A SIMULATION MODEL FOR CONTINUOUS MINING SYSTEMS

by

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Chapter 1

INTRODUCTION

Until recently most of the operational decisions made by the mining industry were based upon previous experience, analysis, and intuition. These decisions were highly subjective depending on the quality and experience of managerial personnel. As mining operations grew larger and more complex in nature, a large number of variables and the interaction among these variables became an important factor in the decision making process. In addition to the size and complexity of the operations, such external factors as Federal Safety and Health Regulations, deterioration of labor-management relations, inflation and competition required management to control costs more effectively and to minimize risks involved in decision making. It became apparent that less subjective methodologies were needed to address the problems of planning mine layouts, selecting equipment, scheduling operations, and comparing alternatives.

Because of the large number of variables involved in mining and the variability and interaction among them, many analytical modeling techniques have not been developed or adopted in the mining industry. However, computer simulation has been one of the most widely used techniques of operations research in mining because of the ability of computers to store, retrieve and manipulate much data in the modeling mining systems. Computer simulation models are used by mine management to aid in solving design, engineering,managerial and operational problems. Significant progress has been made in the design and the selection of equipment for new mining operations, in the analysis of existing operations for possible improvements, in the design of material handling systems, and in calculations of the ore reserves.

Most of the computer simulation models in use require computers possessing generous memories and rapid execution. Along with a user experienced in computers and simulation models, the models have required extensive data preparation and long execution time resulting in significant cost implementing these models. Consequently, they have limited the use of computer simulation models in the mining industry. With the availability of the improved micro- and mini-computers, these difficulties have been largely overcome and have become more valuable to mine management for decision making.

With the computer program entitled FACESIM, the computer simulation model of face operations in room-and-pillar mining used widely in the mining industry, it was decided to adapt this versatile and useful program in the following manner:

1. Modification of FACESIM to simulate continuous mining systems on microcomputers equipped with a minimum of 64K random access memory and a FORTRAN compiler;

2. Reduction in the data to be prepared for input into FACESIM to assist the user, who may not possess experience in simulation and data preparation;

3. Modification of the program to be able to simulate equipment breakdowns without greatly adding to the complexity of the program.

The objective of the careful adaptation of the computer program FACESIM hopefully would result in a computer program capable of being able to achieve the design and selection of equipment for continuous mining operations, the design of mining layouts, and the analysis of existing operations.

To assist the mining engineer in the design process, the adopted simulation model may provide output data on coal production with the analysis of the time required for the equipment to perform the various activities.

Chapter II

COMPUTER SIMULATION

2.1 GENERAL

As the industry has grown in size and complexity, the methodology to solve the problems faced in mine planning, scheduling and operations has to include more and more details of the system to obtain realistic results. When using analytical methods to solve the problems, it is difficult, if not impossible, to include a large amount of details. These difficulties in using analytical methods to get reasonably accurate results have made computer simulation the most widely used management science and operations research technique.

Computer simulations have been used in analyzing various systems. They are used to better understand the existing system, to evaluate changes proposed in the existing system, to evaluate the proposed alternatives or to forecast and aid in planning.

The wide use of computer simulation is due to many technical attractions that it can offer compared to other management techniques available. Some of these advantages are (Fishman, 1978, and Law and Kelton, 1982) as follows:

1. Several years of activities can be simulated in minutes without disturbing the real system.
2. The detailed structure of changes in real system over small intervals of simulated time, which can not be observed in real time, can be studied.
3. Sources of variation can be identified and studied. This is important when statistical analysis of the relations between the input and output variables is to be performed.
4. Measurement errors do not occur.
5. Simulation experiment can be stopped to review the results to date and then the experiment can be resumed without the loss of continuity.
6. The state of simulation can be restored.
7. Replication of an experiment is possible.
8. Greater amounts of detail of the system can be included in the model.

In general, the greater the amount of details to be included in the model, the more realistic the model is. Consequently, the results from the simulation model conform to reality more closely. However, judicious restraint on the part of the modeler in regard to details is often the better policy for the following reasons:

1. To include details, time and effort need to be devoted to preliminary observations of individual characteristics of the system. This introduces a cost that must be justified with respect to the objective.
2. Added details require added programming, especially for the contingencies that the details specify; it also makes it difficult to locate sources of error because of many potential trouble spots.
3. Added details in the model increase computer time and memory requirements and, therefore, the cost. Testing for special situations, along with the need to update and manipulate system attributes, contributes to this cost.

The following are the disadvantages associated with simulation studies that one should keep in mind when developing a simulation model:

1. Greater confidence is placed on simulation results

than is justified because of large volume of numbers produced. However, if the model is not a 'valid' representation of the system, the results will be of no use.

2. The simulation model is often used to predict beyond the range of its applicability without proper qualification.

3. Though simulation models are expensive and time-consuming to develop, there is no guarantee that the time, effort and money spent will return useful results with satisfactory-benefits.

4. Since a stochastic simulation model produces estimates of the model's true characteristics, several independent runs of the model will be required for each set of input parameters. For this reason, simulation models are not as good as analytical models for optimization.

5. There is sometimes the tendency of the investigator to defend his particular depiction of the problem as the best representation of reality.

2.2 SIMULATION PROCESS

A model may be defined as a description of a system. A system is a group of interdependent objects which perform a specified function (Shannon, 1975). To build a model of a system, an objective must be developed and the essential features of the system must be abstracted by defining significant elements and the relationships among them. The computer simulation model should also include the desired performance measures and design alternatives to be evaluated. Model-building is an iteractive process requiring redefinitions and redesigns. Typically, the development of simulation model begins with a simple model which is embellished in an evolutionary fashion to meet the problem-solving requirements. The model-building approach to problem solving is illustrated in Figure 1.

Simulation model building is a part of simulation process in which Shannon (1975) identified several stages. The following stages are slightly modified from the one presented by Shannon.

1. Problem formulation: Definition of the boundaries of the systems, restrictions and measures of performance including the statement of objective.

2. Model formulation: The abstraction of the real system

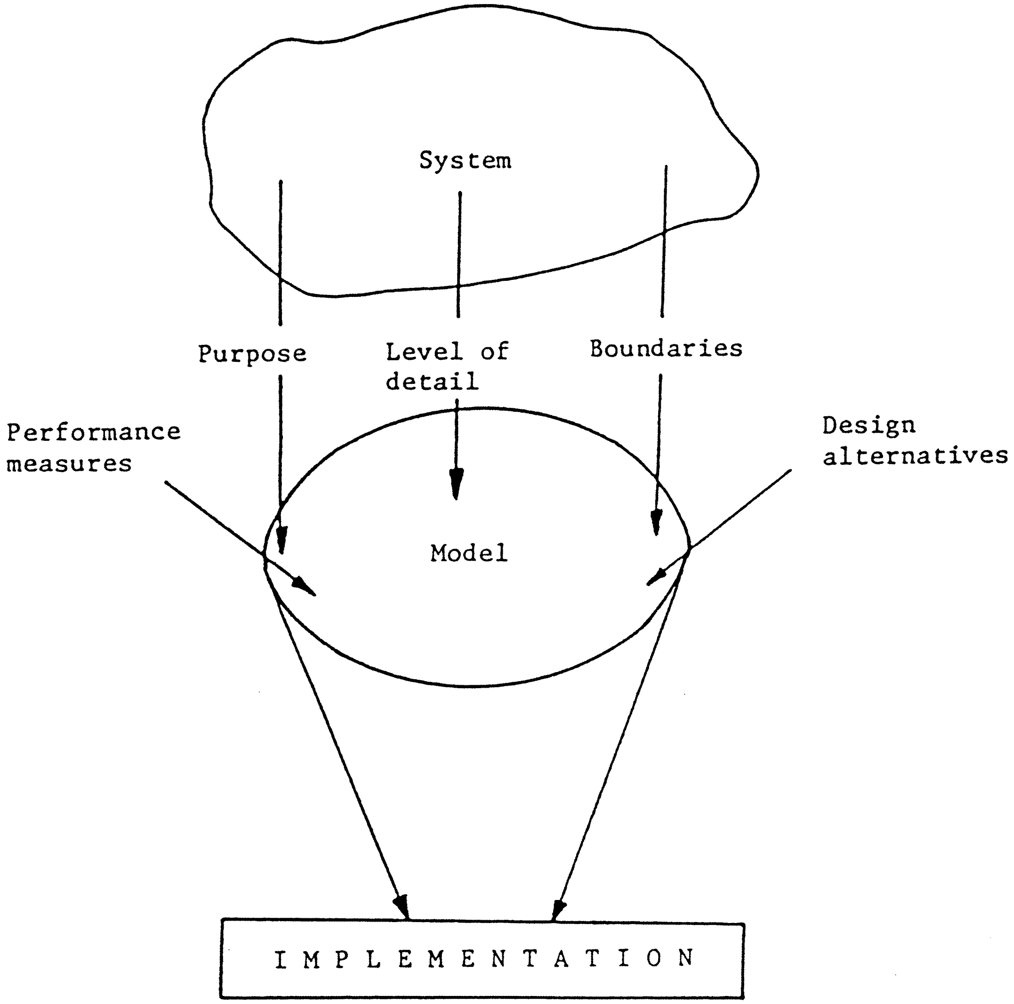


Figure 1

A Model-building Approach for Problem Solving

(Pritsker and Pegden, 1979)

into mathematical and logical relationships in accordance with the objective. The crucial decisions are what simplifying assumptions are valid, what elements to be included and what interactions occur among the elements. The amount of details to be included should be based on the purpose of the model.

