Computer Modeling of Underground Mine Production Systems

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ABSTRACT

This paper addresses three approaches for modeling underground mining production systems based on alternative requirements for different levels of planning. The first approach relates to time step simulation of face operations in which the system state is observed several times per minute, which is a very high level of detail appropriate to modeling one or two shifts.

The second approach uses analytical equations to estimate machine place time and a critical path to describe machine place interactions over several cycles of a cut plan, or perhaps 50 to 100 shifts or more. This is appropriate for investigating stochastic behavior and machine failure-repair mechanisms.

The final model addresses full mine life planning over periods of perhaps 5 to 20 years. A mine strategy tree and equipment pool are processed in event step sequence to analyze equipment utilization, advance and production rates, and long term economics of mining. The models are compared over a range of problems.

INTRODUCTION

Underground room-and-pillar mining is a multi-cyclic process with repetition of cycles occurring at many levels. Face operations include cycles for each machine type—drilling, blasting, loading, haulage—at each operating face. The faces are worked in sequence, providing a second cycle to the process, as the sequences are repeated. Panels are developed and mined within the context of an overall mine plan, which is again cyclic in nature. Main haulage tunnels and airways are developed in order to achieve access to the ore body, and production faces or panels are initiated and repeated to follow the development cycle.

In evaluating the mining process, the unit of production that is to be analyzed may be considered at several levels of detail. The industrial engineer may be concerned with unit operations for the face production system, where vehicles for hauling rock have payloads of perhaps 5 to 50 tons and cycles ranging from 5 to 30 minutes. The process of loading and hauling is modeled by tracking these payloads as they move from the working face to the mine haulage system.

A systems analysis of the production cycle is conducted by analyzing the interactions among machines and working faces. The appropriate unit of production is the tonnage in a lift, perhaps 100 to 500 tons and a time cycle of perhaps 30 minutes to two hours. This decreased level of precision is acceptable because the modeling approach adds new information on the interactions among additional system components, providing a broader view of the process.

The process of mining a complete panel consists of taking a large number of lifts in the sequence which has been identified by the mining plan. In the overall scheme, development and production panels are mined in pre-defined sequences, making the per-shift tonnage the appropriate unit of production. Interactions among panels that utilize available equipment and extend the mine geometry are analyzed at this level, with panel production tonnages of perhaps 200,000 to one million tons with a time period of three months to perhaps one year. Again, the added visibility and scope of this level of analysis requires two levels of production, the panel tonnage and a daily or per shift production rate, perhaps several hundred to several thousand tons.

A mine life represents the ultimate level of a mine planning project. Annual production of perhaps two to twenty million tons and lifetimes of 20 to 30 years are typical. Under these conditions, the panels and annual production levels become the planning parameters. Integration of labor, machines, supplies, power and maintenance resources as well as their associated costs become the issues at this level of planning.

Over a period of eight years KETRON has developed a computerized modeling and data management system to address the set of problems that span this spectrum of production levels and time lines. These models consider the unit operations relating to each machine process step at one end of the spectrum to the annual production profiles and line item costs associated with each year of a mine's life. The information bases required to operate the system are integrated so that lower level analyses are used to provide input to subsequent steps at higher levels and broader planning horizons.

THE SYSTEM OF MODELS

The set of models that are applied to mine production planning is structured as in Figure 1. At the bottom of the hierarchy is an industrial engineering system to acquire and analyze the unit operations for each machine type which is employed. The top of the structure provides the overall costs and resources which are consumed in achieving the mine production levels. A description of each of the models is provided in the left hand column of Figure 1.

MINIE

The mining industrial engineering system is a sequence of programs which is used to assist in managing and analyzing time study data. The basic building block of the system is a machine process flow diagram which describes the sequence of unit operations performed by a machine in working a face. An example of a process flow diagram for a roof bolting machine is illustrated in Figure 2. Similar diagrams have been developed for face drills, LHD's, continuous miners, longwall systems and other underground mining machines.

The process flow diagram describes the sequence of machine operations in terms of events and activities. An event is a point in time, while an activity consists of two events that define the start and end of the activity. The approach is borrowed from the conventional critical path planning

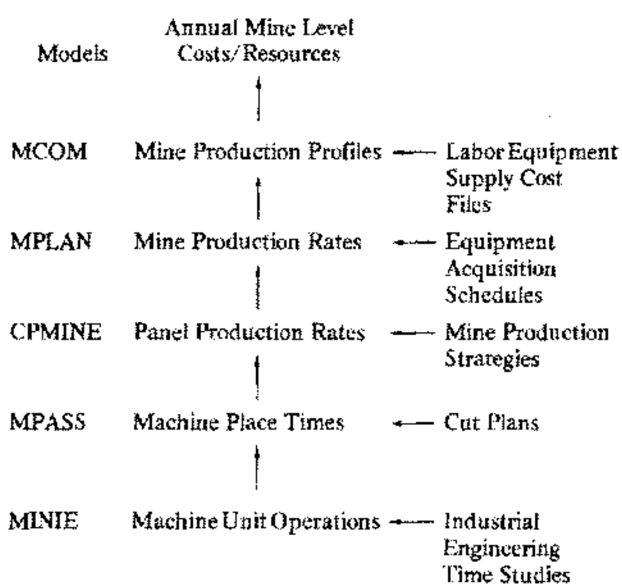


Figure 1. Modeling System Structure.

(CPM) method, but the diagrams contain loops to define repetitive, cyclic operations which are not a part of the CPM approach.

An industrial engineer expects to see the process occur in accordance with the network diagram. Usually, several cycles of the process are observed in order to formulate the process flow diagram. As a consequence, the observer is prepared to record the operational data in conjunction with the elements in the process flow diagram. To do so, a tape cassette recording technique has been employed in which the necessary process elements are voice recorded by the observer. This recording is transcribed later and converted into machine readible data in accordance with the following code:

Characters	Meaning	Example	Code
1	Machine Code	Roof Bolter	R
2–3	Location	Entry Four	40
4–5	Event	Start Drilling	06
6–11	Time	Hrs., Min., Sec.	091533

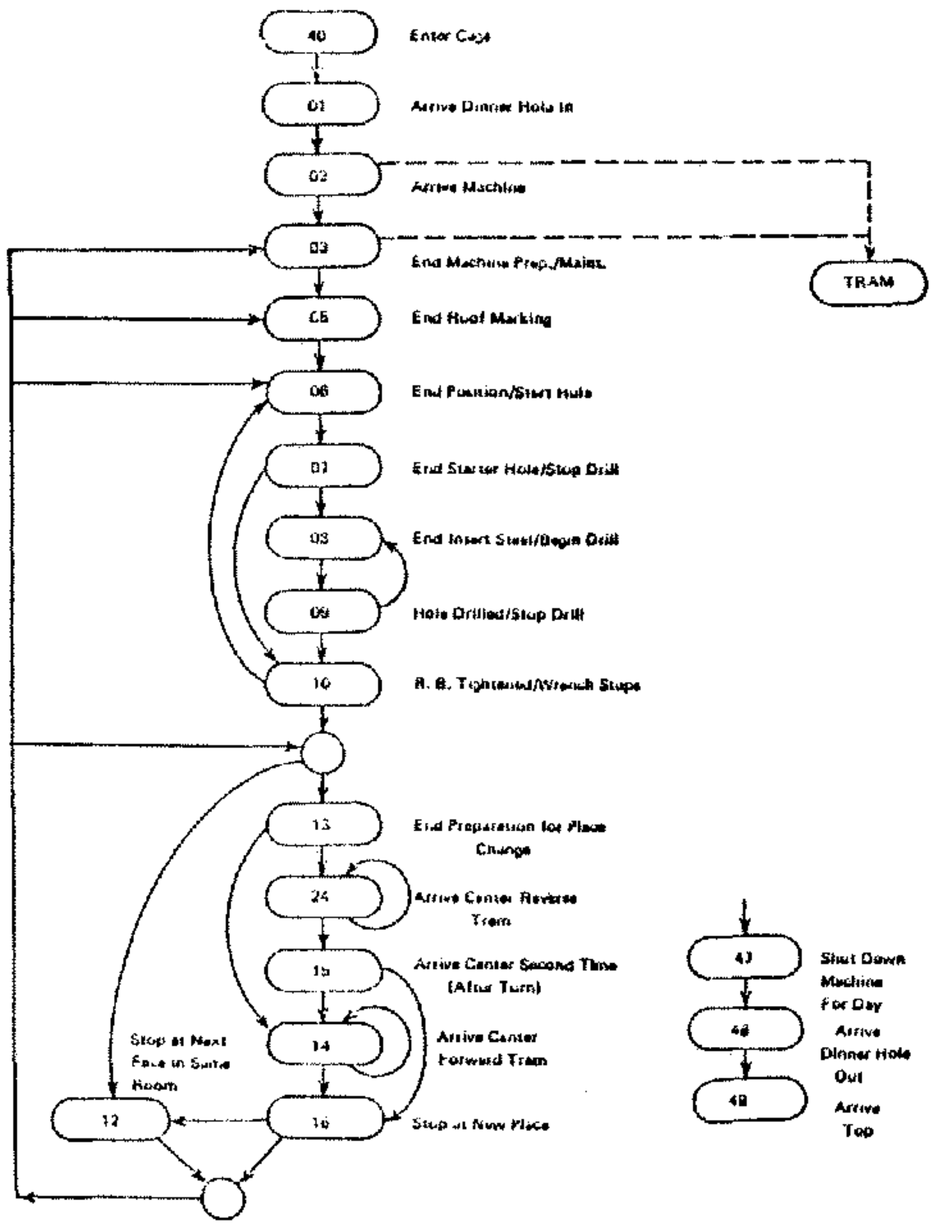
Hence, the event "Roof Bolter initiates drilling in entry #4 at 9:15:33" is coded "R4006091533." The observer simply voice records "nine fifteen thirty three, start drill," because the machine and location are pre-defined once at the beginning of a set of mine-face activities.

The MINIE system processes the data to produce a time line re-creation of the observations. A sample time line is illustrated in Figure 3. It represents the sequence of events which were recorded and coded, as processed by the computer. Differences between events are shown as "activity durations" for each line item. This output is usually obtained after a number of passes during which the MINIE system edits the input data, flags inconsistencies and assists the observer in preparing a logically correct observation set.

