COAL MINE BELT SYSTEM DESIGN SIMULATION

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Abstract

Design of a belt system to convey coal from the mine face to mine mouth can not economically be based on manufacturers rated output of mining equipment due to the high probabilities of random equipment breakdown. A model of the mining environment was developed such that the configuration of the mine can be easily redefined without reprogramming. Coal production is simulated at the mine face and belt overload conditions are checked for as the model simulates conveyance of the coal over the defined system of belts.

1. INTRODUCTION

The decision to construct a fossil fuel electric generating station must be based on the assumption that the coal mine developed by the prime contractor will be capable of providing the necessary quantities of coal to maintain an economic level of generation. This assumption must, and does, have a degree of assurance in that when a contract of this magnitude is let to a coal mine operator the power company retains veto power over proposed mine shaft designs and engineering specifications. Thus, the power company's engineers are confronted with two major areas of concern:

(1) Do the physical areas to be mined in a given year contain enough coal?

(2) Is enough mining equipment scheduled and can the proposed belt conveyor system adequately feed out the coal once it is mined?

The first area of concern is investigated by analyzing the results of geological drillings. The second is not so tangible a task. To design for the manufacturer's rated maximum output of each mining machine is unsatisfactory due to the high cost involved and the very high probability that at any given time at least one piece of equipment will be out of service. The costs involved in installing an over-adequate belt system can mean the difference in a net profit or loss for the mine operator. To under-design the belt system is to invite spillage, which can also be very costly as it must be manually re-loaded onto the belt system and if excessive spillage occurs the belt system must be stopped and associated mining activities must then be curtailed until the belts can be started again. Thus, either an over or under designed system can spell failure for a large scale mining operation in that costs are either unnecessarily high or that production is unnecessarily curtailed.

The possible solutions that lie between these two extremes are varied and expensive. The solution chosen, once begun, is adhered to under penalty of even further excessive costs incurred by changing design in mid-stream of mining operations.

2. CONCEPTION OF THE MODEL

2.1 INITIAL MODEL CRITERIA

Company philosophy in this situation was to seek information as to the feasibility of a lesser expensive design solution. It was decided that in a contract of this magnitude (several million dollars), "seat of the pants" direction was inadequate.

An inadequately designed belt system could either force the mining company into forfeiture of the mine to the power company for failure to provide the contracted tonnage (in the process of this failure to deliver, the additional cost of purchasing coal elsewhere under smaller volume unfavorable terms could be in excess of ten thousand dollars per week to the power company) or if overdesigned cause loss of profits due to higher overhead costs. An adequate system of minimum investment needed to be established, to the interest of both parties.

Thus, investigation into the feasibility of a computer simulation was begun. The model would have to be designed to allow variable definition of the belt system and mining equipment involved so that the company engineers could vary the design from run to run. Output would have to include both tonnage of mined coal and tonnage of coal spillage, for the acceptance of a belt conveyor design hinges upon its capability to carry from mine face to mine mouth the number of tons per shift necessary to fulfill the utility's contract and yet keep coal spillage at a level that is tolerable. (It should be noted that mine shafts are low, narrow places not requiring too many tons of spilled coal to block them, thus bringing the entire operation to a standstill.)

2.2 HUMAN AND DATA RESOURCES

Those familiar with coal mine operations were unfamiliar with computer techniques and vice versa. Two analysts in the Operations Research group were exposed to a crash enlightenment on coal mining techniques and equipment for one week. They then, with a Coal Bureau engineer, hashed out what data was necessary to define the environment that was to be simulated. The mining configuration and belt design originally proposed by the mining contractor was available. The factory specified maximum output rates were available from factory literature and other studies; there were discrepencies here and the Coal Bureau engineer was called upon to provide the most probable rate of output. The missing link was the entire area of equipment reliability. It was well known from experience that due to a myriad of causes mining equipment was seldom "up" for an entire shift and was sometimes "down" for an entire shift. Our mine is to use two distinct types of mining equipment; Longwall and Continuous Miners. The only source of the required information was found to be foreman's daily logs from current mining operations where the conditions are similar to those expected in the new mine and where the miners used are of the types proposed for use in the new mine. These logs contained the durations during a shift when the miner was not producing and the reason for the delay.

Two two man teams were assigned to develop frequency distributions from these logs of the "up" and "down" times for both Continuous and Longwall mining units. The recorded time durations provided erratic frequency patterns due to the apparent reluctance of foreman to deal in time intervals of 25, 35, 55, 65, etc. minutes, they preferred to record "round" time of 30, 60, etc. However, independent segmentation of each of the four frequency distributions provided subdivisions with frequency ranges such that within each segment the frequency of observations could logically be expressed by either a mean value or a linear equation. (See Figures 1a-d). This technique transformed the reliability information into a form that was compatible with a computer application.