3. Data preparation: The identification, specification and collection of data.

4. Model translation: Coding the simulation model in a computer language.

5. Verification and validation: Verification is the process of determining that the simulation model functions as intended, that is, debugging the computer program. See Law and Kelton (1982) for different verification techniques and Fishman and Kiviat (1967) for statistical methods used in the verification process.

   Validation is the process of determining that the simulation model is a reasonable representation of the real world system under study (Van Horn, 1971). See Law and Kelton (1982), Fishman (1973, 1978) and Kleijnen (1974, 1975) for details on model validation.

6. Strategic and tactical planning: This refers to

the task of establishing the experimental conditions for simulation runs. Strategic planning is developing an efficient experimental design to determine the relationship between input and ouput variables or to optimize the desired output variables.

Tactical planning is the determination of how each of the simulation runs is to be made to obtain the most information from the data. Two specific issues are the starting conditions and methods of reducing the variance of output variables (Pritsker and Pegden, 1979).

7. <u>Experimentation</u>: Experimentation is the execution of the computer program.

8. <u>Analysis</u> <u>of</u> <u>Results</u>: Analysis of simulation results is done to draw inferences about the system or to compare alternatives. See any of the following: Law and Kelton (1982), Fishman (1967, 1973, 1978) and Kleijnen (1974, 1975) that provide detailed procedures for statistical methods to analyze simulation results.

9. <u>Implementation</u> <u>and</u> <u>documentation</u>: This process puts the results from the simulation model to use and documents the model and its use. The successful implementation of the results is largely dependent on

the degree of success achieved in the previous stages of the simulation process, involvement of the user in model development and the degree of his understanding of the model and its results.

Stages in the simulation process rarely occur in the sequence mentioned above because of changes made in assumptions, reformulation of the problem, redefinitions and redesigns of the model as the model builder understands the system better and develops insight into the problem, and difficulties involved in different stages. The relationship among the stages in the simulation process and how one advances through them are shown in Figure 2.

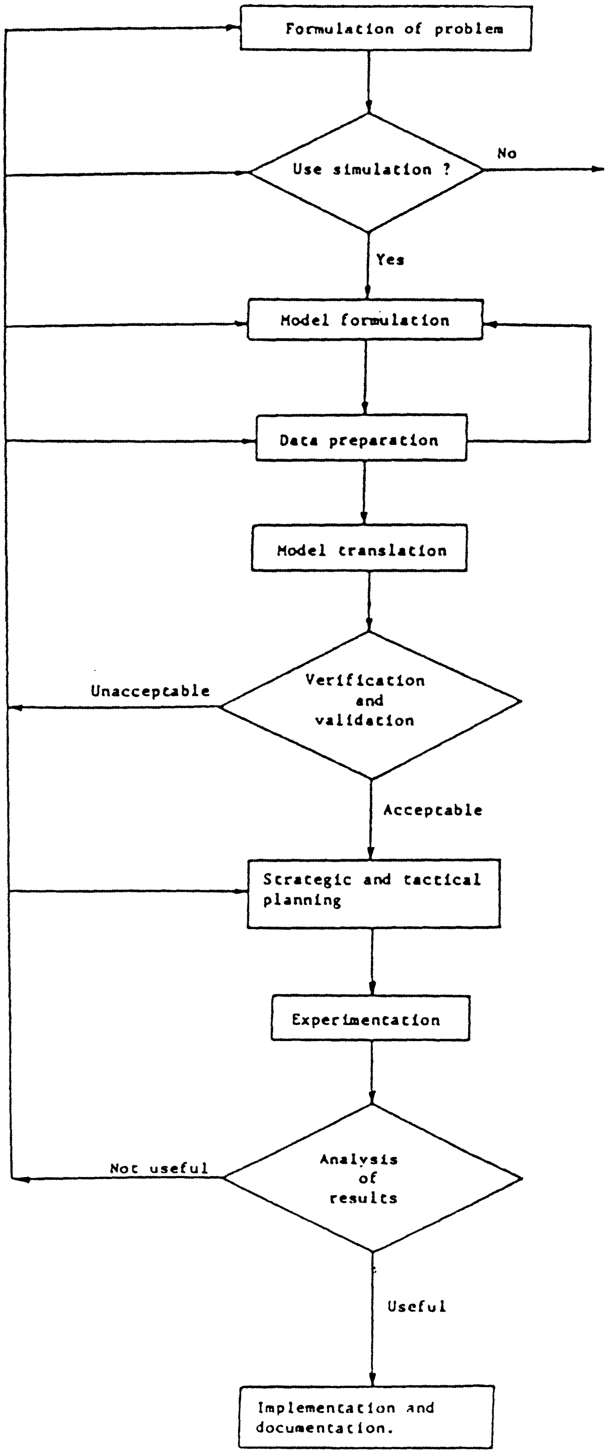


Figure 2

Interaction Among Stages in Simulation Process

(Shannon, 1975)

Chapter III

FACESIM

FACESIM (FACE operations SIMulator) is a computer simulation model developed at Virginia Polytechnic Institute under the sponsorship of the Office of Coal Research during the period 1962-64 primarily to simulate room-and-pillar mining systems with the maximum capability to use three shuttle cars with a loader or a continuous miner.

3.1 CONVENTIONAL MINING SYSTEMS

The conventional room-and-pillar mining of coal involves five operations at the face. They are (1) cutting, (2) drilling, (3) blasting, (4) loading and hauling and (5) roof bolting. Since loading and hauling of coal take place simultaneously in a cut, they are considered as one operation for the purpose of building a simulation model. These operations are performed by the coal-cutting machine, drilling crew, blasting crew, loader and conveying equipment (shuttle cars or conveyors) and roof bolter respectively. All these operations are carried out in the same sequence mentioned above in each cut. Of these five operations, loading-and-hauling is the primary operation and the rest are supporting operations necessary to loosen coal in the seam and to provide safe operating conditions.

The number of headings advanced in a panel must be greater than or equal to the number of operations to be performed at each cut to mine coal. Therefore, in conventional mining, the minimum number of headings is five, one operation per face. The conventional mining system may be compared to the pure flow shop in production scheduling where jobs are routed through machines to perform operations on jobs in a predetermined order. However, in conventional mining, unlike in a typical flow shop, the machines (the equipment in the mine face) move from one job (face) to another while jobs are stationary as shown in Figure 3.

In the mining context, the number of jobs waiting for machines is limited by the number of headings advanced and there may be jobs waiting in queue for the loading-and-hauling operation. This comparison of a production scheduling system and a conventional mining system is useful for developing and understanding a mine simulation model like FACESIM.

3.2 ASSUMPTIONS MADE IN FACESIM

As in any model building process, there are assumptions made in developing FACESIM. It is appropriate to mention them here to understand modifications made in FACESIM to build CONSIM. This will also help the users familiar with