Once the time line has been established, it is processed in a second step to produce summary statistics for the observation period. The data summary which defines the number of observations of each activity, the mean, standard deviation and range of the observations is illustrated in Figure 4. This information may be maintained in the form of disk files or printed format for use in comparing systems and identifying problem areas. Such data may be employed as information input in production analysis models which are used to analyze performance of the system resulting from modifications to operate parameters.

MPASS

The unit operations data available from the MINE system provides a basis for modeling face operations. KETRON has developed a unique graphical simulator of face operations which provides a dynamic display of machines in plan view as they conduct face and haulage activities. The Mine Performance Analysis Simulation System



SAFETY RELATED

78 -- Gas Check
51 -- Curtain Handling Delay
60 -- SAfety Jack
68 -- Torques Test
67 -- Test Hole
81 -- Other - Safety

OPERATOR RELATED

84 -- Operator Delay

MACHINE RELATED

55 -- Mechanical Delay - Scheduled
56 -- Mechanical Delay - Unscheduled
50 -- Cable Handling Delay
87 -- Cable Splice
86 -- Bit Change
57 -- Suction Delay
66 -- Clean Dust Collector
82 -- Other - Machine

SYSTEM RELATED

52 -- Inspection and Prep. of Room
71 -- Traffic Delay - Cutter
74 -- Traffic Delay - Loader
72 -- Traffic Delay - Coal Drill
75 -- Traffic Delay - Shuttle Car
76 -- Traffic Delay - Scoop

64 -- Place Delay - Loader
69 -- Shooting Delay
53 -- Section Power
54 -- Section Water
80 -- Loose Bolt
58 -- Supply
83 -- Other - System
79 -- Lunch
65 -- Wrench Delay
70 -- Misc. Tramming Delay

CONDITIONS RELATED

88 -- Scaling
89 -- Roof/Rib Fall
77 -- Bolting Cut of Place
85 -- Other Delay - Conditions

Figure 2. Roof Bolter Flowchart and Delay Codes.

INPUT EVENT LIST MINE ID NO. = 433 SHIFT = 2 MACHINE = MINER ID = FG PAGE NO. 1

			MACH CODE	PLACE CODE	EVENT CODE	EVENT NAME	EVENT TIME HH/MM/SS	EVENT CLOCK TIME IN MIN.	ACTIVITY ELAPSED TIME IN MIN.	ACTIVITY CODE END/BEG	ACTIVITY NAME
1 1	1		M	00	40	LEAVE TOP	8 1 0	481.00			
1 2	2		M	00	41	ARRIVE BOTTOM	8 3 0	483.00	2.00	4140	CAGE TRIP IN
1 3	3		M	00	42	MANTRIP LEAVES IN	8 9 0	489.00	6.00	4241	WAIT FOR MANTRIP IN
1 4	4		M	00	43	ARRIVE DINNER HOLE IN	8 25 0	505.00	16.00	4342	MANTRIP IN
1 5	5		M	34	44	ARRIVE MACHINE	8 33 0	513.00	8.00	4443	FACE TRIP IN
1 6	6		M	34	3	END MACHINE PREP/MAINTENANCE	8 33 1	513.02	0.02	344	MACHINE PREPARATION/MAINTENANCE
2 1	7		M	34	87	CABLE REPAIR	9 21 0	561.00	49.98	8703	CABLE REPAIR
2 2	8		M	24	24	ARRIVE CENTER AFTER REVERSE TRAM	9 23 1	563.02	0.02	2487	REVERSE TRAM
2 3	9		M	24	15	ARRIVE CENTER 2ND TIME(AFT TURN)	9 24 30	564.50	1.48	1524	MANEUVER FOR TRAM
2 4	10		M	24	70	TRAMMING DELAY - OTHER	9 25 41	565.68	1.18	7015	TRAMMING DELAY - OTHER
2 5	11		M	2M	16	STOP IN NEXT PLACE	9 26 3	566.05	0.37	1670	FORWARD TRAM
2 6	12		M	2M	4	BEGIN CUT	9 26 4	566.07	0.02	416	POSITIONING
3 1	13		M	2M	6	STANDARD S.C. ARRIVES EMPTY	9 26 23	566.38	0.32	604	CUTTING/WAITING FOR STD SC
3 2	14		M	2M	57	LOADING DELAY - MANEUVERING	9 26 30	566.50	0.12	5706	LOADING DELAY - MANEUVERING
3 3	15		M	2M	5	END CUT	9 26 47	566.78	0.28	557	CUTTING
3 4	16		M	2M	4	BEGIN CUT	9 27 7	567.12	0.33	405	POSITIONING
3 5	17		M	2M	5	END CUT	9 27 46	567.77	0.65	504	CUTTING
3 6	18		M	2M	4	BEGIN CUT	9 28 9	568.15	0.38	405	POSITIONING
4 1	19		M	2M	5	END CUT	9 28 40	568.67	0.52	504	CUTTING
4 2	20		M	2M	4	BEGIN CUT	9 28 47	568.78	0.12	405	POSITIONING
4 3	21		M	2M	5	END CUT	9 29 15	569.25	0.47	504	CUTTING
4 4	22		M	2M	8	STANDARD S.C. LEAVES LOADED	9 29 27	569.45	0.20	805	LOAD STANDARD SHUTTLE CAR
4 5	23		M	2M	10	THIRD S.C. ARRIVES EMPTY	9 29 40	569.67	0.22	1008	CUTTING/WAITING FOR OTHER SC
4 6	24		M	2M	4	BEGIN CUT	9 29 41	569.68	0.02	410	POSITIONING
5 1	25		M	2M	5	END CUT	9 30 22	570.37	0.68	504	CUTTING
5 2	26		M	2M	4	BEGIN CUT	9 30 58	570.97	0.60	405	POSITIONING
5 3	27		M	2M	5	END CUT	9 31 35	571.58	0.62	504	CUTTING
5 4	28		M	2M	11	THIRD S.C. LEAVES LOADED	9 32 2	572.03	0.45	1105	LOAD OTHER SHUTTLE CAR
5 5	29		M	2M	6	STANDARD S.C. ARRIVES EMPTY	9 32 12	572.20	0.17	611	CUTTING/WAITING FOR STD SC
5 6	30		M	2M	57	LOADING DELAY - MANEUVERING	9 32 18	572.30	0.10	5706	LOADING DELAY - MANEUVERING
6 1	31		M	2M	4	BEGIN CUT	9 32 45	572.75	0.45	457	POSITIONING
6 2	32		M	2M	5	END CUT	9 33 33	573.55	0.80	504	CUTTING
6 3	33		M	2M	8	STANDARD S.C. LEAVES LOADED	9 33 58	573.97	0.42	805	LOAD STANDARD SHUTTLE CAR
6 4	34		M	2M	4	BEGIN CUT	9 34 15	574.25	0.28	408	POSITIONING
6 5	35		M	2M	5	END CUT	9 34 35	574.58	0.33	504	CUTTING
6 6	36		M	2M	10	THIRD S.C. ARRIVES EMPTY	9 35 59	575.98	1.40	1005	CUTTING/WAITING FOR OTHER SC
7 1	37		M	2M	84	OPERATOR DELAY	9 36 9	576.15	0.17	8410	OPERATOR DELAY
7 2	38		M	2M	4	BEGIN CUT	9 36 15	576.25	0.10	484	POSITIONING
7 3	39		M	2M	5	END CUT	9 36 30	576.50	0.25	504	CUTTING
7 4	40		M	2M	4	BEGIN CUT	9 36 40	576.67	0.17	405	POSITIONING
7 5	41		M	2M	5	END CUT	9 37 2	577.03	0.37	504	CUTTING
7 6	42		M	2M	11	THIRD S.C. LEAVES LOADED	9 37 3	577.05	0.02	1105	LOAD OTHER SHUTTLE CAR
8 1	43		M	2M	6	STANDARD S.C. ARRIVES EMPTY	9 37 13	577.22	0.17	611	CUTTING/WAITING FOR STD SC
8 2	44		M	2M	4	BEGIN CUT	9 37 37	577.62	0.40	406	POSITIONING
8 3	45		M	2M	5	END CUT	9 38 18	578.30	0.68	504	CUTTING
8 4	46		M	2M	8	STANDARD S.C. LEAVES LOADED	9 38 45	578.75	0.45	805	LOAD STANDARD SHUTTLE CAR
8 5	47		M	2M	10	THIRD S.C. ARRIVES EMPTY	9 41 25	581.42	2.67	1008	CUTTING/WAITING FOR OTHER SC
8 6	48		M	2M	4	BEGIN CUT	9 41 35	581.58	0.17	410	POSITIONING
9 1	49		M	2M	5	END CUT	9 42 10	582.17	0.58	504	CUTTING
9 2	50		M	2M	11	THIRD S.C. LEAVES LOADED	9 42 58	582.97	0.80	1105	LOAD OTHER SHUTTLE CAR
9 3	51		M	2M	6	STANDARD S.C. ARRIVES EMPTY	9 43 10	583.17	0.20	611	CUTTING/WAITING FOR STD SC

Figure 3. Example of Machine-Shift Event Report.

(MPASS) allows the user to enter a section cut plan and machine performance data interactively with the support of CRT prompting. The model can use machine performance parameters obtained from time study summaries in the MINIE system, or as an alternative, manufacturer's performance rating data.

MPASS is a time step simulator which displays the status of mining activities at regular time intervals on the CRT screen. A sample cut sequence from the MPASS system is illustrated in Figure 5. Once the plan has been accepted, the user defines haulage and tramming routes with the aid of the numbering scheme and a cursor that traces selected routes. Machines are placed to start the simulation and mining activities are initiated. The machines perform and may be observed during simulation at the user's direction. A snapshot of mining activities from a thermal printer which duplicates the CRT screen contents is illustrated in Figure 6. Haulage and place changing as well as associated traffic problems become clear from such displays.

Summary statistics describing the system performance over the entire time period are output at the end of the simulation. A production time line and machine performance statistics for one shift of simulated activity are contained in Figures 7 and 8.