2.3 INITIAL MODEL FLEXIBILITY CRITERIA

There are several ways to both increase total coal outflow capability from a mine and lessen spillage; these ways were examined as to the necessity of including provisions for them in the model. It was decided that the model would have to be capable of handling the following without re-programming:

(1) Variable definition of the physical belt layout.

(2) Variable definition of the displacement of mining units within the mine.

(3) Ability to change any or all of four factors that define a particular belt and its carrying capability, i.e.

- (a) Speed that the belt travels at (f.p.m.)
- (b) Width of belt
- (c) Idler arm angle
- (d) Length of belt

3. SELECTION OF PROGRAMMING LANGUAGE

At this point the language to be used in programming the model was selected. GPSS was ruled out due to the requirement for varying definition of the mine/belt profile. Fortran was considered, but PL-1 was chosen on the strength of its 'structure' capabilities. Structures were recognized as the most compatible method of developing the Definition Control Tables that would have to be programmed for, if the model was to be a flexible tool that could simulate any conveyor belt design in any mine or portion thereof.

4. IN DEPTH PROBLEM ANALYSIS

4.1 BACKGROUND ON SPILLAGE

The belt system in any mine is made up of a main belt that deposits the coal outside the mine mouth and a series of feeder belts that empty their loads on either the main belt or other feeder belts. There can thus be several "levels" of feeder belts. (See Figure 2, the originally proposed belt design.) Throughout the mine, the production of any given miner is deposited on a belt, probably a feeder, and then is conveyed to the mine mouth. Overloads (spillage) can occur wherever the production of a miner is deposited on a belt or wherever a lower level feeder belt deposits its load on another belt. Thus, the Definition Control Tables for both miners and belts would have to reflect their respective point of deposit so that the model could chain the flow of coal from the point of mining, over the belts and out of the mine mouth.

4.2 MODEL DEVELOPMENT

With this background of the problem known, the philosophy for the computer model could then be defined. The facilities in this model would be defined by card input and would be known to the program from the Miner Definition Control Tables. These facilities would generate transactions (tons of coal), which would be deposited in a storage element. These storage elements would be the conveyor belts; they, too, would be defined by card input and would be known to the program from the Belt Definition Control Tables. While a moving belt is really a continuous thing, for the purposes of this simulation each belt was considered in terms of segments; these segments were taken to be the length that the belt would travel in one minute. Thus, a belt 8,400 feet long, defined to be run at 550 fps would have sixteen segments in our model. The clock is incremented in one minute intervals, in the space of one model time unit transactions advance one belt segment. The transactions advance through the model and are accumulated as either spillage or tons of output, as the simulation dictates. The chaining of feeder belts from mine face to opening is defined in the Definition Tables; the model is programmed such that it only needs to know onto which segment of which belt a given feeder belt terminates.

4.3 MODEL LOGIC

4.3.1 Initial Status

At the start of the simulation, mine and belt definition data is read in as card input (See Figure 3) and the Definition Tables are built by the model. All of the data necessary to define any belt system in any mine layout is contained in the data cards, the exception being any mining environment that might utilize other than Longwall or Continuous mining devices. For each miner a Miner Definition Table is created from the miner definition data cards.

The miner output rate and the segment of the feeder belt that the miner deposits its output on are calculated. All miners are placed in "down" status at the start of the simulation; this conforms to experience in an actual mining environment. The duration of down time units are obtained randomly from subroutines based on the frequency distributions of "up" and "down" times for miners mentioned above. The time so obtained is then stored in the Miners Definition Table (See Figure 4a). One Belt Definition Table per belt is created from the belt definition data cards, belt capacity (per segment, i.e. tons per minute), number of segments and the segment of the next highest level belt onto which this belt deposits its load are calculated (See Figure 4b).

4.3.2 Incrementation of One Time Unit

As the model clock is incremented (one simulated time unit is equivalent to one minute), each Miner Definition Table is checked for the due time to reverse its status. If there is a match, the proper subroutine, outlined above, is called to randomly obtain the time interval for the next "due up" or "due down" time. If the miner is now "down", it is bypassed. If it is "up", another random number is obtained to determine if it is in a "produce" or "wait" state; this reflects delays at the mine face due to equipment positioning or shuttle car positioning. When the miner is in a state of production, its output rate is added to the feeder belt segment pointed to by the miner's Definition Table. The output rate, in tons per minute, is obtained either from a control card (continuous type miners) or is randomly selected from a frequency distribution of output rates (Longwall type miners).