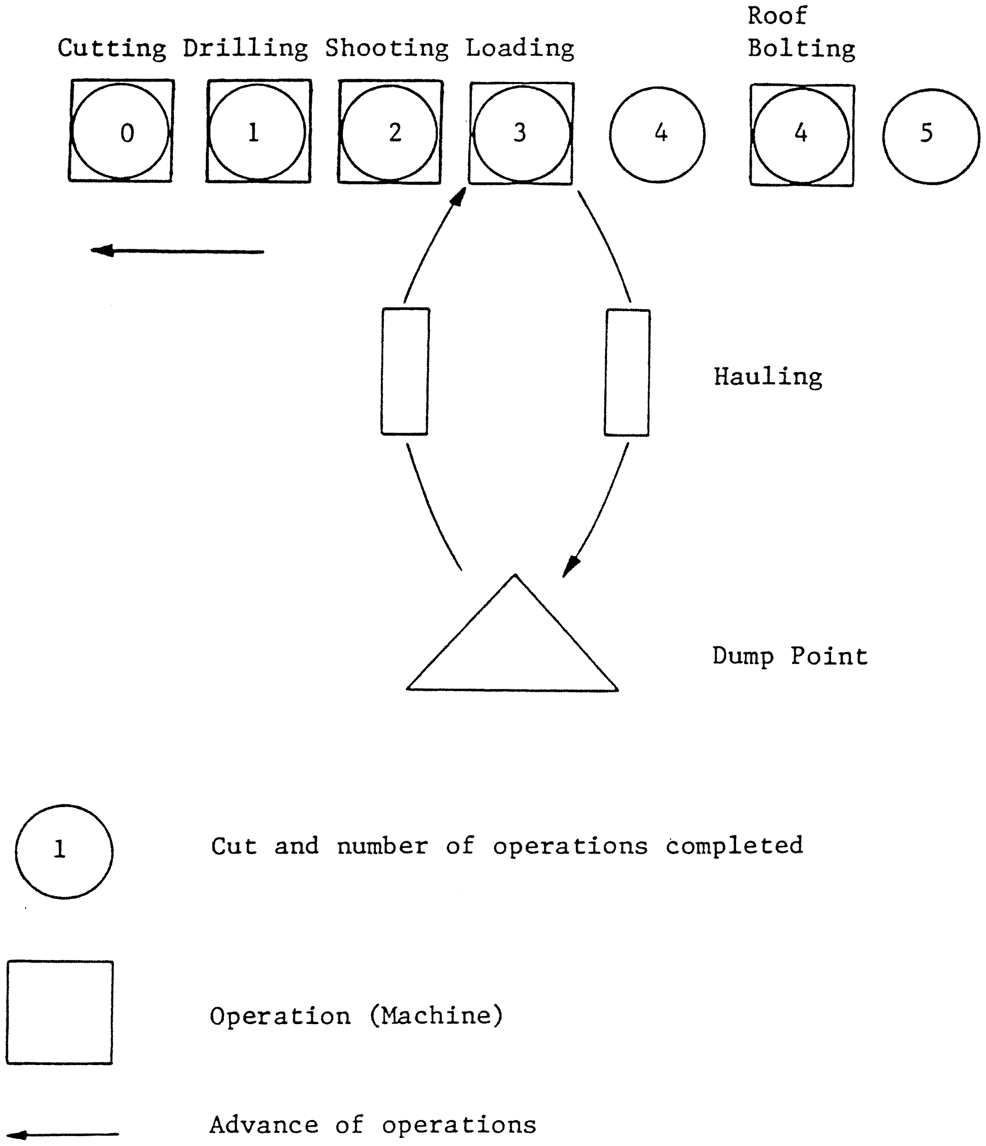
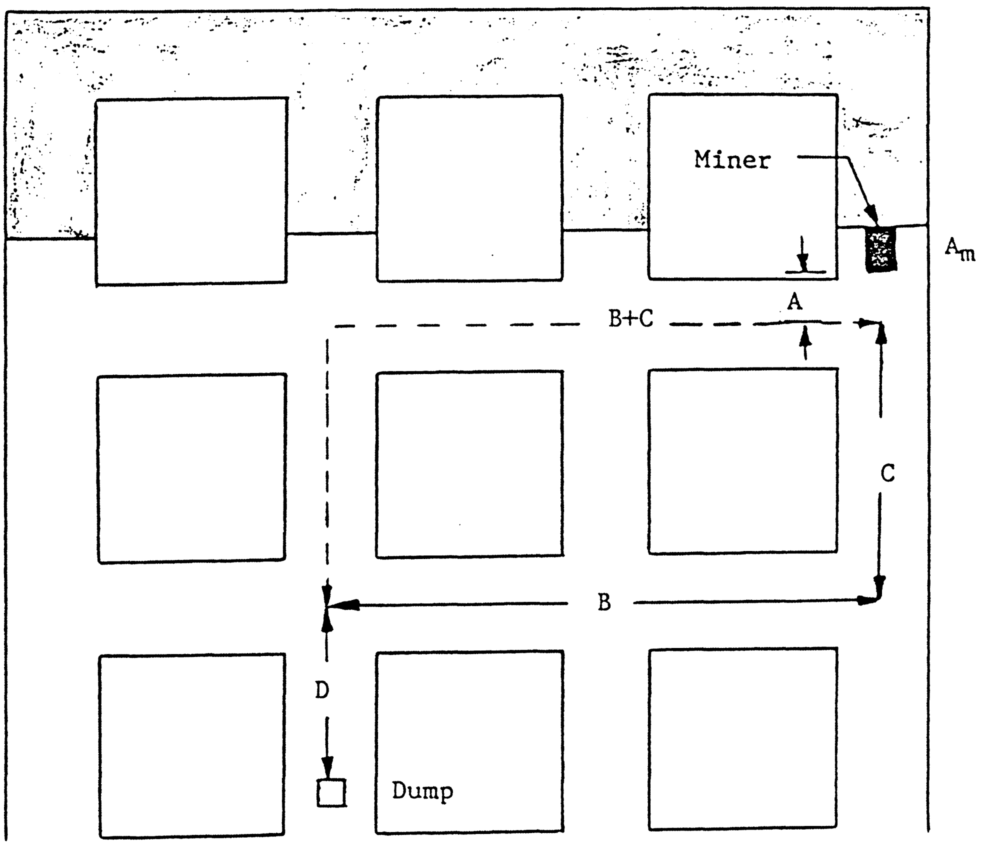


Figure 3
Schematic Diagram of a Conventional Mining Operation

FACESIM to understand and use CONSIM and vice-versa. It is not to be construed that the assumptions made in FACESIM are wrong because they are modified in CONSIM. The changes were necessitated because of the simplification that was to be achieved in CONSIM and additional details incorporated in CONSIM. To facilitate understanding of different distances and times discusssed under the assumptions some of the variables are schematically shown in Figure 4.

The following are the assumptions made in FACESIM:

1. A shuttle car is available for loading immediately after tramming of the miner is completed.
2. All shuttle cars change out at the same location.
3. All shuttle cars discharge at the same location.
4. All shuttle cars have the same operational characteristics such as haul rates and payload.
5. When only one shuttle car is used in conjunction with the miner, the shuttle car is left in the cut after loading for the last time. However, when more than one shuttle car is used, the last shuttle car loaded in the cut is unloaded at the discharge point hauled to the change point of the same cut.



A_m	Length of miner
A	Change out distance
B+C	Haul distance
D	Discharge change out distance

Figure 4
A Schematic Layout Showing Some FACESIM Variables

6. More than two shuttle cars can be discharged simultaneously in a two-way dump (Note that a maximum of three shuttle cars can be used with loader).

7. Shuttle cars may switch in and out only when the loader is in the transport heading, i.e., the heading where the dump is located.

8. The change-out time includes, in addition to the time spent by the shuttle car hauling over the change-out distance,the time required for switch-in and switch-out and the time shuttle cars have to wait for the loader to maneuver.

   When only one shuttle car is used in conjunction with the loader, the change-out time also includes the discharge time and trip change time, if a push-pull system is in use.

9. All the coal in the cut will be loaded into shuttle cars even if the last load is negligibly small.

   For example, if the last load is only 0.01 tons, which may be left in the cut without any problem in practice, FACESIM will load it into a shuttle car.

10. The supporting operations will be advanced forward only one cut when the loader is to be moved to the

next cut, though not necessarily at the same time on simulation clock.

11. Shuttle cars are loaded and unloaded in a predetermined order. For example, the shuttle car numbered one is loaded before car number two which is loaded before car number three.

3.3 EQUATION FOR LOADER CYCLE TIME

FACESIM is constructed with the assumption that the cycle time (i.e. the time between starting operation at one cut and the next) of the loader satisfies the following equation:

$$LCT = LT + WL + CT + TT + WP$$

where

LCT - the loader cycle time,

LT - the time the loader spends in loading coal during the cycle,

WL - the time the loader waits because no shuttle car is available at the change point during the cycle, CT - the change-out time during the cycle, and

TT - the time spent on tramming the loader to the next cut.

WP - the time the loader waits for coal, i.e., for entry into the next cut,

The above relation also holds for shift time and the time required to mine all the cuts.

3.4 FACESIM INPUT AND OUTPUT

The input data required to run FACESIM program are essentially the empirical distributions of the loading rate of the loader, the travel rates -- loaded and empty -- of shuttle cars and the discharge rate; the tram rates, tram functions, etc. of the loader and other auxiliary equipment; dimensions of cuts and pillars; and the data required for each cut, called G-card data. The number of data cards required depends on the number of cards required to define the empirical distributions and to input G-card data. Prelaz, et al. (1964) provide details of the input data required for FACESIM. All the input data must be prepared and input manually. FACESIM simulates the operations in a conventional mining system over a specified number of cuts and it stops when all the cuts are mined and roof bolted. The macro flowchart for FACESIM is shown in Figure 5.