The graphical nature of MPASS provides the user with extensive visibility into mining activities which is not available in other production simulators. As such, it lends credibility to the simulation and provides confidence that it is performing in accordance with the user's intent. Furthermore, it establishes a basis for communication of ideas and information in management and supervision of face operations and also has applications as a training aid which are currently being explored.

CPMINE

An alternative approach to face production analysis is the application of analytical models to describe the time consumed by a mining operation. KETRON has applied this technique in conjunction with critical path network processing in the CPMINE model. The resulting system allows one to simulate long term production over a production period which consists of one or more complete se-

1. ROOF BOLTER ACTIVITIES

	FREQ.	TOT.TIME	MEAN	STD.DEV	HIGH	LOW
MANTRIP -IN	1.	16.58	16.58	0.0	16.58	16.58
FACETRIP -IN	1.	4.23	4.23	0.0	4.23	4.23
POSITION DRILL	77.	18.37	0.24	0.19	1.47	0.05
DRILL STARTER HOLE	78.	46.24	0.59	0.08	0.96	0.42
CHANGE STEEL	26.	6.30	0.24	0.06	0.40	0.07
DRILL HOLE	26.	25.60	0.98	0.18	1.74	0.72
INSERT AND TIGHTEN ROOF BOLT	78.	26.42	0.34	0.15	0.83	0.18
FACE TRAM	8.	7.15	0.89	0.26	1.15	0.42
PREPARE FOR PLACE CHANGE	5.	1.21	0.24	0.07	0.32	0.12
FORWARD TRAM	12.	6.45	0.54	0.06	0.65	0.43
MANEUVER FOR TURN	7.	2.48	0.35	0.18	0.78	0.22
REVERSE TRAM	11.	6.70	0.61	0.09	0.80	0.48
PREPARE FOR DEPARTURE	1.	0.02	0.02	0.0	0.02	0.02
FACETRIP -OUT	1.	18.08	18.08	0.0	18.08	18.08
MANTRIP -OUT	1.	14.73	14.73	0.0	14.73	14.73

2. ROOF BOLTER DELAYS

	FREQ.	TOT.TIME	MEAN	STD.DEV	HIGH	LOW
CABLE HANDLING	3.	3.23	1.08	0.69	1.92	0.23
INSPECTION AND PREP. OF ROOM	1.	0.47	0.47	0.0	0.47	0.47
SECTION POWER DOWN	1.	0.77	0.77	0.0	0.77	0.77
SUPPLY DELAY	3.	25.79	8.60	1.91	10.92	6.25
WAITING ON OTHER DRILL	7.	10.36	1.48	1.00	3.27	0.17
SAFETY JACK/TIMBERS	12.	35.16	2.93	2.17	8.37	0.25
PLACE DELAY -LOADER	3.	86.12	28.71	17.54	44.10	4.17
INSERT WRENCH	19.	2.69	0.14	0.04	0.28	0.10
CLEAN DUST COLLECTOR	1.	0.58	0.58	0.0	0.58	0.58
TORQUE TEST	1.	0.33	0.33	0.0	0.33	0.33
TRAMMING DELAY -MSC.	2.	0.75	0.38	0.09	0.47	0.28
TRAFFIC DELAY -SHUTTLE CAR	2.	2.32	1.16	0.01	1.17	1.15
TRAFFIC DELAY -SCOOP	2.	18.23	9.11	4.91	18.03	0.20
GAS CHECK	2.	0.63	0.31	0.21	0.53	0.10
LUNCH	1.	28.35	28.35	0.0	28.35	28.35
OTHER DELAY -SAFETY	3.	24.75	8.25	7.00	18.15	3.23
OTHER DELAY -MACHINE	5.	3.61	0.72	0.58	1.77	0.23
OTHER DELAY -SYSTEM	10.	4.89	0.49	0.33	1.25	0.13
OPERATOR DELAY	7.	5.20	0.74	0.65	1.77	0.08
CHANGE DRILL BIT	1.	5.20	5.20	0.0	5.20	5.20
ROOF SCALING	2.	5.21	2.60	1.08	3.68	1.53

3. PLACE CHANGE (TRAM)

TRAM TIME	BEGIN	END	DELAY	COORDINATES									
3.98	444.47	454.53	1.06	43	33	23	2L						
1.48	471.30	473.13	0.35	28	23	13	1D						
4.31	501.85	556.30	50.14	1R	13	23	33	43	53	63	64	65	6D
3.15	597.12	634.53	34.30	6L	65	64	63	53	54	55	5D		
3.31	648.55	669.75	18.09	5L	55	54	53	43	44	4R			
3.10	763.58	774.23	7.55	4L	44	43	33	23	24	2R			

4. TOTAL ROOF BOLTS (45C-1C0) = 78 BOLTS

5. OPERATING TIME .... 158.04 MIN
NON-MAINTENANCE DELAYS-NECESSARY .... 65.92 MIN
NON-MAINTENANCE DELAYS-UNNECESSARY .. 147.68 MIN
PREVENTIVE MAINTENANCE DELAYS .... 0.0 MIN
CORRECTIVE MAINTENANCE DELAYS .... 0.0 MIN
LUNCH .... 28.35 MIN
TOTAL FACE TIME .... 390.30 MIN

Figure 4. Example of COALS Output Reports.

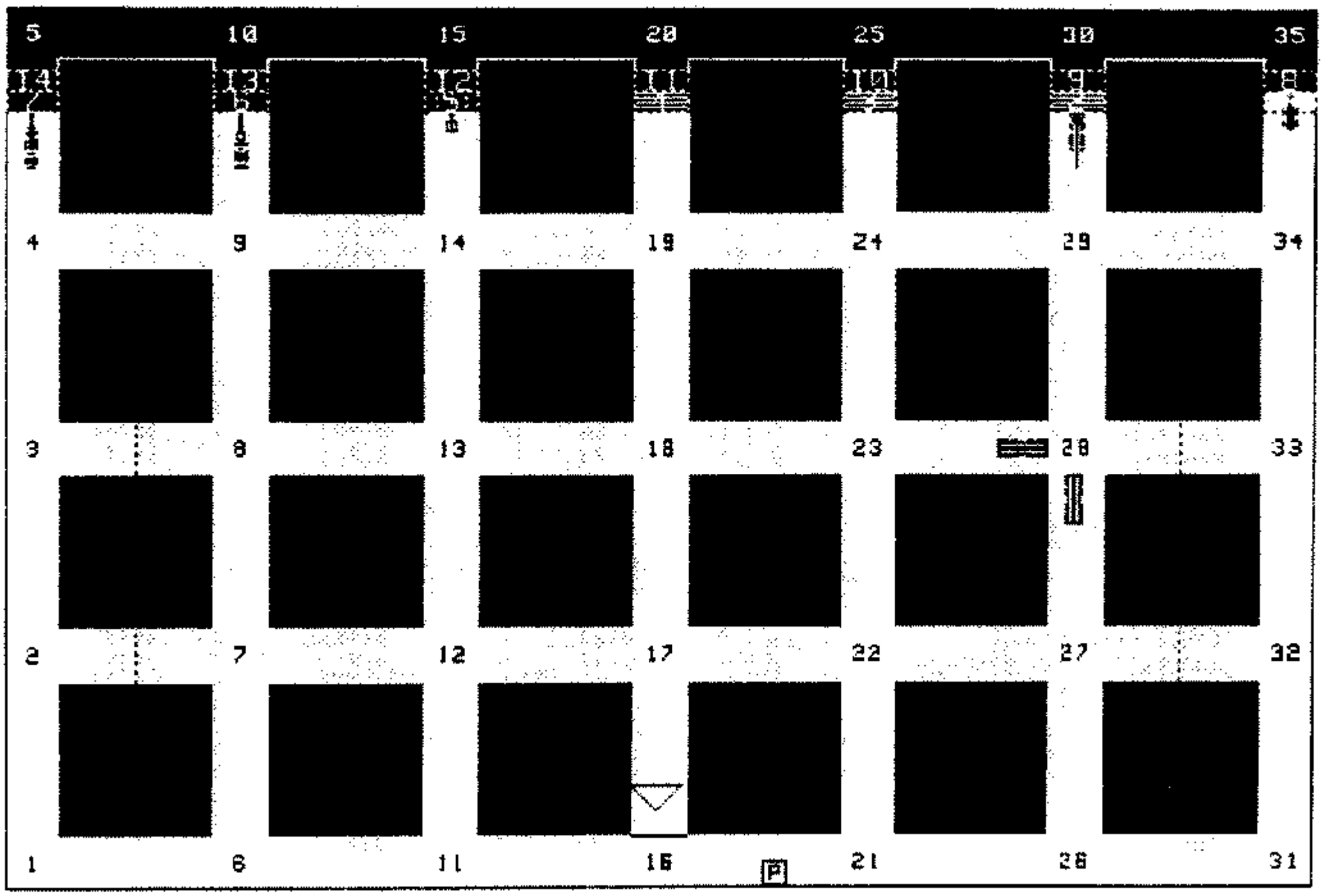


Figure 5. Input Cut Sequence for MPASS.

quences of lifts. For example, a sequence of perhaps 30 lifts might be required to represent the mining between two successive cross cuts in a room-and-pillar mine. CPMINE is an efficient method for obtaining the shift production distribution over the course of this mining cycle.

The nature of a room-and-pillar mining system is one which lends itself to the critical path approach. A critical path network for a five-step conventional mining system: cut, drill, shoot, load, bolt is illustrated in Figure 9. Each lift is illustrated by a serial sequence of these process steps with dummy steps (zero duration) included for the purpose of mathematical process modeling. The diagonal lines represent roof support constraints, indicating that a given lift cannot be mined until the predecessor lift in the same entry has been roof bolted.

The regular cycle of the process allows the network to be constructed by the model with a minimum amount of inputting. The user defines the number of cuts, the mining sequence and the roof bolting constraints, and the model prepares a critical path network of the process, coding the network in terms of predecessor and successor events for each activity. There are four types of activities: working a lift, changing places, roof bolt constraints and dummies.

The remaining input into the network consists of the duration for each activity. A probablistic approach has been adopted to represent actual mining experience. Each machine type is modeled in terms of equations that describe the place time for the machine. For example, the roof bolting time is based on the drill rate, bolt length, number of bolts and positioning time per bolt. These variables are entered into the program as statistical distributions through user selected distribution types and distribution parameters. The model uses these distributions to obtain a place time distribution for each machine type. A Monte-Carlo selection from this distribution is used to obtain place time input for each machine lift in the critical path network. A similar approach is applied to the place change process which uses input values for place-to-place distances.