This belt segment is then checked for an overload condition; if found the amount of spillage is accumulated and an output message notes which miner overloaded which belt by how many tons. Three approximations were made in the model here that did not completely reflect the real-world situation. Loading of coal was assumed to fall only into the one segment of a belt; the coal was assumed to be evenly displaced over the segment and the continuous miners output rate was treated as a constant (redefineable by input control card). The first two of these approximations were felt to have little impact on total spillage, which is the prime output sought and substantially reduced programming time. Continuous miner output rate was held constant only because no data on variations of output rate were known to exist; the effect here would be to slightly inflate spillage, which might serve as a safety factor.

4.3.3 Chaining of Belt Segments from Mine Face to Mouth

Next, the loading on all belts is advanced one segment, the deepest level belts are advanced first, their termination into the next level of belts is checked for overflow and spillage, if any, is accumulated and posted as noted above (See Figure 5). Chaining of coal flow through the several levels of belts thus is facilitated by the information stored in the Belt Definition Tables.

After the belt that deposits its coal out of the mine mouth (lowest "level") is processed the clock is incremented and the cycle is repeated. The model is run over ten simulated seven hour shifts under any given design.

5. OUTPUT CONSIDERATIONS

5.1 PRINTED OUTPUT CONTENT

To help make the results of the simulation communicative to non-computer oriented engineers and mining officials, the printed output was held to a minimum. Each occurence of spillage is pinpointed, total spillage, total coal production and production per mining unit are the only output (See Figure 5). This provides the pertinent results of each simulated shift for analysis without the rigors of extracting necessary data from a possible vast myriad of extended background information.

5.1.1 Output Verification

The simulated production tonnages for mining devices were compared with actual tonnages for like equipment in operating mines and found to be compatible; this was our only significant means of comparing the output of this model to the real world. Corporate time limits prevented gathering data on an existing mine (we would have to go through a third party) for comparisons. Verification of a model such as this is somewhat of an impossibility without actually developing a coal mine and measuring its output and spillage; a very expensive verification, yet the only real verification and indeed the raison d'etre for this model in the first place.

6. CONCLUSION

This model was concieved and completed by two analysts within a three week period to help analyze the design originally proposed by the mining company (See Figure 2) prior to a design acceptance meeting. The results of the first simulation run, and succeeding ones since then have definitely helped to prevent what in all probability would have been a multi-million dollar mistake.

As simulation runs indicated excessive spillage the mine design and belt specifications were varied via input data cards. Output for each succeeding run was examined for the necessary production tonnage accompanied by an acceptable level of spillage. The result being that engineers from both the mining company and Pennsylvania Power & Light Company have agreed to use the "two mine mouth" concept as part of the least expensive design capable of conveying the required tonnage within tolerable spillage limits (See Figure 6). Acceptance of the model as a design tool by all parties concerned was a most gratifying experience.

The model currently fits into 15K of IBM 360 storage and executes ten simulated shifts in under five minutes. Should another fossil fuel generating plant be planned by our company the same analysis of some future coal mine will be required. This model will be applicable to that situation with only minor, if any, changes due to the completely universal mine configuration data input capabilities (See Figure 3) and the Definition Control Tables (See Figure 4). Frequency distributions for "up" and "down" times of new types of mining equipment could easily be added, allowing expansion of this model to handle any future configuration.

7. BIOGRAPHY

Mr. Juckett is a Procedures Analyst with Pennsylvania Power and Light Company, where he is currently involved in the implementation of control modules for the corporate customer/management information system. He has a BA in economics from Union College.