To show how to use FACESIM, a seven heading system (Figure 6) with 70 X 62.5 feet center-to-center distance mined conventionally was simulated (Prelaz, et al., 1964). The input data for this system are shown in Table 1. Card type A contains the data to define the empirical distribution for loading rate, shuttle car payload, shuttle car haul rates and discharge time. Card type B contains the cycle times and tram functions for auxiliary operations and cut dimensions. The number of the first and last cut to be mined are given in card type C. Seed numbers for random number generator, shift time, density of coal, time required to start and stop work in a shift, etc. are given in card type D. Card type E provides tram rates and in-place constants for auxiliary operations and switch-in and switch-out times. The relative position of the preparation cycle and the first cut to be loaded are indicated on card type F. One card of type G is required for each cut. This card contains haul and tram distances, codes for cut dimensions and for cycle times and tram functions of auxiliary operations, loader tram constants and roof support work sequence and number of shuttle cars. In the example twenty-four cards were used to input card type A; nine cards for card type B; and twenty-nine cards for card type G. With the data shown in Table 1

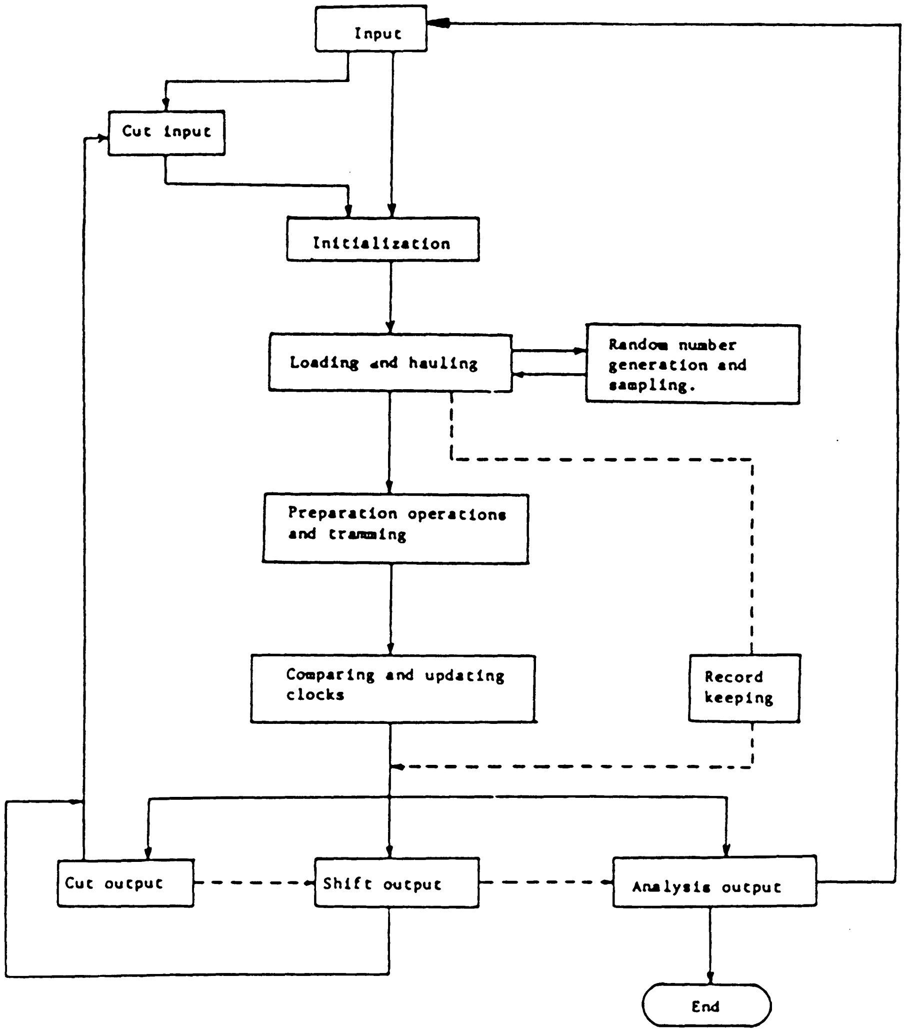


Figure 5

Macro Flowchart for FACESIM

(Prelaz, et al., 1964)

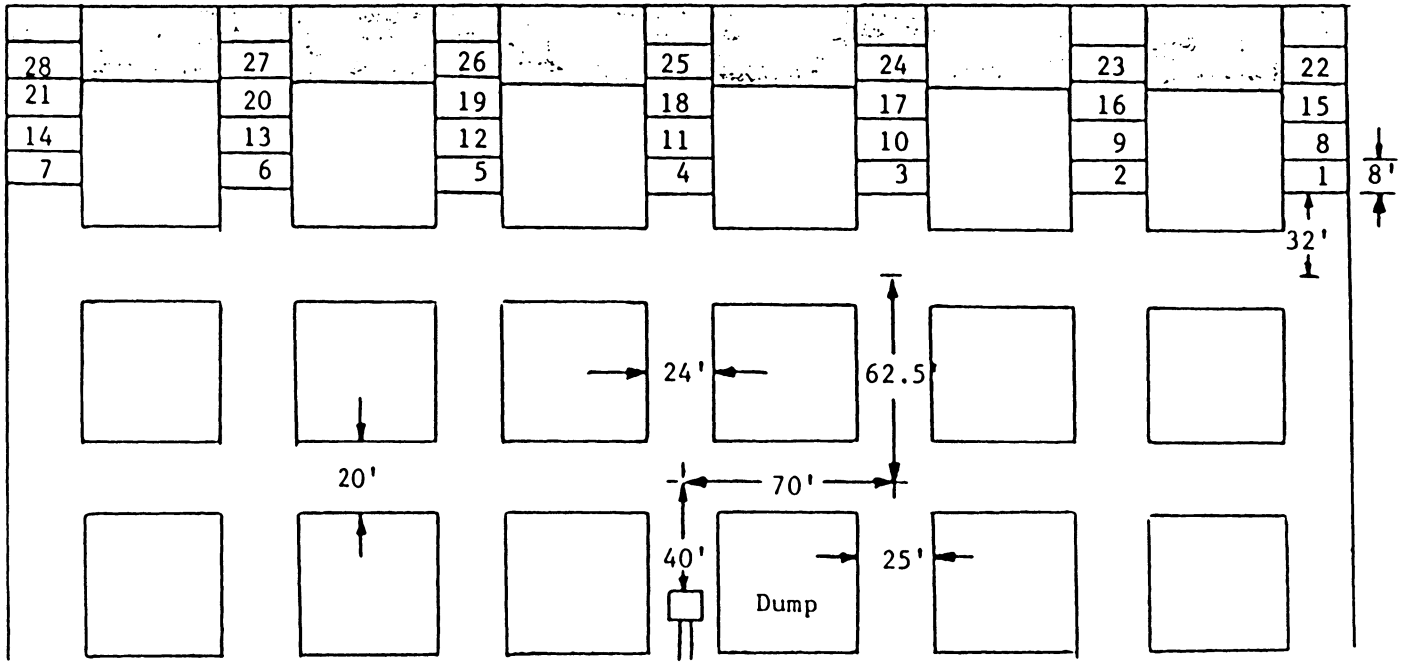


Figure 6

Layout for FACESIM Input Data

(Prelaz, et al., 1964)

Table 1

A Sample Input for FACESIM

```
                          Input Data                                          Card Type

     9    40    24    23    22    21    58          40 267  14  13  29  45  21
    11    41    25    24    23    25    62         173 467  27  38  71 119  62
    13    42    26    25    24    26    64         260 733 110 288  86 179 124
    15    44    27    26    25    27    66         380 933 205 425 186 299 206
    17    45    28    27    26    28    68         4331000 315 550 271 328 247
    19          29    28    27    29    70         520     329 625 429 373 289
    21          30    29    28    30    72         553     507 675 529 463 361
    23          31    30    29    31    74         640     589 775 657 522 412
    25          32    31    30    32    76         713     658 788 743 627 495
    27          33    32    31    33    78         787     671 850 814 687 536
    29          34    33    32    34    80         827     726 863 900 716 577
    31          35    34    35    35    82         847     808 875 914 731 639
    33          36    35    36    36    86         880     822 888 943 776 691
    35          37    37    37    37    88         893     849 900 971 791 742      A
    37          38    38    40    38    90         913     863 9251000 821 784
    39          39    39          39    92         927     904 938     866 825
    41          40    43          40    94         933     959 950     925 856
    43          41    47          43    96         953     973 963     940 887
    45          43    50          45    98         967     986 988     970 918
    47          48    52          47   100         973    10001000    1000 928
    51                               104         980                     938
    53                               106         987                     959
    57                               110         993                     979
    65                               118        1000                    1000

  1168 0000 1341  142  915  000 1482 0000 04.83 25.00 008.00
  2000  520 1309  611 2785  200 2317   70  7.67 24.00
  1060  590 1146  000  688  180 1200  460       20.00
  1890  450 2073  469 1230      2267            40.00
  1910  660 2167  318 1317      2352            45.00
  2040      2362      1631      2528            57.50
  2740      3143      2004      3114            45.25                                 B
  2500      3108      3874      3979            58.75
  1894      2108      1364      2021            37.50

  0001002901                                                                        C
```

Table 1 (Continued)