The process of machine delays and repairs is also included in the model. These are superimposed on the critical path by defining the reliability of each machine in terms of tons between delays and downtime per delay. These parameters are entered as distributions and selected randomly. Delay times are added to each place for which a delay has been specified by the random process. The total

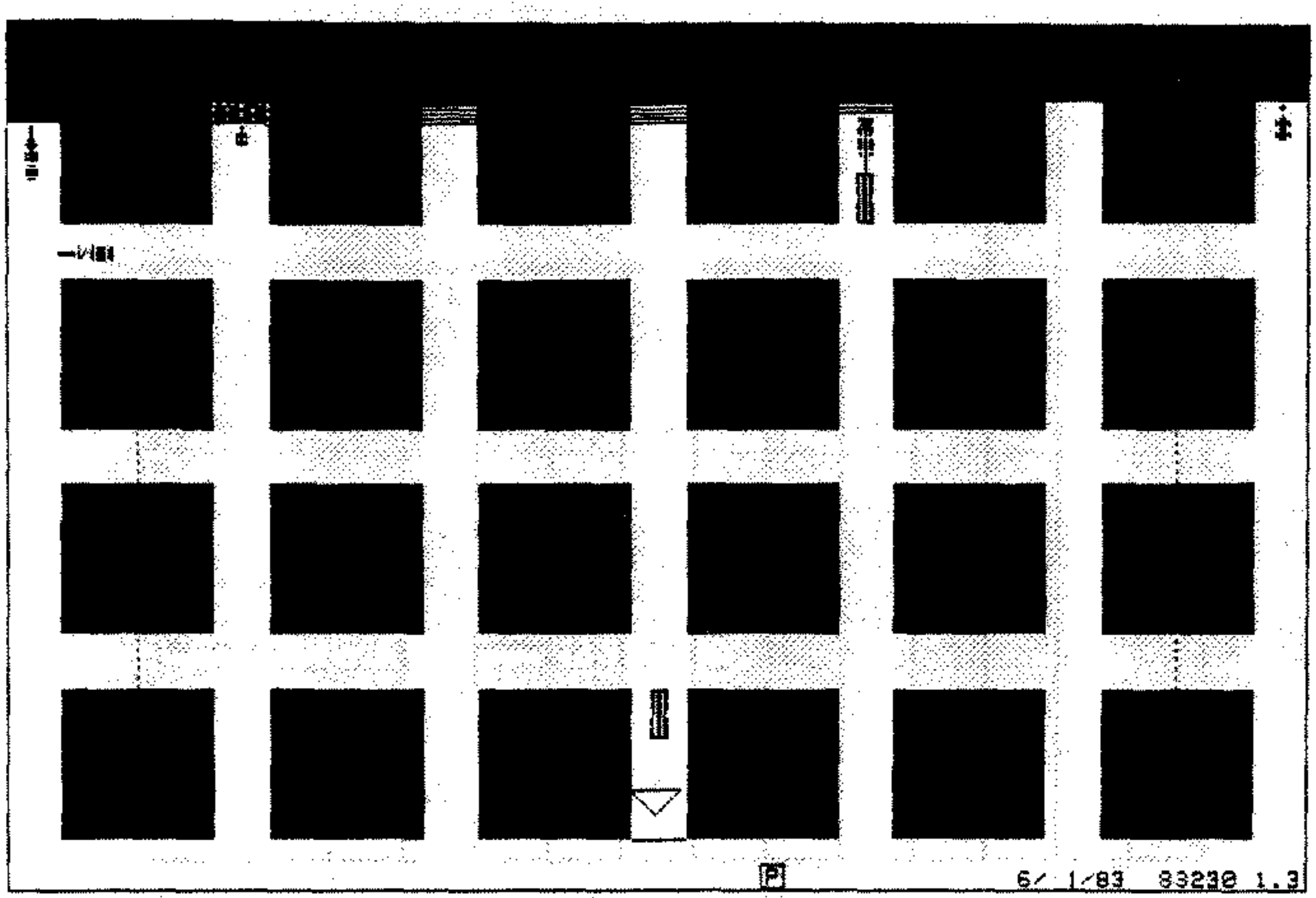


Figure 6. Snapshot of Mining Activities from MPASS.

place time for each machine is the sum of its working time and its delay time.

The network is processed to obtain the start and end time for each activity, from which the network critical path is obtained. The model reduces the network into a shift production time line which is then processed to obtain the distribution of shift production over the production period.

Sample inputs for a CPMINE run are illustrated in Figure 10, and Figure 11 contains the production distribution for the process. The results are representative of a mining process in which variations occur due to geometric variations, failures and repairs, and changes in mining conditions.

Using CPMINE one can obtain statistical distributions of shift production for each process type in a mining system. These outputs are presented in terms of histograms and summary statistics for each different process as defined by number of entries, seam height, cut sequence and machine type or sequence.

MPLAN

In planning the design of a mine, the network approach is extended one more level in the MPLAN model, wherein the network elements consist of major mine segment types. A segment type is defined as a length of a main entry, a length of submain, a production panel, a shaft or slope, etc. Each segment type has an associated production and drive rate that may be obtained from CPMINE, or simply by user selection. In addition, each segment type is assigned data relating to equipment types required to mine the segment.

The mine-life process is described in terms of a strategy network which defines the allowable sequence of mining. A sample mine layout consisting of mains, submains and production panels is illustrated in Figure 12. The strategy network that is to be implemented for mining is shown in Figure 13. The network is constructed from mine segments, and each segment is defined by a unique set of descriptive characters which include the segment type and a numerically unique identification code. In the network, initiation of a segment is constrained by its "father," the segment which must be completed before it can be initiated. The segments which may be completed after one or more fathers are completed are called "sons."

The mine strategy network consists of fathers and sons arranged in a manner that describes the allowable sequence and required constraints on the mining process. A

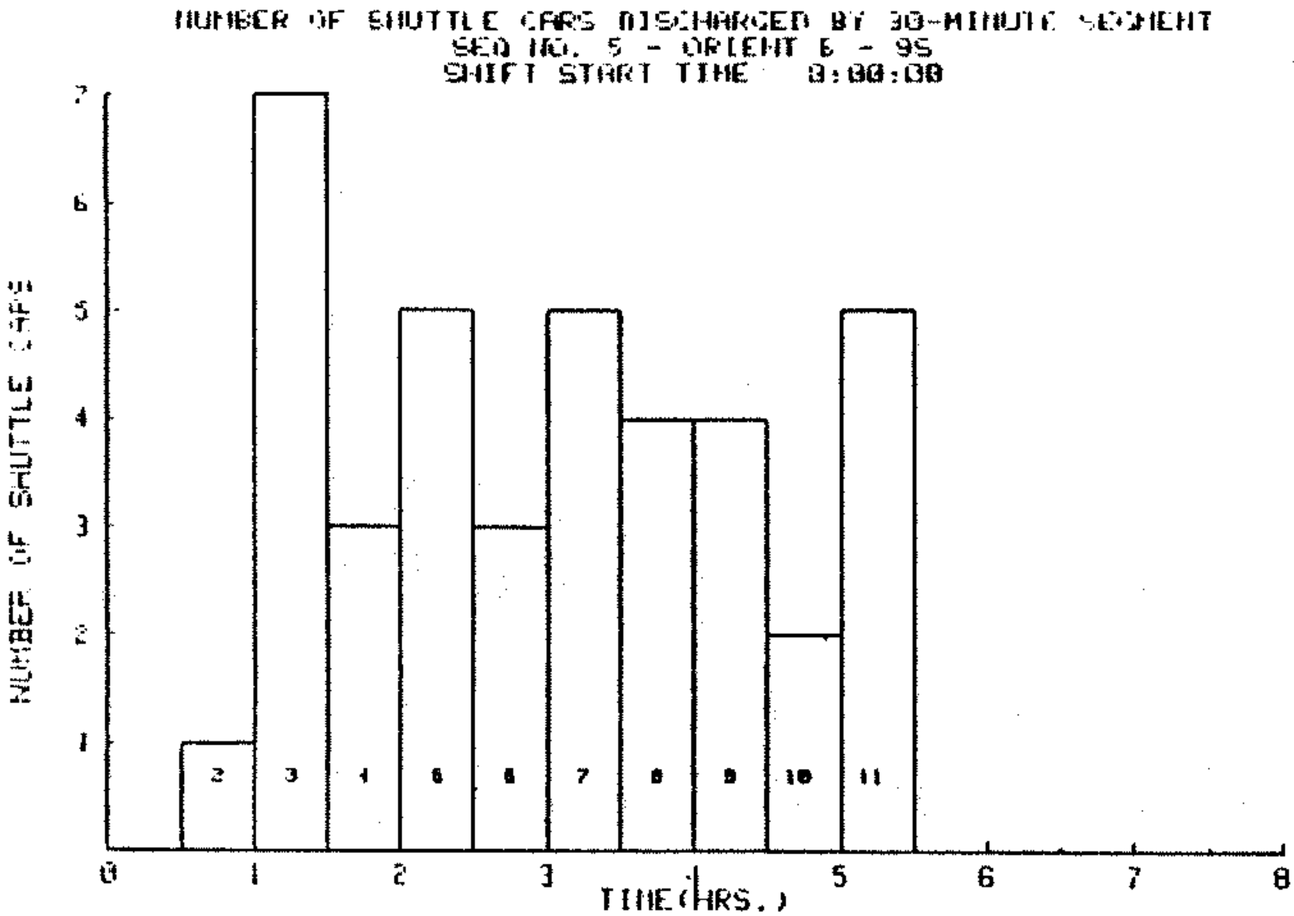


Figure 7. MPASS Production Time Line.

pool of available equipment is defined by a user specified acquisition schedule. MPLAN processes the network by allocating equipment to the segments as it becomes available on completion of predecessor segments. MPLAN records the year and shift for the start and completion of each segment, equipment usage and equipment requests and denials for segments. The model then develops an annual production time line for each segment type and for the complete mine.

