill method, but to systems other than cut and fill. Overhand stoping, undercut and fill, sub-level stoping, and even room and pillar mining, can all be calculated. Furthermore, if stopes of all these different types occurred in the same mine, the forecast tabulation would include accurate schedules for each.

The only serious limitation of the program as it now stands is that once the mucking cycle is started the entire tonnage blasted is mucked out; this means that it cannot be applied to such methods as shrinkage stoping, in which ore is pulled only partially after blasting. Expansion of the program to eliminate this problem is under consideration.

	APR																			
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
2	24 M	48 M	28 M	20 M	F	S	S	H	M	41 M	45 M	28 M	S	S	31 M	52 F	160 F	160 F	160 F	S
5	96 M	66 M	30 M	74 M	22 M	S	S	H	D	D	96 M	8 M	S	S	88 M	16 M	80 M	24 M	72 M	S
6	48 M	27 M	21 M	19 M	29 M	S	S	H	FP	160 F	160 F	160 F	S	S	119 F	D	M	24 M	24 M	S
7	D	D	D	D	D	S	S	H	28 M	39 M	60 M	40 M	S	S	58 M	42 M	56 M	44 M	54 M	S
11	60 F	140 M	D	10 M	FP	S	S	H	160 F	160 F	160 F	119 F	S	S	D	14 M	46 M	47 F	160 F	S
14	14 M	14 M	14 M	14 M	14 M	S	S	H	D	M	24 M	24 M	S	S	24 M	24 M	FP	F	M	S
19	48 M	D	D	D	D	S	S	H	D	D	D	D	S	S	D	D	D	M	65 M	S
TOTAL MKD	230	155	93	137	65	0	0	0	28	80	225	100	0	0	201	96	182	92	215	0
AV OZ AG	3.69	3.07	3.10	3.56	4.00	.00	.00	.00	4.00	2.46	3.40	3.16	.00	.00	3.54	4.00	4.00	4.00	4.00	.00
AV % CU	1.81	1.50	1.50	1.50	1.50	.00	.00	.00	1.50	1.50	1.50	1.50	.00	.00	1.50	1.50	1.50	1.50	1.95	.00
TOTAL FLD	60	140	0	0	0	0	0	0	160	320	320	279	0	0	119	52	160	207	320	0

Fig. 1. Twenty-day stope schedule.

For the stopes listed in the far left column, numbers in the body of the table indicate tons mucked or filled, followed by a letter specifying the operation in progress. Daily summaries and grades are tabulated below the stope output.

YESTERDAY'S PRODUCTION – MINE DEP'T DATA

5 14 3 0123

THE ABOVE YESTERDAY'S PRODUCTION CARD PUNCHED WRONG. THIS CARD HAS BEEN IGNORED.

7 4 1 0 0

DRILLING OR MUCKING IS INDICATED FOR STOPE NO. 7 WHICH WAS IN THE FILLPREP CYCLE OR IN WHICH FILLING WAS NOT COMPLETED. FILLING OR FILLPREP WAS TERMINATED AND DRILLING WAS STARTED ON CUT NO. 8.

6 8 5 0 0

PRODUCTION CARD FOR STOPE NO. 6 INDICATES FILLPREP BEFORE CUT NO. 4 HAS BEEN COMPLETED. CUT NO. 4 HAS BEEN TERMINATED.

PRODUCTION CARD FOR STOPE NO. 6 INDICATES FILLPREP FOR NON-DIMENSIONED CUT. THIS OPERATION WAS IGNORED AND DRILLING HAS BEEN STARTED ON A NEW CUT.

2	4	3	120	0
14	9	0	0	0
11	9	12	5	0
12	12	12	0	0

Fig. 2. Yesterday's production data.

Typical cards are shown for the seven stopes exhibited in Fig. 1. Usually only one production card per day per stope is needed. For instance, the card for stope No. 2 indicates 120 tons were blasted during the shift, and 3 hours remained before blasting the next round. The card for stope No. 6 is the April 14 input mentioned in the text example.