A Sample Input for FACESIM

Input Data	Card Type
87. 87. 480. 0.04315.0015.00 7.50 7.50 .37 1	D
0094.0050.0088.0069.0106	E
00010008	F
1 1 1 1 248.248. 0. 12. 40. 70 32 101 101 102 102 0.2 0.0 7 7	G
2 1 1 1 178.178. 0. 12. 40. 70 32 101 101 102 102 0.2 0.0 1 8	
3 1 1 1 108.108. 0. 12. 40. 70 32 102 102 102 102 0.2 0.0 2 9	
4 2 2 1 0. 0. 0. 50. 40. 70 32 203 203 201 201 0.2 0.0 3 10	
5 1 1 1 108.108. 0. 12. 40. 70 32 101 103 101 101 0.2 0.0 4 11	
6 1 1 1 178.178. 0. 12. 40. 70 32 101 104 101 101 0.2 0.0 5 12	
7 1 1 1 248.248. 0. 12. 40. 420 32 104 105 103 103 1.9 0.0 6 13	
8 1 1 1 248.248. 0. 20. 40. 70 40 101 101 102 102 0.2 0.0 7 14	
9 1 1 1 178.178. 0. 20. 40. 70 40 101 101 102 102 0.2 0.0 8 15	
10 1 1 1 108.108. 0. 20. 40. 70 40 102 102 102 102 0.2 0.0 9 16	
11 2 2 1 0. 0. 0. 58. 40. 70 40 203 203 201 201 0.2 0.0 10 17	
12 1 1 1 108.108. 0. 20. 40. 70 40 101 103 101 101 0.2 0.0 11 18	
13 1 1 1 178.178. 0. 20. 40. 70 40 101 104 101 101 0.2 0.0 12 19	
14 1 1 1 248.248. 0. 20. 40. 420 40 104 105 103 103 1.9 0.0 13 20	
15 1 1 1 248.248. 0. 28. 40. 70 48 101 101 102 102 0.2 0.0 14 21	
16 1 1 1 178.178. 0. 28. 40. 70 48 101 101 102 102 0.2 0.0 15 22	
17 1 1 1 108.108. 0. 28. 40. 70 48 102 102 102 102 0.2 0.0 16 23	
18 2 2 1 0. 0. 0. 66. 40. 70 48 203 203 201 201 0.2 0.0 17 24	
19 1 1 1 108.108. 0. 28. 40. 70 48 101 103 101 101 0.2 0.0 18 25	
20 1 1 1 178.178. 0. 28. 40. 70 48 101 104 101 101 0.2 0.0 19 26	
21 1 1 1 248.248. 0. 28. 40. 420 48 104 105 103 103 1.9 0.0 20 27	
22 1 1 1 248.248. 0. 36. 40. 70 56 101 101 102 102 0.2 0.0 21 28	
23 1 1 1 178.178. 0. 36. 40. 70 56 101 101 102 102 0.2 0.0 22 29	
24 1 1 1 108.108. 0. 36. 40. 70 56 102 102 102 102 0.2 0.0 23 30	
25 2 2 1 0. 0. 0. 74. 40. 70 56 203 203 201 201 0.2 0.0 24 31	
26 1 1 1 108.108. 0. 36. 36. 70 56 101 101 101 101 0.2 0.0 25 32	
27 1 1 1 178.178. 0. 36. 36. 70 56 101 104 101 101 0.2 0.0 26 33	
28 1 1 1 248.248. 0. 36. 36. 420 56 104 105 103 103 1.9 0.0 27 34	
-1	
70 64 101 101 102 102	

FACESIM was run and the output, shown in Table 2, was obtained. From Table 2, it may be read that in the first shift 995.5 tons of coal was loaded in 222.2 minutes by the loader and the loader spent 96.7 minutes on waiting for shuttle cars, 8.1 minutes waiting for entry into next cut, 52.6 minutes for tramming and 56.3 minutes on change-out. The shuttle cars travelled 20.5 miles.

Table 2

A Sample Output from FACESIM

```
SHIFT NO.     1      SHIFT TONS                    995.5      TIME     435.89
TONS PER FACE MINUTE                               2.28
TOTAL LOADING TIME                 222.21          PERCENT FACE TIME          50.97
TOTAL TRAM TIME                     52.57          PERCENT FACE TIME          12.06
TOTAL WAIT TIME-NO SC               96.71          PERCENT FACE TIME          22.18
TOTAL WAIT TIME-COAL                 8.10          PERCENT FACE TIME           1.85
TOTAL CH.OUT TIME                   56.29          PERCENT FACE TIME          12.91
TOTAL TRIP CHANGE TIME                              .00
TOTAL WAIT-OPERATION 2                            35.11
TOTAL WAIT-OPERATION 3                            17.90
TOTAL WAIT-OPERATION 4                            72.50
TOTAL WAIT-OPERATION 5                            10.70
TOTAL HAUL DIST.       FEET =                      94664.          MILES =  17.92
TOTAL CH.OUT DIST.                                 13522.                    2.56
```

Chapter IV

MODEL FORMULATION

4.1 CONTINUOUS MINING SYSTEMS

Since the continuous miners were first introduced to the coal mining industry in 1948, the trend has been toward their greater use because of high productivity that can be achieved and less auxiliary equipment and manpower requirements. Though the continuous miner was initially introduced for use in coal mines, it also finds application in various sedimentary type of ore deposits such as potash and soda ash mines.

The continuous miner eliminates the need for cutting, drilling and blasting. It mechanically breaks and loads coal. The coal may be directly loaded on to shuttle cars or a conveyor system or dumped behind and subsequently loaded by a loader. The coal loaded on the shuttle cars or conveyors is discharged into the dump, located at or more than a center-line distance between pillars. The depth of cut is limited by the length of the continuous miner so as to keep the operator under a supported roof at all times. The depth of cut by continuous miners with a roof bolter mounted on them is limited only by the ventilation requirements. The number of headings driven by a continuous miner in a section may be three or more.

There are four types of continuous miners in use -- the ripper-type, the boring-type, the milling or drum-type and the auger-type. Of these, the milling-type machines are most widely used.

As with conventional mining operations, the operations in continuous mining systems can be compared to pure flow shop. Unlike conventional mining, there are only two operations -- (1) cutting and loading (by miner) and hauling (by shuttle car) and (2) roof-bolting (by bolter). Since cutting and loading and hauling are carried out simultaneously in a cut, they are grouped as one operation. This is schematically illustrated in Figure 7. The difference between the continuous mining system and the conventional mining system is the number of operations to be performed in each face.

4.2 OBJECTIVES OF THE RESEARCH

The following three objectives were to be achieved in development of CONSIM, the CONtinuous mining SIMulator:

1. Modification of FACESIM for the simulation of a continuous miner operation and simplification of the program for use on microcomputers and ease of understanding by the user.

2. To augment the capability of the simulation model to

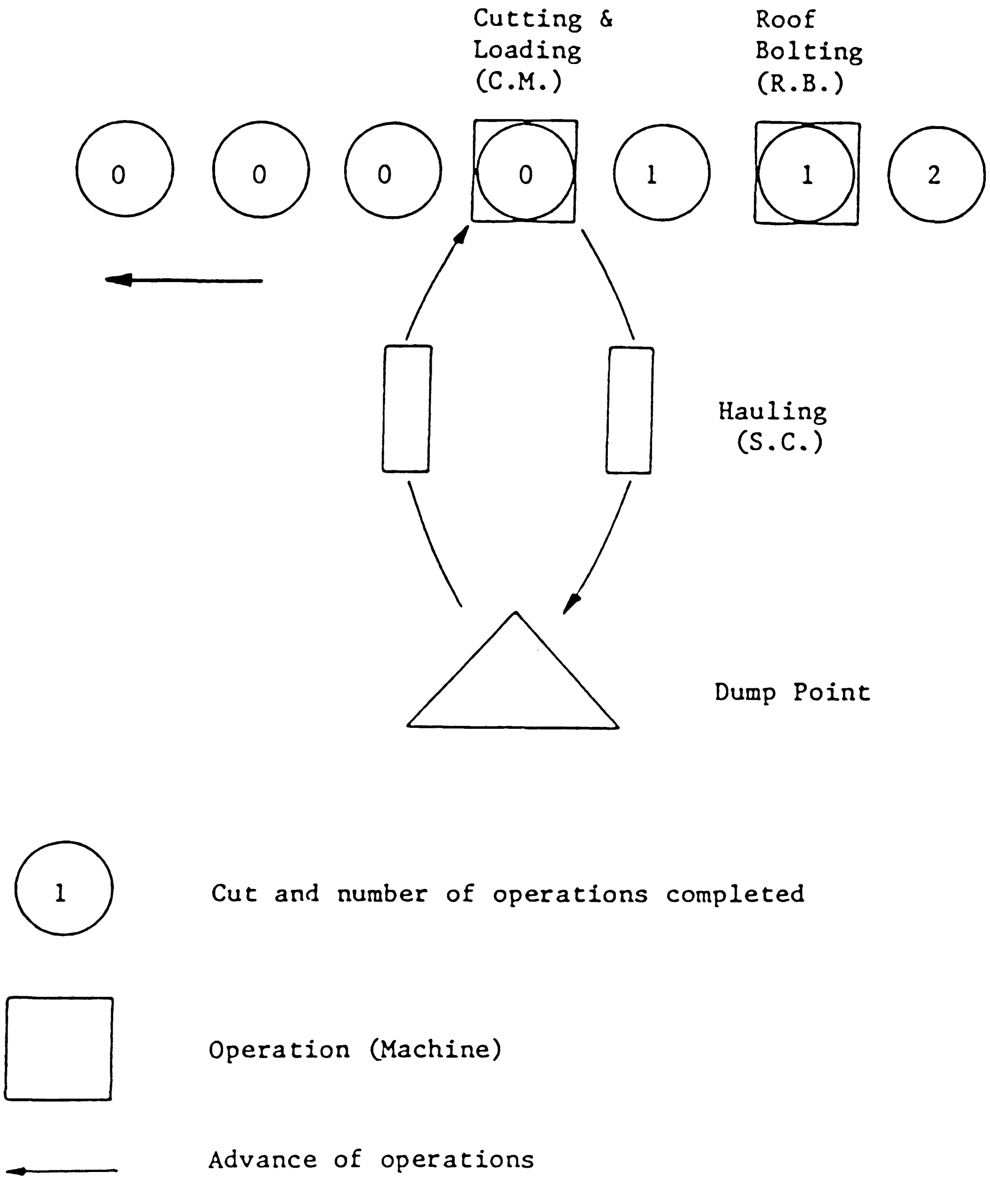


Figure 7

Schematic Diagram of a Continuous Mining Operation simulate equipment breakdowns without greatly adding to its complexity.