FIGURE 1a

Longwall Miner Down Frequency Distribution-Weighted Segments

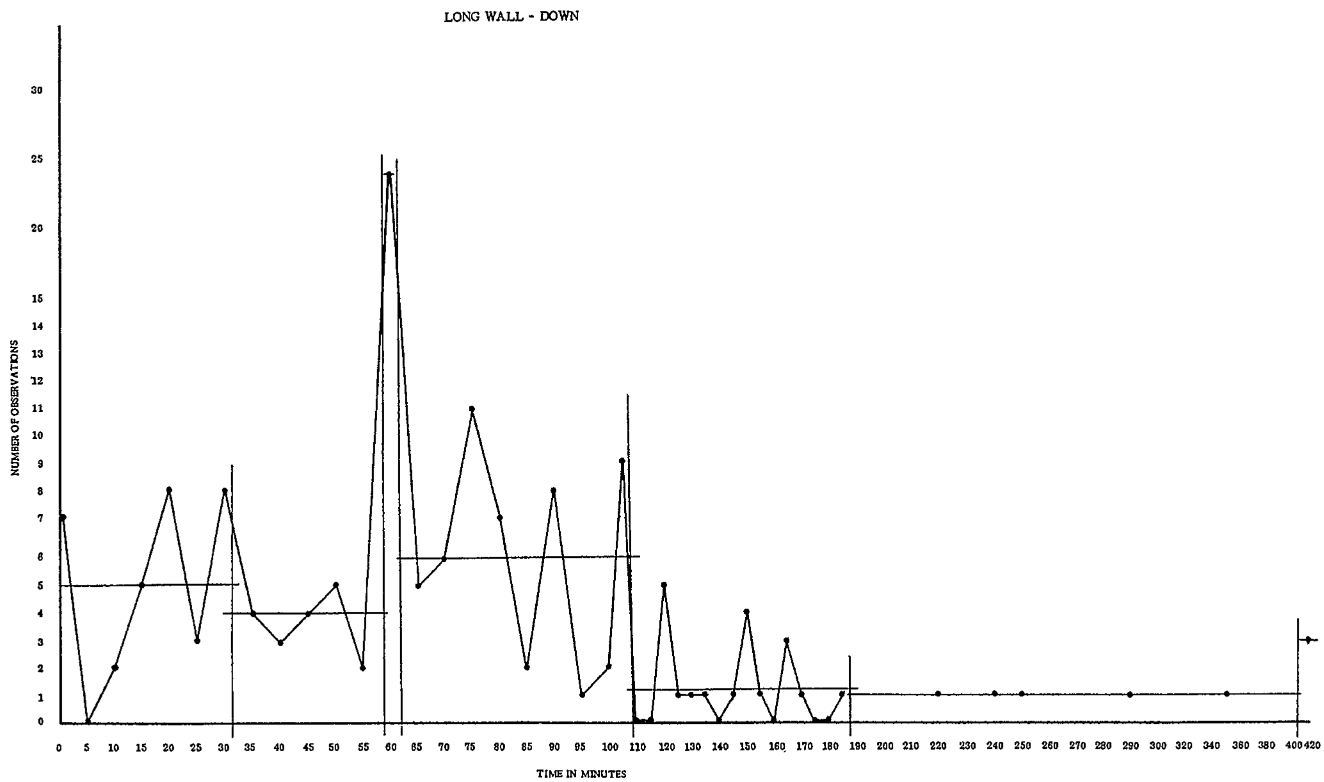


FIGURE 1b

Longwall Miner Up Frequency Distribution-Weighted Segments