INDATA – STD VALUES FOR ALL STOPES

1 ROUND LENGTH = 8
2 CUTHEIGHT = 6
3 CUT WIDTH
4 CUT LENGTH
5 GRADE CU, % × 10 = 15
6 GRADE AG, OZ × 10 = 40
7 TONNAGE FACTOR (CU FT/TON × 10) = 100
8 FILL PREP TIME/CUT = 9 HRS
9 OTHER PREP TIME/CUT = 13 HRS
10 FILL RATE, CU FT PLACED/HR = 40
11 PROD EFF, TONS/DRILL SHIFT = 100
12 RESERVED FOR PROGRAM USE
13 PROD EFF, TONS/MUCK SHIFT = 100
14 CUT TO BE FILLED IS CUT FINISHED BEFORE CUT JUST MUCKED

ENG & GEOL DATA INPUT

STOPE NO	CUT NO	FUNCT	QUANT
6	3	3	10
6	3	4	10
6	4	3	10
6	4	4	20
6	5	3	5
6	5	4	30
6	6	3	10
6	6	4	20
11	9	3	10
11	9	4	10
11	10	3	10
11	10	4	10
11	11	3	10
11	11	4	10
6	5	11	30
6	4	11	30

Fig. 3. Engineering and geological data input.

Standard values are shown in the top part of the figure. Specific values for cut width and cut length are shown in the bottom part of the figure for stopes 6 and 11. Also, the drilling efficiency for stope 6 has been changed to 30 tons per shift. These values are those used for the output exhibited in Fig. 1.

STOPE NUMBER = 6
CUT IN PROGRESS = 4
TONS REMAINING IN CUT = 120
TOTAL STOPE TONS BROKEN = 120
TOTAL STOPE TONS HAULED = 105
STATUS AT END OF SHIFT = 5
HRS DRILLING REMAINING = 1

STOPE NUMBER = 11
CUT IN PROGRESS = 10
TONS REMAINING IN CUT = 40
TOTAL STOPE TONS BROKEN = 2304
STATUS AT END OF SHIFT = 9
STOPE WAS DOWN AT END OF SHIFT. 5 HRS
DOWNTIME REMAINED PLUS OTHER HOURS SHOWN.
HRS FILLING REMAINING = 10

Fig. 4. Summary of current stope status

This figure is a partial list showing the starting status of two of the stopes for the forecast period in Fig. 1. This conversational listing is output by STATUS for visual confirmation. The data are transmitted to FORECAST in list form, which is also printed out. If errors occur they can be corrected by submitting cards directly to FORECAST.

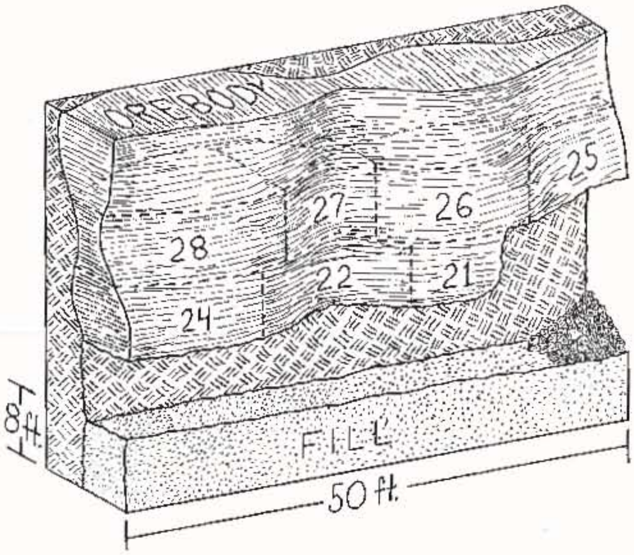

Fig. 5. Cut-and-fill stope showing typical choice and numbering of cuts.

INPUT DATA DECKS

Eight input data decks are required by the program. These are:

First day of the year (1 card). This card indicates the day of the week of the first day of the year, for use in CALENDAR.

Leap year option (1 card). This card is blank for a normal year.

Today's date (1 card). This card contains the calendar month followed by the date.

Dates of holidays (multiple cards). Each card contains the dates of holidays and the holiday code. This deck can also be used to change specific weekend days to working or to non-working status.

Weekend day status (1 card). This card contains two codes which indicate whether Saturdays and Sundays are working or non-working days.

Standard engineering and geological values (1 card). This card sets the standard or default values of the 13 cut variables listed earlier in the text.

Specific engineering and geological values (multiple cards). These cards are used to set the length and width of each cut, and to input non-standard values for any of the other cut variables.

Forecast downtime (multiple cards). Each card contains a date (month and day), a stope number, and the number of hours a stope will be down on that day. A value exceeding eight hours will result in downtime being carried over to successive days.