3. To minimize the input data requirements by internally generating them with the minimum data that the user has to input.

4.3 MODEL DEVELOPMENT

Initially, modification of FACESIM for a continuous mining system essentially involved removal of the unnecessary parts from the FACESIM program. Further work required to achieve the first two objectives were carried out simulataneously since they were interrelated, often the work involving the second objective necessitating more work to satisfy the first objective. The third objective to minimize the input data requirements was achieved by adding subroutines to generate data internally with the minimum data to be input by the user.

4.3.1 Assumptions made in CONSIM

Simplification of the program required changes in some of the assumptions made in FACESIM. Additional assumptions were made to include more details in the model. The assumptions made in FACESIM, therefore, also hold true in CONSIM with the exception of the following:

1. The change-out time is the time spent by shuttle cars hauling over the change-out distance and that required for switch-out. This time is considered zero if it occurs while the miner is under breakdown. The change-out also includes the time spent hauling the last shuttle car over the change-out distance.
2. The shuttle car may switch in and out when the continuous miner is in any heading.
3. The last shuttle car loaded in a cut is unloaded at the discharge point and hauled back to the change point of the cut, irrespective of the number of shuttle cars assigned to the loader.
4. A maximum of two shuttle cars can unload simultaneously in a two-way dump. The alternate shuttle cars unload from the same location at the dump. Only one shuttle car can unload at a time in a one-way dump.
5. Any maneuver of a continuous miner in the cut is considered part of production work.
6. The breakdown time of any equipment is the production time lost due to breakdown, i.e., the total shift time the equipment is under breakdown minus the time required to start work at the beginning of the shift

and the time required to stop work at the end of the shift, if the time of breakdown overlaps these times.

Time between breakdowns of equipment is the production time between consecutive breakdowns of the equipment, excluding the breakdown time.

Production time in a shift refers to the duration of the shift from the time when work is started at the beginning of the shift to the time when work is stopped at the end of the shift.

7. The time between breakdowns and breakdown time are exponentially distributed.

   This assumption is made because exponential distribution has been widely used to fit these variables and its parameter can be easily estimated by anyone without much knowledge in statistics.

   If the exponential distribution does not fit the data satisfactorily, some other distribution can be used without much difficulty by merely changing the function subprogram with an appropriate one.

8. The shuttle cars may have different failure characteristics, i.e., different mean times between

breakdowns and different mean breakdown times.

9. Breakdown of a continuous miner may occur only after the loading of a shuttle car is completed.

10. Breakdown of a shuttle car may occur only at the change point after switching in when it is empty.

11. Breakdown of a roof bolter may occur only after moving into the cut to be roof-bolted.

12. At the start of simulation all the equipment at the face is in working condition and the shuttle car numbered one is ready to be loaded. The continuous miner is initially in cut number one which may be the first or last heading.

13. The shuttle cars are loaded in a predetermined order as in FACESIM. If the shuttle car to be loaded is under breakdown, the next shuttle car in working condition is loaded.

    When all the shuttle cars are under breakdown, the one which will be repaired the earliest is the shuttle car to be loaded next. If this happens after loading the last load in a cut and if the time on the the shuttle car is greater than the time on the miner clock after it is moved to the next cut, then the difference is accumulated as miner waiting time for the shuttle car during the next cut.

14. The loading rate, shuttle car payload, shuttle car haul rates and discharge time are continuous random variables. Their cumulative distribution functions are defined empirically, i.e., by observed data in the field.

4.3.2 Changes Made in FACESIM

With these modifications in assumptions made of FACESIM, the resulting computer simulation model, CONSIM is simpler, more efficient and easier to understand. CONSIM can also simulate breakdowns of a continuous miner, shuttle cars and roof bolter. Unlike in FACESIM, during the time that the miner mines one cut, the roof bolter may roof-bolt more than one cut and vice-versa. This change was incorporated in CONSIM since it has the capability to simulate equipment breakdowns. It is realistic to expect the equipment in working condition to continue to operate, if they can, while some equipment is under breakdown. For example, the following situations can be simulated in CONSIM:

1. Suppose the roof bolter is under breakdown. If there are cuts available for mining and if the continuous

miner is in working condition, the miner will mine all the cuts that are available and vice versa.

2. Suppose three shuttle cars are used in conjunction with the miner and two of them are under breakdown sometime during operation. The roof bolter will roof-bolt available cuts and the miner will continue mining by using the available shuttle car.

The push-pull system for transportation of coal from panels, which is not popular anymore, is omitted in CONSIM. The CONSIM can make multiple runs and produce statistics (mean and standard deviation) for performance measures of the system by shift and/or by the time required for mining all the specified cuts. The CONSIM program can be run interactively or in batch mode. Running the program in batch mode is faster, but running it interactively makes it easier to input data and gives insight into what is going on in the program.

4.3.3 Equation for Continuous Miner Cycle Time

In CONSIM, the cycle time (i.e. the time between starting operation at one cut and the next) of the continuous miner satisfies the following equation:

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all copies

4.3.4 Subroutine GCARD

When using FACESIM, it is time consuming to prepare input data, called G-card data for each cut. This requires a lot of effort and time on the part of user. This problem is solved for the CONSIM user by adding the subroutine GCARD which generates these data internally. The input data required by subroutine GCARD are the dimensions of the workings and the equipment. Subroutine GCARD has the following features incorporated in it:

1. Any number of headings may be driven.
2. Any of the headings can be used as the transportation heading.
3. It can generate data for single cuts in headings and single or multiple cuts in breakthroughs.
4. The breakthrough need not be at a right angle to the heading.
5. The discharge point may or may not be advanced as the development work advances.
6. A specified number of cuts may be made or a multiple of center-line distance between pillars may be advanced during the development.

If a specified number of cuts are to be made in development, the multiple of center-line distance between pillars is specified just large enough that all the cuts will be within that distance. If the development is to be advanced a specified multiple of the center-line distance, input a large number for number of cuts to be made.

4.3.5 Uniform Random Number Generator

A uniform (0,1) random number generator is required to generate random variates from any distribution. The uniform (0,1000) random number generator in FACESIM was replaced by RANDOM(L), a uniform (0,1) random number generator (Wichman and Hill, 1982). This random number generator has better statistical properties and is faster than many currently available random number generators. The sequence of random numbers generated by this are independent of the machine. The three variables IX, IY, IZ in RANDOM(L) should be set integer values in the range 1 through 30000. The sum of IX, IY, IZ should not be greater than 30323.

4.4 CONSIM

4.4.1 The Model

CONSIM is a discrete, event-oriented computer simulation model, i.e., the status of the system and the simulation clock are updated when an event takes place. The following are the events in CONSIM: (1) cutting and loading, (2) hauling, (3) roof-bolting, (4) equipment breakdown, (5) completion of cut, and (6) end of job. At the beginning of simulation all equipment are assumed to be in working condition and the miner is in the first or last heading numbered as one. The roof-bolter may be in any heading to be roof-bolted -- not necessarily the one next to where the miner is in.

A macro flowchart for CONSIM is shown in Figure 8. The variables used in CONSIM are defined in APPENDIX A and a detailed flowchart of CONSIM is given in APPENDIX B. The functions and subroutines used in CONSIM, with their purpose, are given in Table 3. The CONSIM program is listed in APPENDIX C.

CONSIM requires a minimum amount of data to be input by the user. These data are essentially the dimensions of workings, the operational and maintenance characteristics of the equipment.