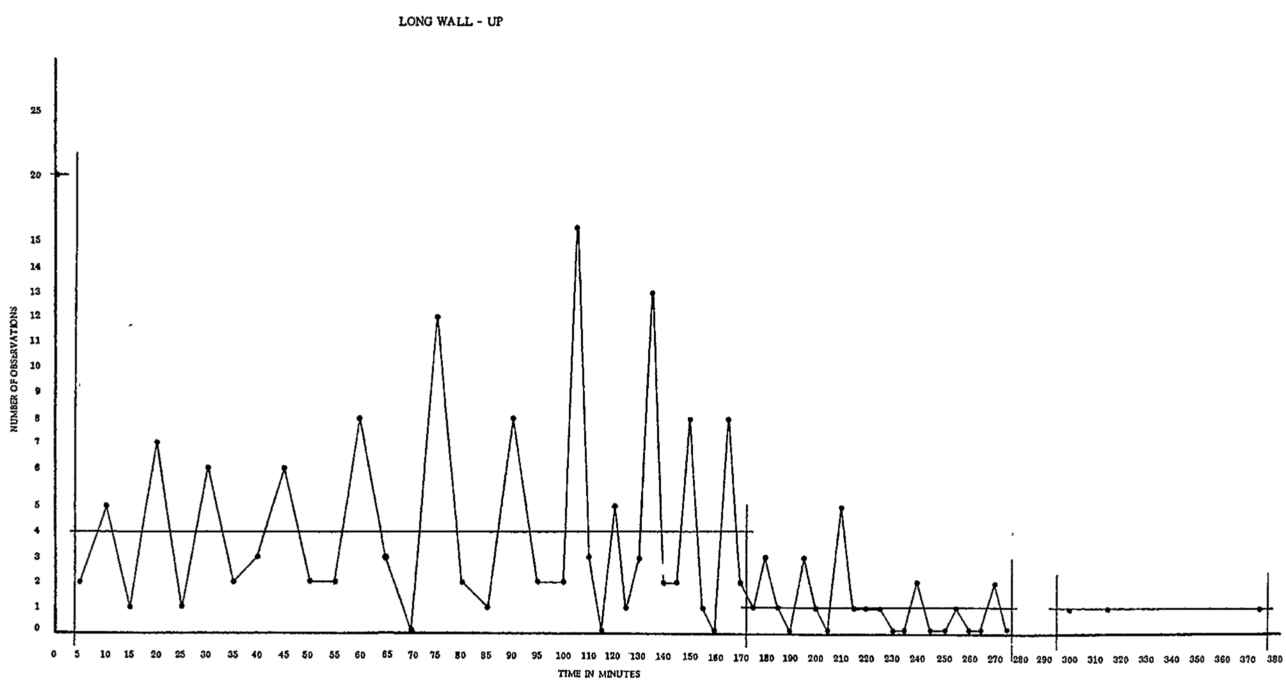


FIGURE 1c

Continuous Miner Down Frequency Distribution-Weighted Segments

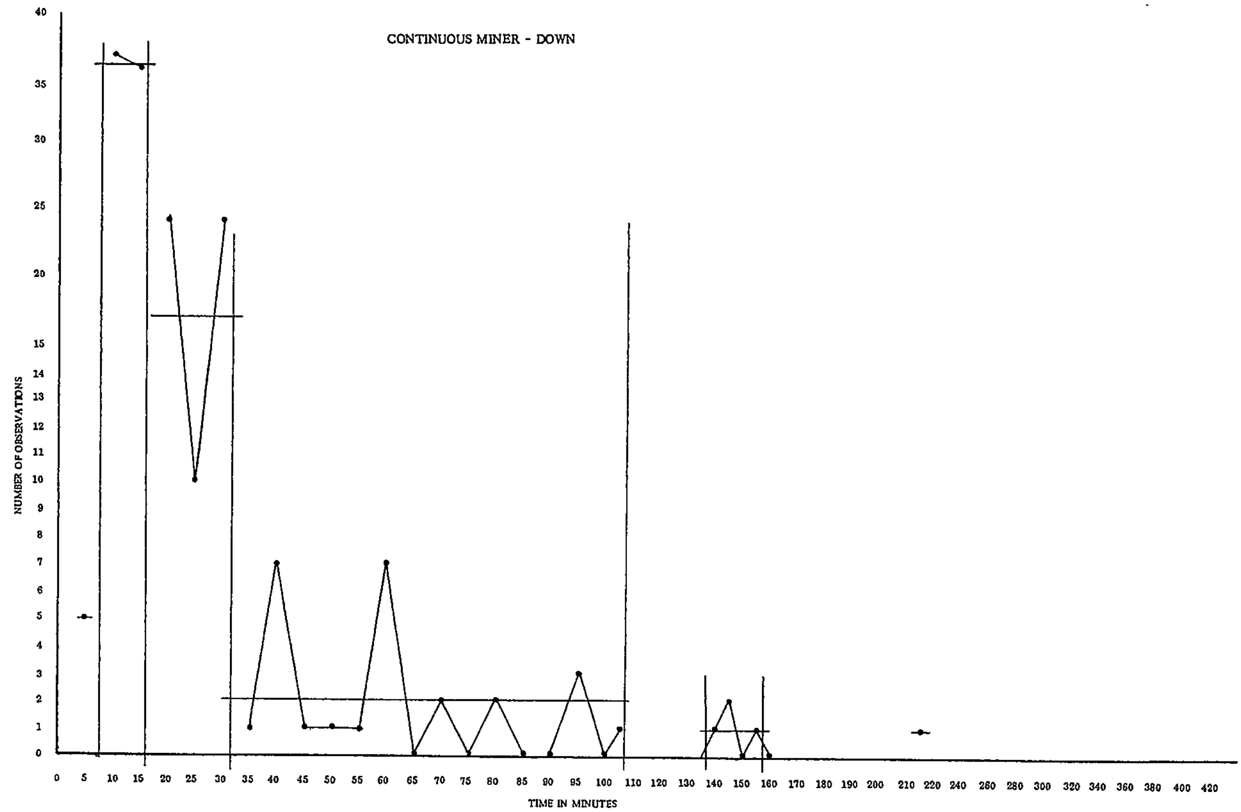