Stope status (multiple cards). This deck indicates the current status of the stope at the start of the production period. This deck is generated by the Status Subroutine for use in FORECAST, and in practice would probably be input and output onto a tape unit. Programmer operator input to this deck would occur only when a stope is being started or temporarily discontinued.

Mine department production data (multiple cards). One card containing three to five values would be input for each working stope. Data would originate from the previous day's production reports.

PROGRAM OUTPUT

The program output consists of nine tabulations:

Table 1. Standard engineering and geological values (this listing is shown in Fig. 3).

Table 2. Specific input of engineering and geological values (a partial listing is shown in Fig. 3).

Table 3. Listing of input values of future projected downtime.

Table 4. Status input values (computer-generated values of current stope status from the previous day).

Table 5. Previous day production data. A listing of data input by the production staff. Messages appear in this list when input differs from theoretical stope status. (A partial listing is shown as Fig. 2.)

Table 6. Current stope status. A conversational listing of the stope status as updated by the STATUS subroutine. (A partial listing is shown as Fig. 4.)

Table 7. Stope status card deck output list. A complete listing of the card deck output list generated by STATUS for use on the following day. This is also a tabulation of the data transmitted internally to the FORECAST subroutine.

Tables 8 and 9. The actual stope production forecast divided into two 20-day segments. A partial list is shown as Fig. 1.

EXAMPLES OF PROGRAM OPERATION

In order to understand the implementation of the program better, an example of a typical mining stope (Stope No. 6) will be followed for several daily cycles, and production department input will be shown. Figures 3 and 4 show the initial input data for this stope, and the current status listing for this stope as of Monday, April 10, 1972. Twenty days of the 40-day production forecast starting April 10 are shown in Fig. 1, along with several other stopes active during this period. In the discussion that follows an attempt is made to indicate how several routine operating problems which arose on subsequent days would be 'explained' to the computer.

On April 10 the stope was down for two hours, otherwise work proceeded as scheduled. One round estimated at 55 tons had been fired during the shift. At the end of the shift, mucking had been almost completed on this round, and the shift foreman estimated that two hours mucking remained. It was learned that the miner assigned to this stope would be off work the following Monday (April 17), and that the stope would be shut down for new chute installation on Wednesday, April 19. Input data for this day are as follows: Stope status card, *6, 5, 2, 55* (stope No. 6 had two hours left to complete operation No. 5 (mucking); 55 tons had been blasted during the shift); and forecast downtime cards, *4, 17, 6, 8* and *4, 19, 6, 8* (on April 17, and again on April 19, stope No. 6 would be shut down for the full shift of eight hours).

On April 11 drilling equipment had broken down, and at the end of the shift it was estimated that three hours of drilling remained on the round, but that repairs would take another two hours of the next shift. Two stope status cards were input, *6, 9, 2* and *6, 4, 3*. These indicated the hours left to the 'tasks' of downtime (9) and drilling (4), respectively.

On April 12 it was decided that because of grade problems the present cut (No. 4) would be terminated, even though it had not been mined to completion. It was also decided that the two cuts immediately above the present cut would be reduced to one-half of their previous width. The stope status card for this day read *6, 8*, indicating that at the end of the shift stope No. 6 had entered the 'fill-prep' cycle. On receiving this input for the morning's run of April 14, the program printed a message saying that it had entered the 'fill-prep' cycle before completion of a cut (shown in Fig. 2). Dimensions of cut No. 4 (for use in the fill cycle) and of cuts Nos. 5 and 6, were also changed; these changes were made in the specific engineering and geological data input deck by adding three cards at the end of the deck: *6, 4, 4, 10*; *6, 5, 3, 2, 5*; and *6, 6, 3, 5*.