Format of the output used in FACESIM was changed. The output may be obtained by cut, shift or the simulation time

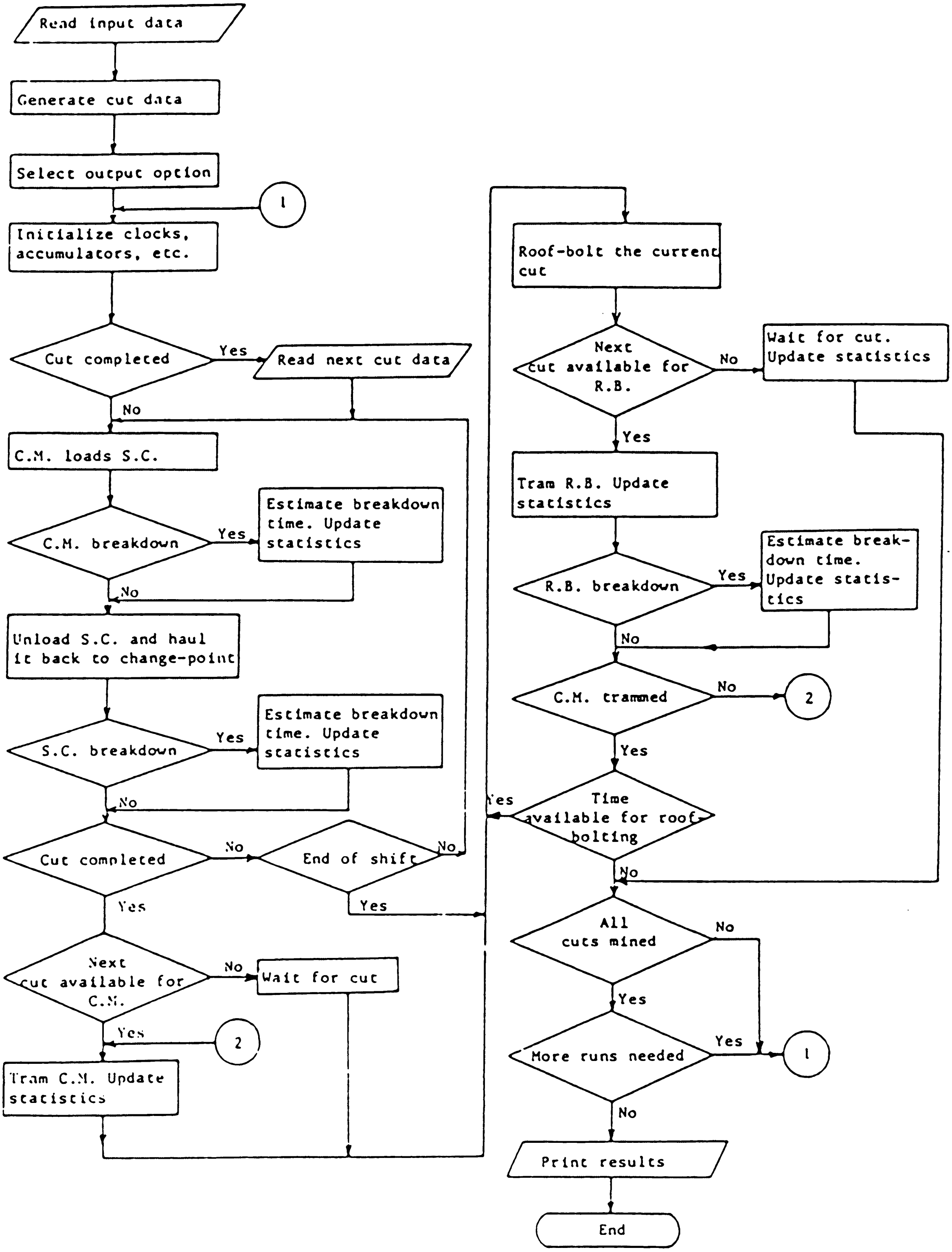

Figure 8

Macro Flowchart for CONSIM

TABLE 3

Subprograms in CONSIM and Their Purposes

SUBPROGRAM	PURPOSE
RANDG	Subroutine to generate continuous random variates from empirical distributions defined by observed values of loading rate, shuttle car payload, haul rates and discharge time.
RANDOM(L)	Function which generates uniform (0,1) random numbers.
EXPON(XM)	Function to generate an exponential random variate with mean XM.
GCARD	Subroutine which generates input data for cuts made in development.
DIST	Subroutine called in subroutine GCARD to calculate distances.

to mine all cuts. The performance measures of the system that can be obtained from CONSIM are more than what one gets from FACESIM. Though the simulation output by cut may not be of any use to make inferences, they will be of help in finding any error in the input data due to some unknown reason. This serves the same purpose as the TRACE command in many simulation languages.

4.4.2 Input Data Preparation

The performance measures (the output) of the system obtained from a simulation model are dependent upon the values of the input variables. Since-the user is interested in evaluating the changes in performance measures as a result of the changes in input variables, it is important for the successful simulation study that the user prepares the input data, making certain that errors are eliminated and accuracy in estimation is improved as far as possible. Therefore, preparation of input data is discussed in this chapter.

4.4.2.1 Input Data Cards

Nine different type of input data cards are needed for CONSIM. These cards named Card Type A through Card Type I in alphabetical order. The definitions of input variables are given are in Table 4 through Table 12. They are listed in the order that they are to be input. The formats of input data are given in parantheses. The number of input data cards equals eight plus the number of cards required to define the empirical distributions (Card Type H) and to input data for roof bolter operation and cut dimensions (Card Type I). Data preparation for Card Type H is explained in 4.4.2.2 Empirical Probability Distributions.

The Table 13 defines the codes (KODE(I) for cut I) for cuts developed by subroutine GCARD. These codes are used in the main program to obtain the dimensions of cuts and roof bolter cycle times and tram functions. First eight codes are used to obtain values of these variables in development and the last one is used for dummy cut(s).

When inputting cut dimensions for multiple cuts taken in breakthroughs during the development, depth of cut should not be changed; however, appropriately modify the width of cut so that the amount of coal mined from the cut remains unaltered. If one of the cuts made in multiple cuts is of reduced depth, use the regular cut depth, but change the width of cut. In addition, a card should be inserted for dummy cuts. This last input data card sholud have zeros for RNRSUP(I) and RMRSUP(I) and any positive numbers for the dimensions of cut.

TABLE 4

Input Data Card Type A

VARIABLE	DEFINITION
KT	The first cut to be worked by the roof bolter. This can be any cut numbered less than or equal to the number of headings but not '1' which is the first cut worked by the continous miner (I5).
NTSC	If different mean breakdown times (and mean time between breakdowns) are used for shuttle cars, enter the number of shuttle cars, NSC. If all the shuttle cars have the same breakdown characteristics, enter '1' (I5).
NSC	Numbers of shuttle cars to be used with continuous miner (I5).
NDUMP	Type of dump. Enter one for one-way dump, two for two-way dump (I5).
ICBCO	Type of output. Enter -1 for output by cut, 0 for output by shift, 1 for output by the total time required to mine all the cuts (I5).
NA	Maximum number input cards used to define empirical distributions for loading rate, shuttle car payload, shuttle car haul rates and discharge rate (I5).
NB	Number of input data cards used to input dimensions of cuts and cycle times and tram functions of roof bolter. It is equal to 9 (I5).
NREP	Replications to be made. Replications are independent runs of the program with the same data but different sets of seeds for random number generator. This is required to calculate the mean and standard deviation of output variables (I5).

TABLE 5

Input Data Card Type B

VARIABLE	DEFINITION
SHFT	Production time in a shift in minutes. This equals the scheduled shift time minus the time required to start work at the face and the time required to get out of the mine at the end of shift (F5.1).
DENS	Density of coal in tons/cu.ft (F5.3).
TL	Tram rate of continuous miner in minutes/ft (F5.4).
TR	Tram rate of roof bolter in minutes/ft (F5.4).
SWI	The time required by an empty shuttle car to provide clearance for a loaded car by tramming into an entry at the change point in minutes (F5.2).
SWO	The time required by the shuttle car to return to the haulage road after switch-in in minutes (F5.2).
CL1	The time required for any function other than production done by miner in by the passing point in minutes. This is called in-place constant. Examples of these functions are gas check, hang bratice. This should be specified in minutes (F5.2).
CR1	Same as above, but for roof bolter, in minutes (F5.2).

TABLE 6

Input Data Card Type C

VARIABLE	DEFINITION
XM1	Mean time between breakdowns for continuous miner (F10.2, 2X).
XM3	Mean time between breakdowns for roof bolter (F10.2, 2x).
XM4	Mean breakdown time for continuous miner (F10.2, 2X).
XM6	Mean breakdown time for roof bolter (F10.2, 2X).

TABLE 7

Input Data Card Type D

VARIABLE	DEFINITION
XM2(I)	Mean time between breakdowns for shuttle car type I. I takes the values 1 through NTSC. See Table 4 (F10.2, 2x).
XM5(I)	Mean breakdown time for shuttle car type I. I takes the values 1 through NTSC (F10.2, 2X).

TABLE 8

Input Data Card Type E

VARIABLE	DEFINITION
L	Dummy variable for uniform (0,1) random number generator (I10).
IX, IY, IZ	Initial seeds for uniform (0,1) random number generator. The sum of IX, IY, IZ should not be greater than 30323. For example, IX = 12345, IY = 6678 and IZ = 7890 (3I10).

TABLE 9

Input Data Card Type F

(Read in Subroutine GCARD)

VARIABLE	DEFINITION
W(I)	Width of cut: in non-transport heading, for I=1; in transport heading, for I=2; in breakthrough for I=3 (3(F5.1)).
DTH	Depth of cut in development in feet (F5.1).
WHPIL	Width of pillar along heading in feet (F5.1).
WPIL	Width of pillar along breakthrough in feet (F5.1).
ALM	Length of continuous miner in feet (F5.1).
SCL	Length of shuttle car in feet (F5.1).
SDIST	Center-line distance of the first cut from the center of breakthrough along the heading in feet (F5.1).
DCPD	Discharge change-out distance in feet (F5.1).