FIGURE 1d

Continuous Miner Up Frequency Distribution-Weighted Segments

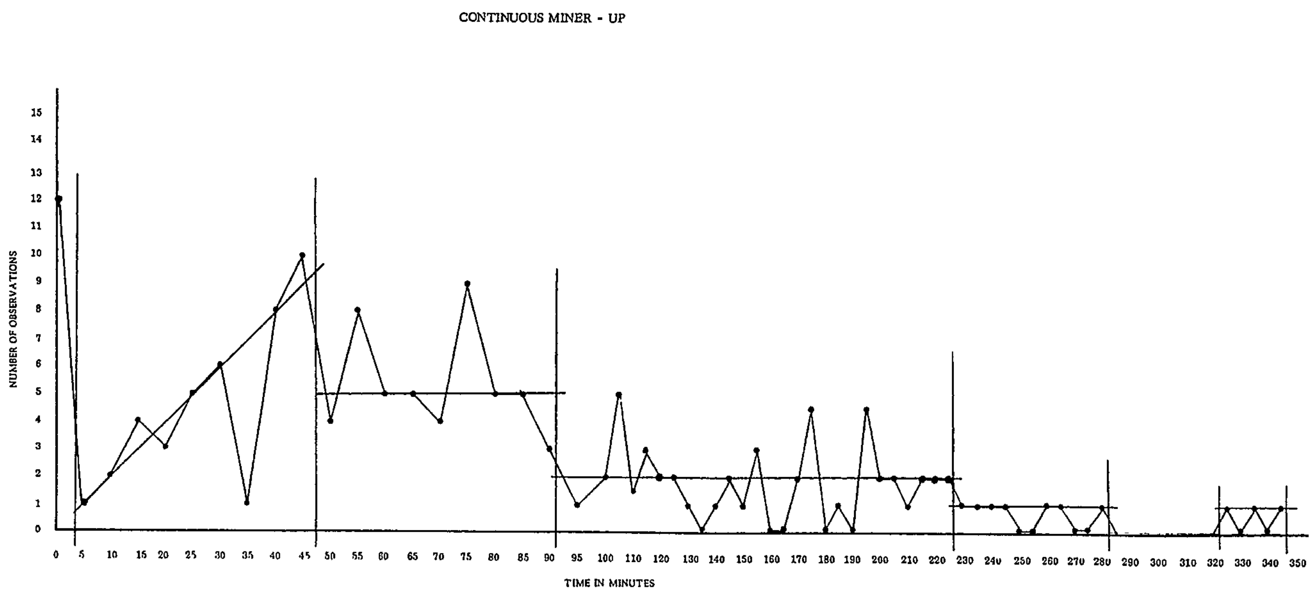
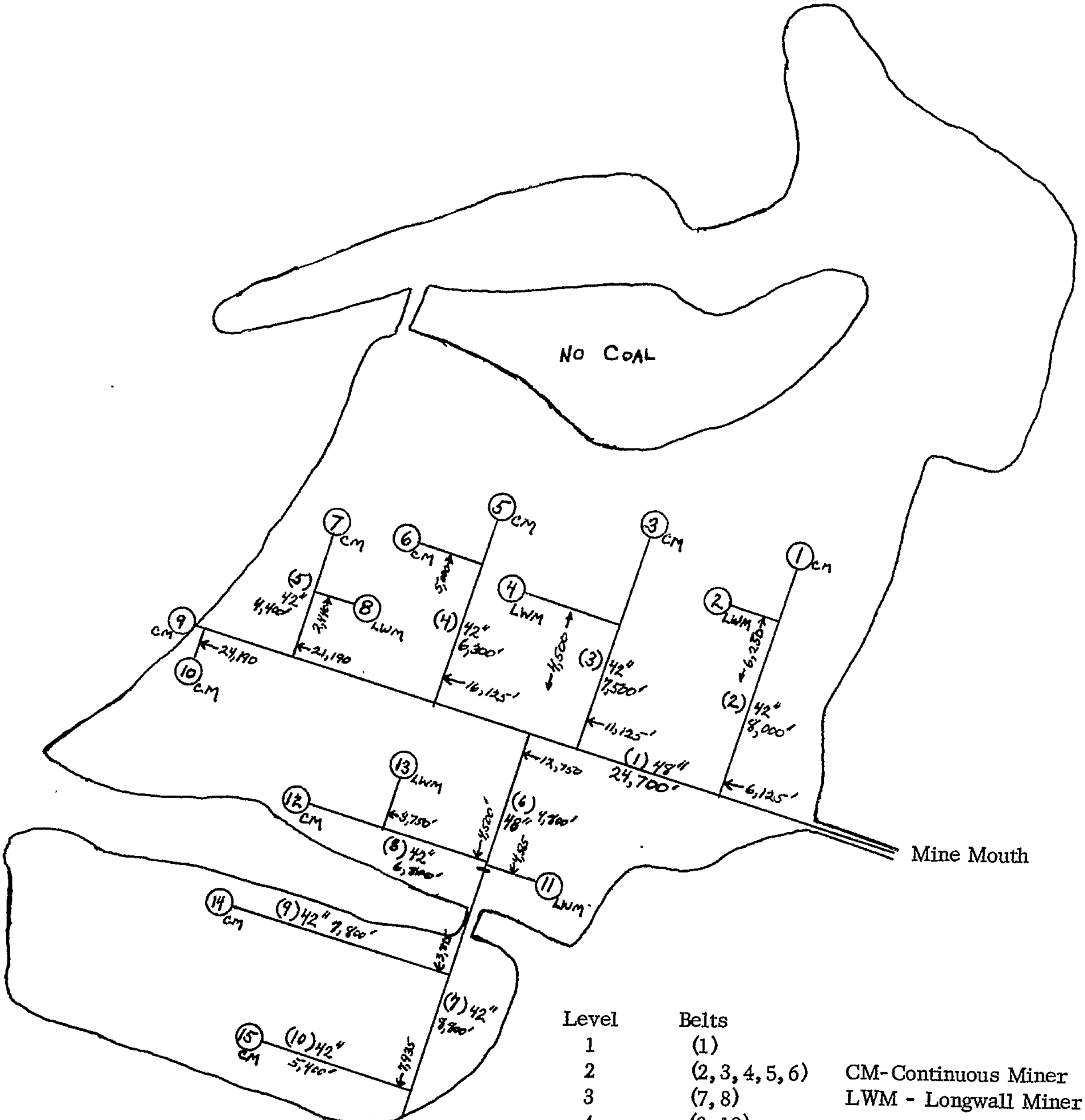