The MPLAN segment completion and production reports are illustrated in Figures 14 and 15. This output provides a means for analyzing the mining strategy as it relates to mine production objectives. Initially, equipment may be allocated to main entry and submain segments to assure adequate resources for mine development. Later in the process, some of these equipment types may be allocated to production mining. The resulting production and equipment utilization may be traced downward to the values that have been input from MINIE and CPMINE. They also provide the basis for the mine cost processing which follows.

MCOM

The mining cost model, MCOM, applies the results of MPLAN processing to determine the mine life costs associated with the project on an annualized basis. Additional input data is required for each segment type for the mine, and for the equipment that is to be used. These include capital costs and depreciation schedules for each unit of face and haulage equipment; management salaries and labor rates for face operations, maintenance and utility crews; unit costs and usage quantities for roof bolts, powder, bits, timber, rock dust, fuel, power and other mine supplies; financial factors including interest and inflation rates; and inventory levels for spare parts required to maintain capital equipment. In addition, the model presents the definition of user defined cost categories and expenditure schedules that may be allocated arbitrarily over time.

MCOM processes the segment completion report and computes the costs incurred in mining each segment based on the production rates, usage factors, and unit costs.

STATISTICS GENERATION RUN OUTPUT REPORT FOR [illegible] NO. 1 - [illegible] 6 - 10

RUN NUMBER 4 [illegible] TOTAL REPORT FOR 1 SHIFTS [illegible] TODAY'S DATE [illegible] 1981

REPORT FOR SHUTTLE CARS (time in minutes)

MACHINE TYPE/ MODEL/ SERIES	NUMBER OF TIMES SC ARRIVED AT DUMP	TOTAL TONS DISCHARGED BY THE SC AT DUMP	TOTAL TIME SC WAITED AT CHANGE POINT	TOTAL TIME SC SPENT AT PRODUCT. MACHINE	TOTAL TIME SC WAITED AT THE WAIT POINT	TOTAL TIME SC SPENT AT THE DUMP	TOTAL TIME SC TRAMMED UNLOADED	TOTAL TIME SC TRAMMED LOADED
JOY 10SC22-8	25.0	219.0	71.7	75.3	9.2	24.0	54.3	44.0
JOY 10SC22-06	19.4	156.0	78.0	56.0	1.2	18.5	51.5	40.5

MACHINE TYPE/ MODEL/ SERIES	TOTAL TIME SC WAITED FOR COORD TO CLEAR	TOTAL TIME SC WAS IN A LOADING/ SITCH. DELAY	TOTAL TIME SC WAS IN A TRAMMING DELAY	TOTAL TIME SC IN EXOG NON-MEAL DELAY	TOTAL TIME SC IN MEAL DELAY	OPER. SC TURNAROUND INDEX (NO DLYS)	ACHIEVED SC TURNARND. INDEX
JOY 10SC22-8	0.0	0.0	0.0	1.5	0.0	.44	.56
JOY 10SC22-06	1.3	0.0	0.0	12.7	0.0	.58	.56

TOTAL TIME THAT THERE WAS NO SHUTTLE CAR INBY THE CHANGE POINT IS .... 18.3 MIN

TOTAL CHANGE OUT TIME (TIME THERE WAS A SHUTTLE CAR BETWEEN THE FM AND THE CP) IS ...... 77.0 MIN

REPORT FOR FACE MACHINES (time in minutes)

MACHINE DESCRIPTION	NUMBER OF CUTS COMPLETED BY THIS MACHINE	TOTAL TIME MACHINE WORKED A PLACE	TOTAL TIME QUEUED WAITING FOR CUT TO CLEAR	TOTAL TIME MACHINE TRAMMED FORWARD	TOTAL TIME MACHINE TRAMMED IN REVERSE	TOTAL TIME MACHINE WAITED FOR COORD TO CLEAR	TOTAL TIME MACH. IN WORKING DELAY	TOTAL TIME MACHINE IN TRAM DELAY	TOTAL TIME MACHINE IN EXOG NON-MEAL DELAY	TOTAL TIME MACHINE IN MEAL DELAY	TOTAL TIME MACHINE IN A PREP PLACE DELAY
CONTINUOUS MINER	5.0	132.2	2	10.2	1.5	83.0	1.5	0.0	0.0	0.0	26.5
BOLTER	4.0	155.5	32.0	16.2	4.5	63.0	2.0	0.0	0.0	32.5	6.7

TOTAL TIME THE PRODUCTION MACHINE WAS WAITING FOR A SHUTTLE CAR WHILE AT A CUT. ... 84.8 MIN.

TOTAL TONS DISCHARGED AT THE DUMP ARE 360.0

TOTAL TIME THE DUMP WAS IN AN OUTBY HAULAGE DELAY IS ... 12.7 MIN

Figure 8. MPASS Summary Statistics.

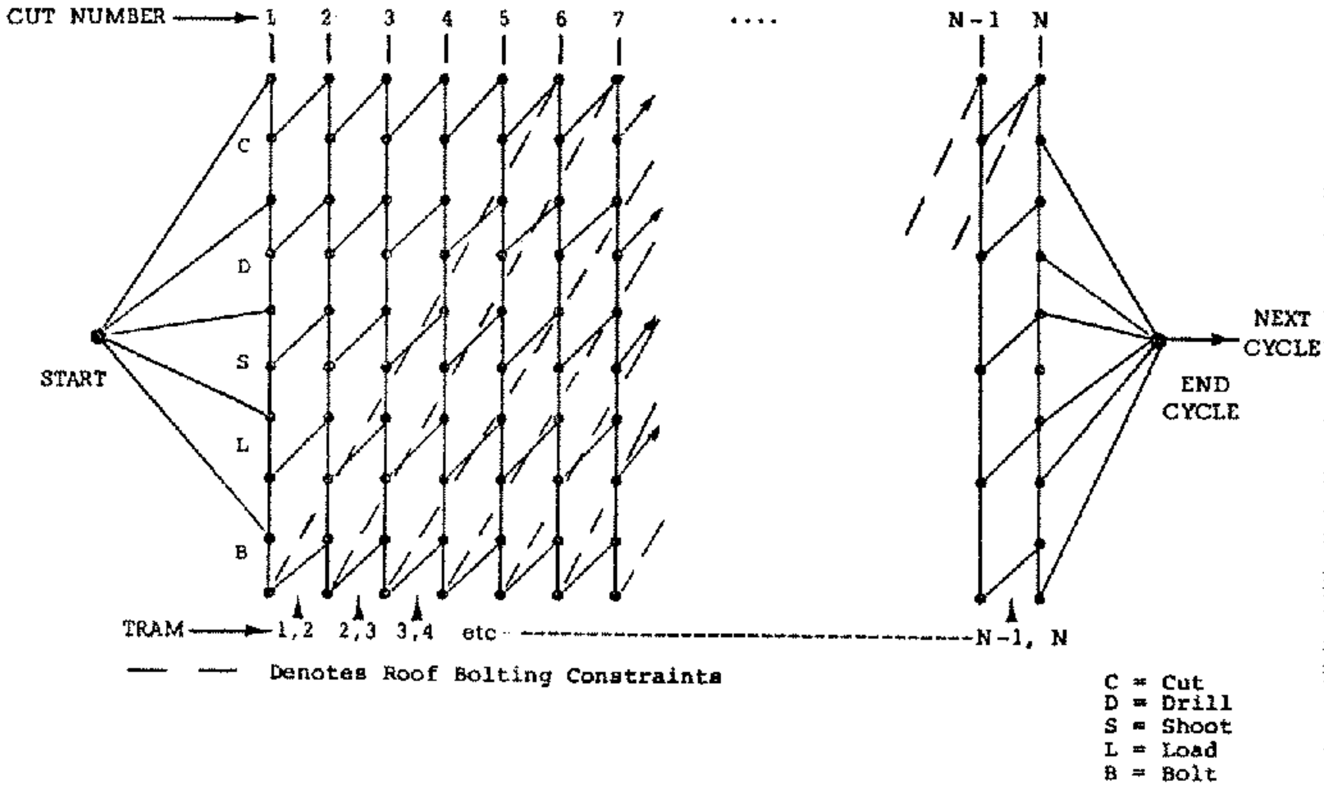


Figure 9. Critical Path Network for Conventional Room-and-Pillar Mining.

Equipment overhauls are incurred as required, rail and belt are acquired, and labor and management are hired as needed to meet the segment production levels. Figure 16 illustrates a sample output from MCOM over a five-year period. The model can handle mine life periods of 30 years, beyond which the uncertainty associated with financial variables makes rigorous quantitative planning less meaningful.

APPLICATIONS

The set of production models have been applied in a number of mine planning projects ranging from face operation analysis to the long range evaluation of new mining ventures with respect to financial viability. Selected applications are summarized below.

Midwestern Coal Mining Operations

For a large midwestern coal producer operating four deep mines, a three-phase application of the industrial engineering and face simulation system was conducted. The company's management required a characterization of its underground mining sections so that decisions concerning these operations could be made by management. Using the MINIE system, industrial engineering time studies were conducted for over 30 continuous mining operating sections. These sections were classified with respect to operating efficiency and maintenance problems through statistical analysis of the data base. A small number of sections were selected for more detailed analysis and were used as a baseline for decision making. These sections were used to define the best available procedures and to identify the most proficient equipment operators and face supervisors in the mine. The information was used by mine management to effect improvements in operating procedures.

The company's industrial engineering group was expanded and trained in application of the MINIE system. Subsequently, the MPASS face production simulator was installed for use by the mining company's IE group. MPASS was then applied to haulage studies in conjunction with data acquired through the MINIE system. The engineers have now become quite efficient in acquiring and analyzing data to support engineering decisions. The MPASS system has been used to demonstrate the benefits of modifying operating procedures both statistically and through the visibility which is available from the dynamic, graphic displays.