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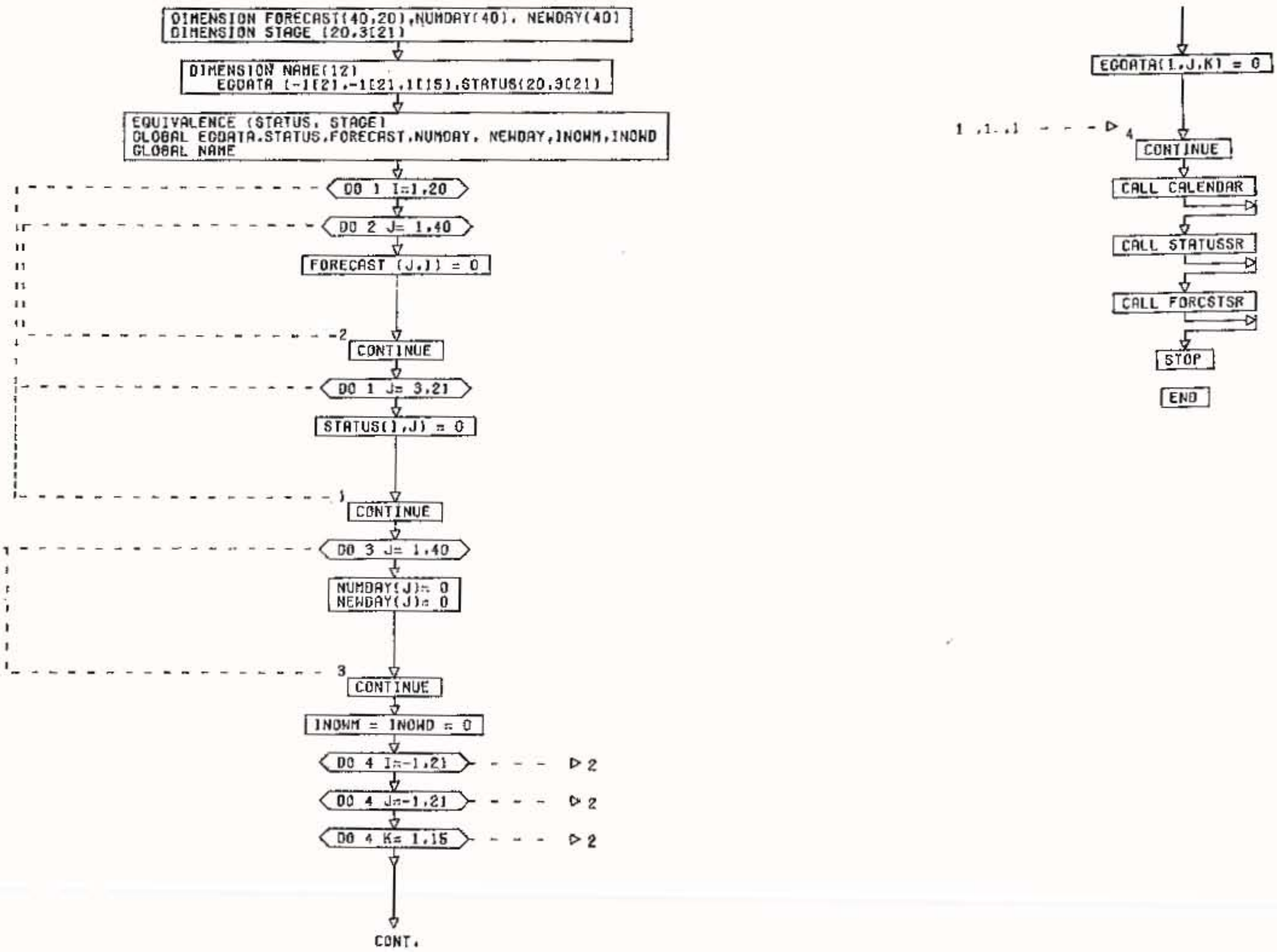
Appendix A



DIMENSION FORECAST(40,20),NUMDAY(40), NEWDAY(40)
DIMENSION STAGE (20,3[21])
DIMENSION NAME(12)
EGDATA [-1[2],-1[2],1[15],STATUS(20,3[21])
EQUIVALENCE (STATUS, STAGE)
GLOBAL EGDATA,STATUS,FORECAST,NUMDAY, NEWDAY,INOWM,INOWD
GLOBAL NAME
DO 1 I=1,20
DO 2 J= 1,40
FORECAST (J,I) = 0
2
CONTINUE
DO 1 J= 3,21
STATUS(I,J) = 0
1
CONTINUE
DO 3 J= 1,40
NUMDAY(J)= 0
NEWDAY(J)= 0
3
CONTINUE
INOWM = INOWD = 0
DO 4 I=-1,2
DO 4 J=-1,2
DO 4 K= 1,15
2
2
2
CONT.
EGDATA(I,J,K) = 0
1 ,1, ,1
4
CONTINUE
CALL CALENDAR
CALL STATUSSR
CALL FORCSTSR
STOP
END