FIGURE 2

Originally Proposed Belt Design



Level	Belts
1	(1)
2	(2, 3, 4, 5, 6)
3	(7, 8)
4	(9, 10)

CM - Continuous Miner
LWM - Longwall Miner

Main Line Belt Layout 1375

Lancashire #26
1-Mile Concept
Scale 1"=2000'

FIGURE 3

Input as Required to Create Definition Tables

MINE BELT SIMULATION

MINER DEFINITION

Unit #	Type	Deposit Pt. Belt Ident	Deposit Pt. Feet From Origin
01	L	03	3500
02	C	05	4000
03	L	04	4500
04	C	04	7500
05	C	04	9500
07	C	09	9100

MINE BELT SIMULATION

BELT DEFINI[TION]

Belt Ident	Level	Terminal Belt Ident	Terminal Feet From Origin	Width	Speed (fpm)	Idler Angle	Belt Length
01	1	0	0	48	550	35	7500
02	2	01	7450	42	550	28	13000
03	3	02					
07	3	06	14000	42	550	28	9300
08	4	07	9300	42	550	28	1700
09	5	08					

(Data above refers to belt design shown in Figure 3.1)

FIGURE 3.1

Proposed Belt Design of Upper Seam-Two Mine Mouth Concept
(referenced by Figure 3)