New Midwestern 4 Million TPY Mine

In planning a new mine in the Illinois coal basin, the MISS models are being applied to a variety of decisions which will affect the productive and economic perfor-

```
INPUT PARAMETERS FOR RUN            85/6.5/BASE

NUMBER ITERATIONS     1
NUMBER CYCLES     1
NUMBER CUTS PER CYCLE   32
NUMBER MACHINES     2
NUMBER ITERATIONS OF MINI-MODEL(IF APPLICABLE)    15
NUMBER ENTRIES IN CUT PLAN     5
STARTING RANDOM NUMBER SEED          13579
CUT WIDTH(FT.)    20
SEAM HEIGHT(FT.)     6
CUT DEPTH(FT.)    20
COAL DENSITY(LBS./CUBIC FT.)     91
AVERAGE WORKING HRS. PER SHIFT       6.00
PRODUCTION REPORT CELL SIZE(TONS)    40
BELT MOVE TIME(MIN.)       0.0        0.0        NORMAL

OPTIONS SELECTED - -
     CPM - PRINT NETWORK IN ORDER OF EARLIEST POSSIBLE START TIME

ROOF SUPPORT CUT CONSTRAINTS --
   0   0   0   0   0   1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  13  12  21  14  23  24  13  24  27  26
  29  28

TRAMMING DISTANCES(FT.) BETWEEN CUT I AND CUT I+1 - -
  135  135  135  135  380  175  175  175  175  420  215  215  215  215  460  255  255  255  255  330  255  275  275  295  350
  275  275  295  350  355  465
```

Figure 10. CPMINE Inputs.

```
INPUT PARAMETERS FOR MACHINE  2 - - BOLTER

MACHINE TYPE     5
FOLLOWS MACHINE NO.     1
TRAMMING SPEED(FT./MIN.)      40.00       0.0       NORMAL
NO DOWN TIME FOR THIS MACHINE
MINI-MODEL WAS USED TO CALCULATE PLACE TIME MEAN,SD

BOLTER INPUTS - -
     DRILL RATE(FT./MIN.)                     3.50      0.0       NORMAL
     POSITIONING TIME/BOLT(MIN.)              0.20      0.0       NORMAL
     INSERT AND TIGHTEN 1 BOLT(MIN.)          0.20      0.0       NORMAL
     TIME TO MOVE TO NEXT BOLT(MIN.)          0.30      0.0       NORMAL
     NUMBER OF BOLTS             10
     BOLT LENGTH(FT.)             5

PLACE TIME(MIN.)                  21.29       0.02      NORMAL

MINIMUM PLACE TIME(MIN.)     0

NUMBER CYCLES =      1

NUMBER ENTRIES =      5

NUMBER CUTS =     32

NUMBER MACHINES =      2


MACHINE NUMBER     1     MINER        IS TYPE    6

MACHINE NUMBER     2     BOLTER       IS TYPE    5
```

Figure 10 *(cont'd.)*. CPMINE Inputs.

mance of the mine. Operating in two seams, the sequence of mine operations and ventilation are quite complex by normal coal mining standards. A sand channel separating one of the seams adds to the complexity of coordination and scheduling of production.

The first step in the planning process consisted of analyzing face production activities for eleven different cut plans, each representing a segment type which defined the mining operations. Similarities among segment types reduced the number of different alternatives to six, and each of these was analyzed by using the CPMINE model. Manufacturer data for both electric and diesel haulage systems was used along with data from KETRON's MINIE data base to develop inputs to the base case runs. Shift production distribution data was obtained for the various segment types using the expected values for input variables. Later, parametric studies of machine reliability and performance were conducted to determine the impact of failures and production rate uncertainties on overall mine performance.

The mine plan for the project was converted into a strategy network and the inputs for MPLAN were prepared. A baseline execution for one seam was conducted to test the strategy tree and related data file. Finally, the complete

```
LOWEST TONS/SHIFT  235.22     HIGHEST TONS/SHIFT  915.79
AVERAGE TONS/SHIFT  486.13  WITH STANDARD DEVIATION OF141.70

FREQUENCY DISTRIBUTION:  CLASS BOUNDS      FREQUENCY
                            0 -   40          0
                           40 -   80          0
                           80 -  120          0
                          120 -  160          0
                          160 -  200          0
                          200 -  240          1    X
                          240 -  280          2    XX
                          280 -  320          5    XXXXX
                          320 -  360          6    XXXXXX
                          360 -  400         11    XXXXXXXXXXX
                          400 -  440          7    XXXXXXX
                          440 -  480          8    XXXXXXXX
                          480 -  520          9    XXXXXXXXX
                          520 -  560          5    XXXXX
                          560 -  600          6    XXXXXX
                          600 -  640          4    XXXX
                          640 -  680          2    XX
                          680 -  720          4    XXXX
                          720 -  760          2    XX
                          760 -  800          1    X
                          800 -  840          1    X
                          840 -  880          0
                          880 -  920          1    X
                          920 -  960          0
                          960 - 1000          0
                         1000 - 1040          0
                         1040 - 1080          0
                         1080 - 1120          0
                         1120 - 1160          0
                         1160 - 1200          0
                         1200 - 1240          0
                         1240 - 1280          0
                         1280 - 1320          0
                         1320 - 1360          0
                         1360 - 1400          0
                         1400 - 1440          0
                         1440 - 1480          0
                         1480 - 1520          0
                         1520 - 1560          0
                         1560 - 1600          0
                         1600 - 1640          0
                         1640 - 1680          0
                         1680 - 1720          0
                         1720 - 1760          0
                         1760 - 1800          0
                         1800 - 1840          0
                         1840 - 1880          0
                         1880 - 1920          0
                         1920 - 1960          0
                         1960 - 2000          0
```

Figure 11. CPMINE Production Time Line.

mine, consisting of two separated sectors in one seam and one sector on the second seam was modeled with the use of MPLAN. The resulting production profiles and equipment requirements were evaluated against mine production objectives based on the MPLAN results. The time-oriented mine status also provided a basis for simulating ventilation fan requirement, using the Penn State simulator, and belt haulage performance, using the VPI Belt Simulator and Mine Haulage Production Impact Model, MHPIM.

As of the writing of this paper, cost analysis has not been initiated for this mine, but the MCOM model is scheduled for future application to mine economics studies. The integrated application of the models was conducted by a team of seven mining engineers via time sharing, in conjunction with the support of KETRON mining and software specialists.

Oil Shale Venture Analysis

In support of oil shale mining venture studies, the CPMINE, MPLAN and MCOM system of models are being installed for time sharing use by a large oil company.

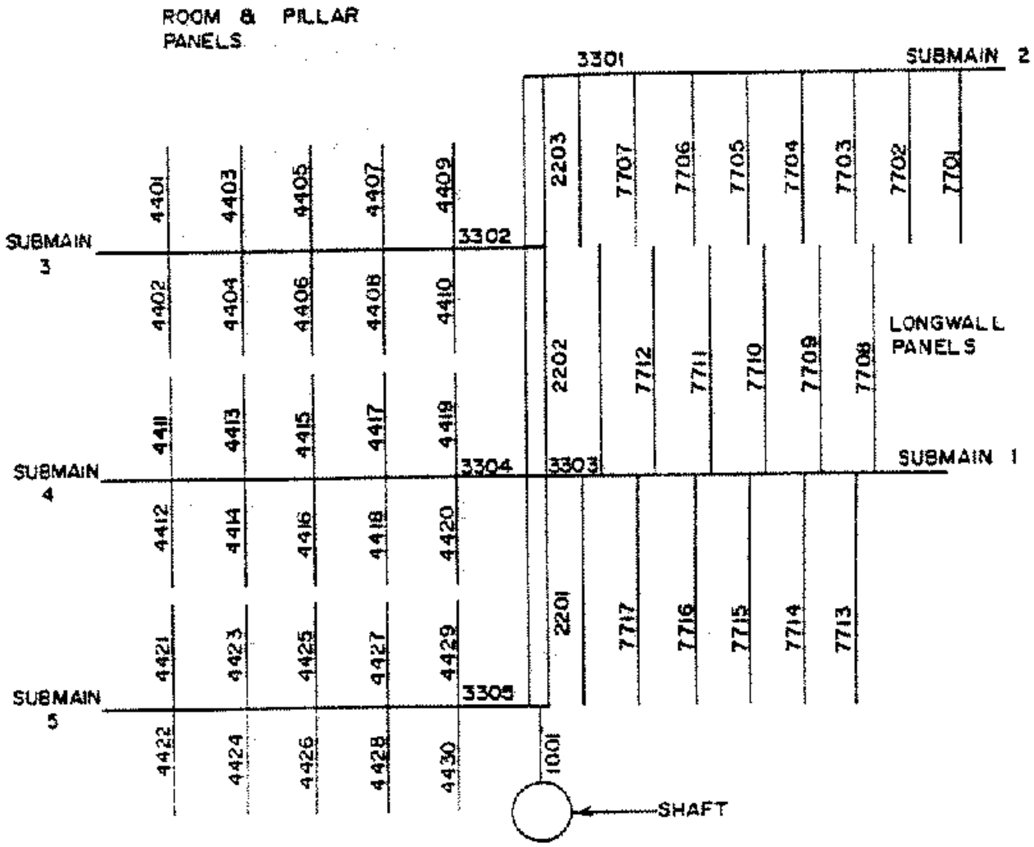


Figure 12. Sample Mine Plan.