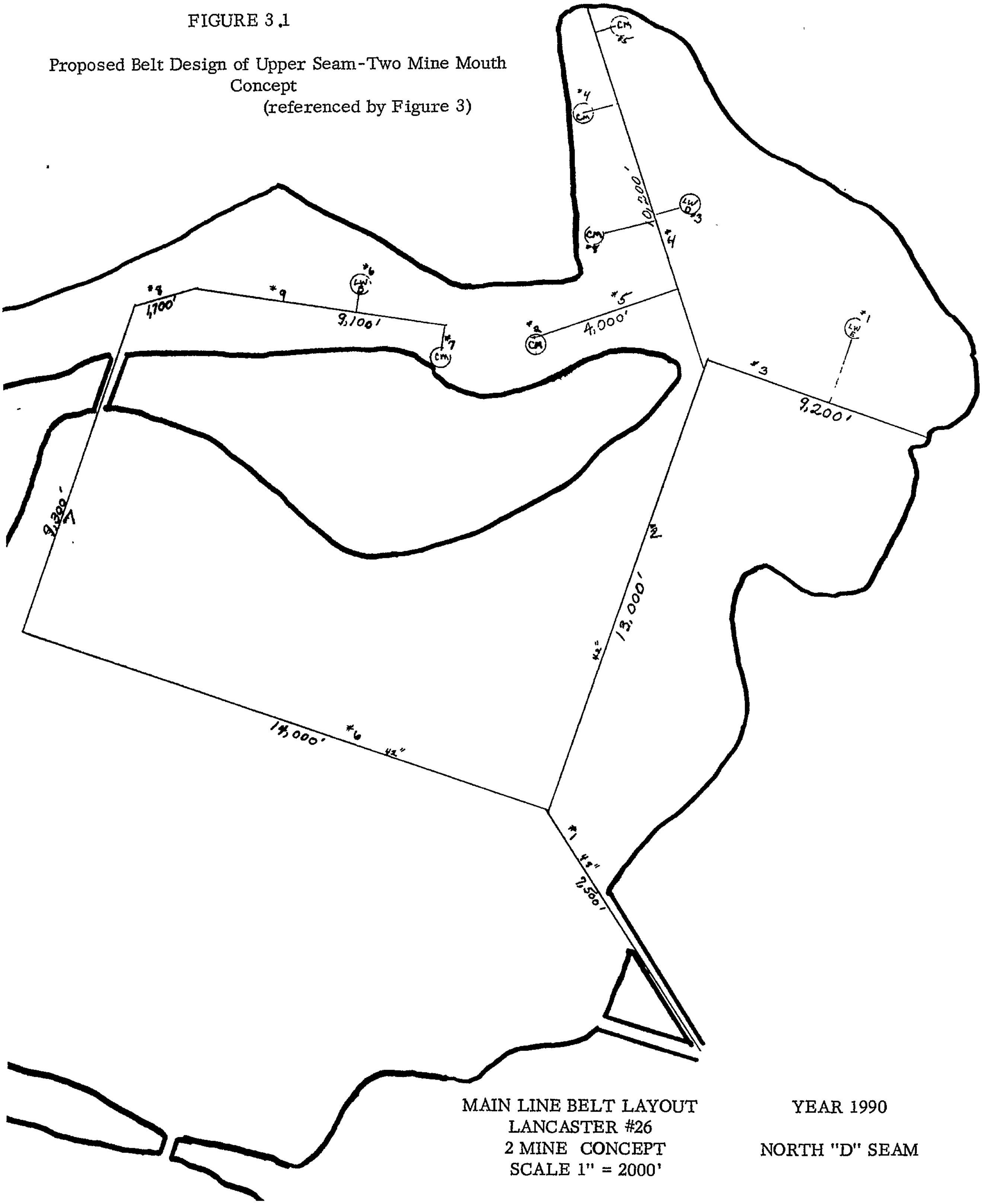


FIGURE 4a

MINER DEFINITION TABLE

1.	TYPE (continuous or longwall)	INPUT
2.	DEPOSIT BELT IDENTIFICATION NO.	INPUT
3.	DISTANCE FROM MOUTH OF DEPOSIT BELT	INPUT
4.	OUTPUT RATE (tons per minute)	CALCULATED
5.	DEPOSIT BELT SEGMENT NUMBER	CALCULATED
6.	UP/DOWN SWITCH	VARIABLE WITHIN SIMULATION
7.	TIME DUE UP	VARIABLE WITHIN SIMULATION
8.	TIME DUE DOWN	VARIABLE WITHIN SIMULATION

FIGURE 4b

BELT DEFINITION TABLE

1.	WIDTH	INPUT
2.	SPEED	INPUT
3.	IDLER ANGLE	INPUT
4.	LENGTH	INPUT
5.	LEVEL	INPUT
6.	DEPOSIT BELT IDENTIFICATION NO.	INPUT
7.	DISTANCE FROM MOUTH OF DEPOSIT BELT	INPUT
8.	BELT CAPACITY (tons per minute)	CALCULATED
9.	DEPOSIT BELT SEGMENT NUMBER	CALCULATED
10.	NO. OF SEGMENTS IN (this) BELT	CALCULATED
11.	LOADING (tons) ON EACH SEGMENT OF (this) BELT AT ANY POINT IN TIME	VARIABLE WITHIN SIMULATION

FIGURE 5

Output of Coal Mine Belt Design Simulation

SHIFT 8	BELT OVERLOADED	LIMIT	LOAD	CLOCK	OVERLOAD FROM BELT MINER
	1	26.6	29.4	190	6
	1	26.6	27.3	373	6
	1	26.6	27.4	375	6
	1	26.6	27.3	379	2
	1	26.6	39.2	379	6
	1	26.6	30.6	384	6
	1	26.6	33.6	387	6
	1	26.6	29.4	391	6
	1	26.6	27.4	397	6
	1	26.6	27.3	411	6

TOTAL PRODUCTION,1 7-HR SHIFT 4660.0 TONS   TIME EMPTY-470

INDIVIDUAL MINER OUTPUT--CONTINUOUS	LONGWALL
UNIT 1 288 TONS	
UNIT 2 96 TONS	
UNIT 3 382 TONS	
UNIT 4 282 TONS	
UNIT 5 234 TONS	UNIT 6 1431 TONS
	UNIT 7 729 TONS
	UNIT 8 1251 TONS

SPILLAGE 32.7 TONS

FIGURE 6

Two Mine Mouth Concept - 1975 Configuration
(Accepted Design)