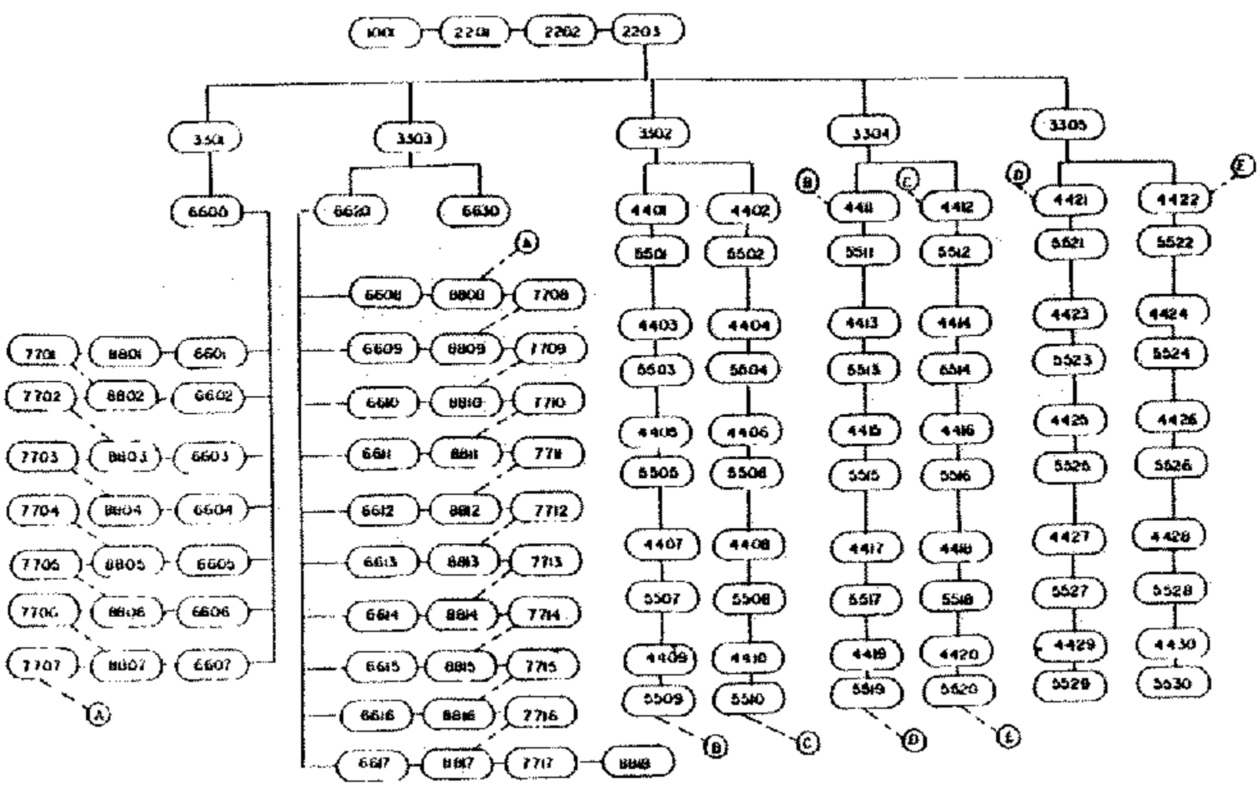


Figure 13. Sample Mine Strategy Network.

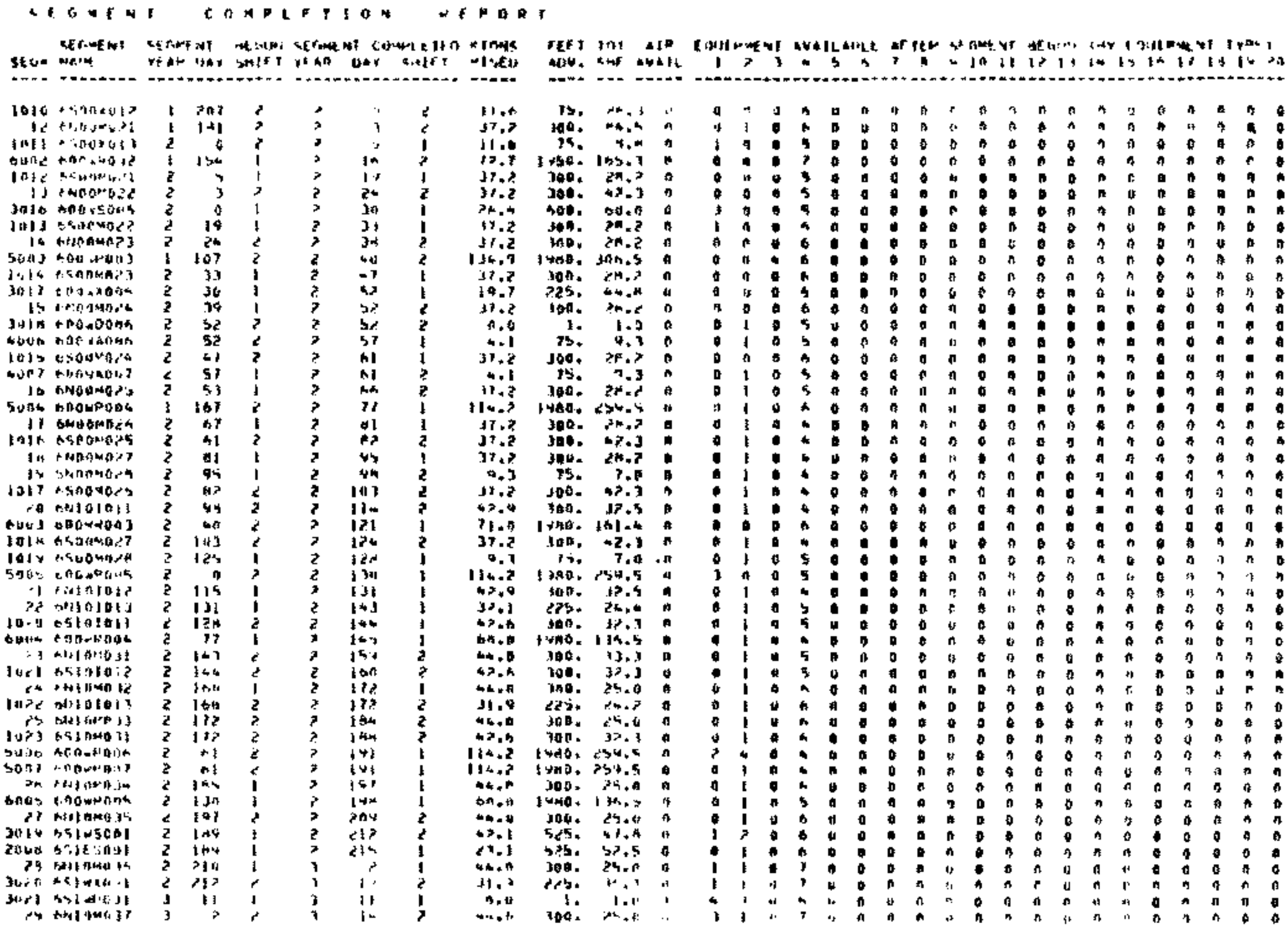


Figure 14. MPLAN Segment Completion Report.

Engineering staff in two locations are being provided with training and access to the models for use in responding to management requests for technical and economic evaluations of proposed ventures. For these applications, the models provides the ability to determine the mining cost per ton of ore and per barrel of shale oil produced, based on input ore grade and retorting efficiency.

South American Phosphate Mine

The MPLAN Model was applied to develop a longwall production plan for a South American phosphate mining project which is being evaluated by the World Bank. The model established the number of development sections required to support longwall operations capable of providing 750,000 tpy of phosphate ore to the processing mill. The MCOM model was used to forecast annual costs and cost per ton for the longwall, which were then compared with costs determined in an earlier study of room-and-pillar mine plan for the same ore deposit.

Advanced Mining Technology Evaluations

The set of models has been applied to a variety of advanced mining technology evaluations for the U.S. Department of Energy over a period of several years. Projects relating to new concept room-and-pillar mining machines, advanced longwalls, tunneling systems and borehole hydraulic mining have been included in these evaluations. In support of these modeling studies, the MINIE data acquisition management system has been applied extensively to obtain operational data and reduce it to statistically meaningful inputs for analytical investigations.

EVOLUTION OF THE SYSTEM

Any computer modeling system must evolve to incorporate advances in computer technology and modeling approaches. The original thrust of the MISS system was based on the application of large, main-frame computers, written in FORTRAN for batch execution, and requiring a

GALATIA MPLAN BASE RUN

TOTAL REPORT OF TONS MINED, FEET ADVANCED AND NUMBER OF SHIFTS
(TONS MINED AND FEET ADVANCED IN THOUSANDS)

KEY - "K TONS" = KILO TONS, "FT AD" = FEET ADVANCED, " # SH" = NUMBER OF SHIFTS

YEAR	TYPE MEASURE	SEGMENT TYPE 1	SEGMENT TYPE 2	SEGMENT TYPE 3	SEGMENT TYPE 4	SEGMENT TYPE 5	SEGMENT TYPE 6	SEGMENT TYPE 7	SEGMENT TYPE 8	SEGMENT TYPE 9	SEGMENT TYPE 10	SEGMENT TYPE 11	TOTAL YEAR	CUMULATE TOTAL
	K TONS	0.0	0.0	0.0	449.7	0.0	0.0	0.0	144.7	0.0	0.0	0.0	594.4	594.4
1	FT AD	0.0	0.0	0.0	1.20	0.0	0.0	0.0	1.20	0.0	0.0	0.0	6.51	6.51
	# SH	0.0	0.0	0.0	253.5	0.0	0.0	0.0	281.7	0.0	0.0	0.0	1170.3	
	K TONS	0.0	0.0	0.0	231.9	0.0	0.0	0.0	166.1	0.0	0.0	0.0	1252.2	1851.6
2	FT AD	0.0	0.0	0.0	1.97	0.0	0.0	0.0	1.34	0.0	0.0	0.0	17.13	23.64
	# SH	0.0	0.0	0.0	305.1	0.0	0.0	0.0	278.8	0.0	0.0	0.0	2583.2	
	K TONS	0.0	0.0	0.0	158.5	0.0	0.0	0.0	224.4	287.7	0.0	0.0	1890.9	3742.5
3	FT AD	0.0	0.0	0.0	1.20	0.0	0.0	0.0	1.81	1.93	0.0	0.0	26.80	50.45
	# SH	0.0	0.0	0.0	110.4	0.0	0.0	0.0	212.4	168.6	0.0	0.0	2416.7	
	K TONS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	355.2	16.3	0.0	0.0	2266.9	6009.4
4	FT AD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.87	0.25	0.0	0.0	36.91	87.36
	# SH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	307.3	28.6	0.0	0.0	4312.6	
	K TONS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	183.9	0.0	0.0	0.0	2272.7	8282.1
5	FT AD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.48	0.0	0.0	0.0	44.95	132.30
	# SH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	418.0	0.0	0.0	0.0	5054.8	
	K TONS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	269.6	0.0	0.0	0.0	2271.1	10553.1
6	FT AD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.17	0.0	0.0	0.0	44.39	176.69
	# SH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	373.2	0.0	0.0	0.0	4775.9	

Figure 15. MPLAN Production Report.

significant level of computer skills. Introduction of powerful mini-computers, having CRT graphics in the mid 1970s provided a technology that was amenable to direct, interactive computing by mining engineers with minimal computer background. The MPASS system was a direct result of the availability of this technology.

The large-scale advent of personal computers employing micro-processing technology has produced yet another step in the evolution of mining related computer applications. KETRON has converted selected MISS systems to personal computers. Interactive prompting is employed, for example, in a BASIC Language personal computer version of the MPLAN program. It is expected that this approach will continue making the software available at several levels for mine planning applications, including installation in-house for large computers, time sharing, and mini-computer or personal computer installation.

Finally, it is important to note that engineering personnel are becoming more comfortable with and proficient in computer applications. They are well aware of benefits of applying computers to production planning problems. KETRON's experience relating to the MISS applications cited above indicates that user-oriented software will find acceptance in the mining industry. Furthermore, computers are becoming a necessity rather than a rarity in the mineral industries, and the 1980s should see an extensive growth in the variety of systems, both hardware and software, that are available to the industry.

SUMMARY

This paper describes a set of computer models that are used to address a wide spectrum of production planning problems ranging from detailed unit operations analysis, of concern to the mining industrial engineering, to the lifetime economics of a complete mine. The modeling system includes five particular programs that have been described: MINIE—an industrial engineering data management system for mining applications; MPASS—a time-step, shift-simulator of face operations employing dynamic graphics; CPMINE—a critical path network model of face operations which produces production distributions over long production periods; MPLAN—a mine strategy network oriented planning model for mine production sequencing analysis; and MCOM—a mining cost model that provides mine life costs based on post processing the MPLAN outputs.

MCOM REPORT FOR MPROD SAMPLE SCENARIO-DEC.22.1982-TEST SCENARIO

DEPRECIATION NON-CASH COSTS PER YEAR (IN THOUSANDS OF DOLLARS)

YEAR	1	2	3	4	5	6
SCHEDULED EQUIPMENT ACQUISITIONS						
PURCHASE PRICE	1139.1	925.5	752.0	651.7	651.7	651.7
REBUILD COST	0.0	0.0	0.0	0.0	1216.6	760.4
INVENTORY COST	304.7	304.7	304.7	304.7	304.7	304.7
TOTAL DEPR. SEA	1443.7	1230.2	1056.6	956.4	2173.0	1716.8
BELT						
PURCHASE PRICE	127.7	108.6	92.3	78.4	74.1	74.1
INVENTORY COST	25.5	25.5	25.5	25.5	25.5	25.5
TOTAL DEPR. BELT	153.3	134.1	117.8	104.0	99.6	99.6
CABLE						
PURCHASE PRICE	16.4	14.8	13.3	12.0	10.8	9.7
INVENTORY COST	1.1	1.1	1.1	1.1	1.1	1.1
TOTAL DEPR. CABL	17.5	15.9	14.4	13.1	11.9	10.8
RAIL						
PURCHASE PRICE	42.5	36.1	30.7	26.1	24.6	24.6
INVENTORY COST	8.5	8.5	8.5	8.5	8.5	8.5
TOTAL DEPR. RAIL	51.0	44.6	39.2	34.6	33.1	33.1
LOCOMOTIVES						
PURCHASE PRICE	60.3	54.3	48.8	44.0	39.6	35.6
REBUILD COST	0.0	0.0	0.0	0.0	0.0	0.0
INVENTORY COST	14.1	14.1	14.1	14.1	14.1	14.1
TOTAL DEPR. LOCO	74.4	68.3	62.9	58.0	53.6	49.7
MINE CARS						
PURCHASE PRICE	92.7	64.9	50.5	50.5	50.5	0.0
REBUILD COST	0.0	0.0	90.6	45.3	45.3	0.0
INVENTORY COST	18.5	18.5	18.5	18.5	18.5	0.0
TOTAL DEPR. MC	111.2	83.4	159.6	114.3	114.3	0.0
TOTAL DEPRECIATION NON-CASH COST	1851.1	1576.5	1450.6	1283.4	2485.6	1910.0

MCOM REPORT FOR MPROD SAMPLE SCENARIO-DEC.22.1982-TEST SCENARIO

LABOR CASH COSTS PER YEAR (IN THOUSANDS OF DOLLARS)

YEAR	1	2	3	4	5	6
MANAGEMENT OVERHEAD	312.8	344.1	411.4	452.5	560.0	616.0
SALARIED SUPERVISORS	759.4	634.4	697.0	767.6	844.3	448.6
PRODUCTION CREWS	3286.5	2745.2	3016.3	3321.7	3653.8	1941.2
MAINTENANCE CREWS	1233.5	1031.8	1135.0	1248.5	1373.3	731.4
DUTRY HAULAGE CREWS						
RAIL	4383.5	4585.7	5038.5	5548.7	6103.6	3238.4
BELT	1179.2	1648.1	1812.9	1994.2	2193.6	1070.3
UTILITY CREWS	822.3	687.9	756.6	832.3	915.5	487.6
TOTAL LABOR CASH COST	11977.4	11677.1	12867.7	14165.4	15644.2	6533.4

Figure 16. MCOM Sample Output.

MCOM REPORT FOR MPHOO SAMPLE SCENARIO-DEC.22,1982-TEST SCENARIO

SUPPLIES CASH COSTS PER YEAR (IN THOUSANDS OF DOLLARS)

YEAR	1	2	3	4	5	6
ROOF BOLTS	718.4	647.6	711.6	783.6	862.0	444.4
POWDER	157.2	142.6	156.7	172.6	189.9	97.8
BLASTING SUPPLIES	555.5	570.6	627.0	690.4	759.4	391.3
ROCK DUST	23.9	21.6	23.7	26.1	28.7	14.8
STOPPINGS	101.9	94.2	103.5	114.0	125.4	64.6
TIMBERING	33.6	29.4	32.3	35.6	39.2	20.2
FACE TUBING	21.0	17.6	19.3	21.2	23.4	12.4
CONSUMABLE PARTS-SEGMENT TYPE	33.7	24.5	27.0	29.7	32.7	16.8
FUEL	0.0	0.0	0.0	0.0	0.0	0.0
LUBRICANTS	9.3	7.7	8.5	9.4	10.3	5.5
BITS	663.6	441.6	485.2	534.3	587.7	303.0
DRILL STEEL	0.0	0.0	0.0	0.0	0.0	0.0
TIRES	36.1	30.1	33.1	36.5	40.1	21.3
CONSUMABLE PARTS-EQUIPMENT TYPE	216.1	196.1	215.5	237.3	261.1	131.9
	--------	--------	--------	--------	--------	--------
TOTAL SUPPLIES CASH COST	2570.4	2223.7	2443.5	2690.7	2959.8	1524.1

MCOM REPORT FOR MPHOO SAMPLE SCENARIO-DEC.22,1982-TEST SCENARIO

OPERATING AND ALLOCATED CASH COSTS PER YEAR (IN THOUSANDS OF DOLLARS)

YEAR	1	2	3	4	5	6
OPERATING COSTS:						
VENTILATION POWER	8.0	13.3	14.6	16.1	17.7	6.9
HAULAGE POWER	50.3	68.9	75.7	83.3	91.7	42.1
FACE MACHINE POWER	165.0	138.6	152.5	167.7	184.5	97.8
WATER SUPPLY/DRAIN	203.0	183.2	201.3	221.6	243.8	125.6
	--------	--------	--------	--------	--------	--------
TOTAL OPERATING CASH COST	426.3	404.0	444.1	488.8	537.7	272.4
ALLOCATED COSTS:						
VENTILATION FAN	250.0	0.0	0.0	0.0	0.0	0.0
SHAFT EQUIPMENT	415.0	0.0	0.0	0.0	0.0	0.0
BRATTICE	10.0	11.0	12.1	13.3	14.6	16.1
COAL STORAGE	100.0	110.0	121.0	133.1	146.4	161.1
	--------	--------	--------	--------	--------	--------
TOTAL ALLOCATED CASH COST	775.0	121.0	133.1	146.4	161.1	177.2

Figure 16 *(cont'd.)*. MCOM Sample Output.

MCOM REPORT FOR MPROD SAMPLE SCENARIO-DEC.22,1982-TEST SCENARIO

SUMMARY REPORT PER YEAR (COSTS IN THOUSANDS OF DOLLARS)

YEAR	1	2	3	4	5	6
NON-CASH COSTS :						
TOTAL DEPRECIATION	1851.1	1576.5	1450.6	1280.4	2485.6	1910.0
CASH COSTS :						
TOTAL LABOR COST	11977.4	11677.1	12867.7	14165.4	15644.2	8533.4
TOTAL SUPPLY COST	2570.4	2223.7	2443.5	2690.7	2959.8	1524.1
TOTAL OPER. COST	426.3	404.0	444.1	488.8	537.7	272.4
TOTAL ALLOC. COST	775.0	121.0	133.1	146.4	161.1	177.2
	--------	--------	--------	--------	--------	--------
TOTAL CASH COSTS	15749.1	14425.8	15888.4	17491.4	19302.7	10507.1
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TOTAL COSTS	17600.2	16002.3	17339.0	18771.7	21788.3	12417.1
ROM TONS PRODUCED (THOUSANDS)	1391.9	1148.4	1147.2	1148.4	1148.4	538.0
COST/ROM TON($)	12.64	13.93	15.11	16.35	18.97	23.08
CLEAN TONS PRODUCED (THOUSANDS)	1252.7	1033.6	1032.5	1033.6	1033.6	484.2
COST/CLEAN TON($)	14.05	15.48	16.79	18.16	21.08	25.65

Figure 16 *(cont'd.)*. MCOM Sample Output.

The modeling system has been applied to a variety of projects, including: an industrial engineering assessment of a midwestern coal mining complex using MINIE followed by installation of MPASS ton conduct face simulation studies; extensive planning associated with the opening of a new, large, two-seam midwestern coal mine in which CPMINE, MPLAN, MCOM and other models in MISS have been applied; long-range venture analysis for oil shale mining employing the same system of models; economic assessment of a South American phosphate mine to support World Bank investment decisions; and assessment of new mining technologies under consideration in government research projects.

The MISS models have been developed over a period of eight years and incorporate applications on large mainframe computers, mini-computers and personal computers. Continuing evolution of MISS is planned to address the growing demands of the mineral industries that have resulted from the revolution in computer technology occurring in the 1980s.