TABLE 10

Input Data Card Type G

(Read in Subroutine GCARD)

VARIABLE	DEFINITION
NCM	Number of cuts to be made in development (I5).
MULTI	Control variable for type of cut to be made in breakthrough. Enter '1' for single cut and '2' for multiple cut (I5).
KHEAD	Number of headings in a panel (I5).
NHT	Number of the transport heading (I5).
KT	The first cut to be worked by the roof bolter. This can be any cut numbered less than or equal to the number of headings but not '1' which is the first cut worked by the continous miner (I5).
NPC	Distance to be advanced in development in terms of number of center-line pillar distance (I5).
LPC	Control variable for movement of dump. Enter '0', if the dump is not to be moved; otherwise, any positive number (I5).

TABLE 11

Input Data to Define Empirical Distributions

(Card Type H)

VARIABLE	DEFINITION
(Note RLA(.) through RH(.) should be specified in each card. There are NA such cards.)	
RLA(.)	Upper limit of interval for loading rate of the miner in minutes/shuttle car (F5.2).
RLB(.)	Upper limit of interval for shuttle car payload in tons (F5.2).
RLC(.)	Upper limit of interval for loaded shuttle car haul rate from miner to change point in min/ft (F5.4).
RLD(.)	Upper limit of interval for loaded shuttle car haul rate from change point to dump in min/ft (F5.4).
RLE(.)	Upper limit of interval for empty shuttle car haul rate from dump to change point in min/ft (F5.4).
RLG(.)	Upper limit of interval for empty shuttle car haul rate from change point to miner in min/ft (F5.4).
RLH(.)	Upper limit of interval for discharge time in minutes (per shuttle car) (F5.2).
RA(.)	Cumulative distribution function for RLA(.) (F5.3).
RB(.)	Cumulative distribution function for RLB(.) (F5.3).

Table 11 (Continued)

Input Data to Define Empirical Distributions

(Card Type H)

VARIABLE	DEFINITION
RC(.)	Cumulative distribution function for RLC(.) (F5.3).
RD(.)	Cumulative distribution function for RLD(.) (F5.3).
RE(.)	Cumulative distribution function for RLE(.) (F5.3).
RG(.)	Cumulative distribution function for RLG(.) (F5.3).
RH(.)	Cumulative distribution function for RLH(.) (F5.3).

TABLE 12

Data for Roof Bolter Operation and Cut Dimensions

(Card Type I)

VARIABLE	DEFINITION
(Note that RNRSUP(.) through DTH(.) should be specified in each card. There are NB such cards.)	
RNRSUP(I)	Roof bolter cycle time for code I in minutes (F6.2).
RMRSUP(I)	Roof bolter tram function for code I in minutes (F6.2).
HT(I)	Height of cut for code I in feet (F6.2).
W(I)	Width of cut for code I in feet (F6.2).
DTH(I)	Depth of cut for code I in feet (F6.2).

TABLE 13

Definition of Codes for Cut Dimensions and Roof Bolter Operation

KODE(I)	Description
1	Non-transport heading.
2	Transport heading.
3	Single cut in breakthrough.
4	Single cut in breakthrough with reduced depth of cut.
5	Multiple cut in breakthrough with regular depth of cut in the first and last heading.
6	Multiple cut in breakthrough with regular depth of cut in headings other than mentioned above.
7	Multiple cut in breakthrough with a reduced depth (the last one in breakthrough, if the last cut of reduced depth) of cut in the first and last headings.
8	Same as above, but in headings other than mentioned above.
9	For dummy cut(s).

4.4.2.2 Empirical Probability Distributions

The observed data are used to specify the probability distribution of the loading rate of the continuous miner, the haul rates (loaded or empty) of shuttle cars, and the discharge time. Different distributions for the haul rates of shuttle cars are used for the distance between the miner and the change point and the distance between the change point and dump both when loaded and empty. If they are expected to be the same (or they are statistically found to be the same) the amount of data required may be minimized by appropriately modifying the subroutine RANDG.

The haul rates of shuttle cars can be obtained by dividing haul time by haul distance. The loading rate of the miner is the loading time divided by the shuttle car load. Loading time includes any unproductive work that has to be done while loading. It is suggested that if the determination of the shuttle car load is difficult or impossible it may be assumed to be its design capacity or a fraction of it, the fraction being the fill factor determined from experience or by some other means.

Since the variables requiring empirical probability distribution are continuous variables, the observed values of each variable are to be grouped into one of k adjacent intervals, say, $[a_0, a_1]$, $(a_1, a_2]$, $(a_2, a_3]$, ... $(a_{k-1}, a_k]$ so that the jth interval contains n_j observations, where

$n_1+n_2n_3+ \ldots +n_k=n$ where n is the number of observations. The intervals need not be equally spaced. A piecewise linear empirical distribution function F is specified by $F(a_0)=0$ and $F(a_j)=(n_1+n_2+\ldots +n_j)/n$ for j=1, 2, ..., k (Law and Kelton, 1982). Interpolating linearly between the a_j's,

$$
\begin{aligned}
F(x) &= 0 && \text{if } x<a_0 \\
&= F(a_{j-1})+(x-a_{j-1})[F(a_j)-F(a_{j-1})]/(a_j-a_{j-1}) && \text{if } a_{j-1}<x<a_j \\
& && \text{for } j=1, ..k \\
&= 1 && \text{if } a_k<x
\end{aligned}
$$

Note that the interval is closed at the upper limit, i.e., the upper limit is included in the interval and each observation enters only one group.

The first data card of NA data cards used to define the empirical probability distributions establish the lower limits of the distributions and the last set of data for each random variable define the upper limit of the distribution (There is no need to have NA intervals for each random variable). Note that the cumulative distribution function for each random variable is zero at the lower limit of the distribution and one at the upper limit of the distribution.

4.4.2.3 Estimation of Parameters for Equipment Breakdowns

In the estimation of distribution parameters for the time between breakdowns and the breakdown times of equipment, only the production time is to be accounted for, i.e. exclude the time required to start work at the beginning of shift and the time required to stop the work at the end of shift.

For the exponential distribution used to generate time between the breakdowns and breakdown times, only one parameter needs to be estimated. This parameter of exponential distribution is the population mean. The maximum likelihood estimator of the population mean for exponential distribution is the sample mean.

If all the shuttle cars have the same mean time between breakdowns and the same mean breakdown time, the input variable NTSC should be assigned the value '1' and one value should be entered for each of these variables. If they are not the same, NTSC should equal NSC, the number of shuttle cars hauling coal from continuous miner to dump.

4.4.2.4 Switch-in and Switch-out Times

If only one shuttle car is being loaded by the continuous miner, the shuttle car does not need to switch-in. Therefore, the input values for switch-in and switch-out should be zero.

Since it was assumed that the shuttle cars may switch in and out of a breakthrough when the continuous miner is in any heading, the number of times the shuttle car does not switch in or out of a breakthrough is also to be counted and the time should be entered as zero when making a time study.

4.4.2.5 Simulation of Conveyor Operation

If conveyors are used to haul coal from the face, the haul rates of shuttle cars, the discharge rates and switch-in and switch-out times should be zero. For the empirical distribution of the pay-load of a shuttle car enter one with a probability of one. For the empirical distribution of the loading rate of a continuous miner, the average loading rate may be entered with a probability of one, if the variation in the loading rate is insignificant or not of interest to the user. The one-way dump is to be used with a conveyor system.

4.4.2.6 Simulation of Automated Miner-Bolter

To simulate the operation of a miner with roof bolter mounted on it, the values of the input variables for the roof bolter should be zero and the loading rate should be adjusted to include the time required for roof bolting or it may be entered as CL1.

4.4.2.7 Estimation of Distribution Parameters in the Absence of Data

If data are not available for times between breakdowns and breakdown times and/or one does not wish to simulate breakdowns of equipment, enter 'infinity' (i.e., a very large number) for mean time between breakdowns and zero for mean breakdown times. This may be done for one or more equipment. In this case, the production time in a shift should be reduced by the average total breakdown time of miner in a shift.

It is not always possible to collect data on random variables of interest because the system being studied does not exist or adequate data may not be available for the system under study. In such cases, if a deterministic simulation is not desired, the heurististic procedures mentioned by Law and Kelton (1982) may be used. These procedures are described here.

In the first method, identify an interval [a, b] (a and b are real numbers such that $a < b$) in which the random variable of interest will lie with probability close to one. Obtain a probability density function on [a, b] which is thought to be representative of the random variable. If the probability density function is expected to be unimodal, the mode being the most likely value, then a triangular probability density function may be considered.

Alternately, beta(α_1, α_2) distribution may be placed over the interval (a, b) since the time to perform a task has been found to be skewed to the right and the beta distribution has been found to fit it satisfactorily. Given subjective estimates of mean u and mode m, the parameters of beta distribution α_1 and α_2 can be obtained from the following expressions:

$$\alpha_1 = \frac{(u-a)(2m-a-b)}{(m-u)(b-a)} \qquad \text{and}$$

$$\alpha_2 = \frac{(b-u)\alpha_1}{(u-a)}$$

Note that if $u > m$, the probability density function is skewed to the right; if $u < m$, it will be skewed to the left. Note that a uniform distribution over an interval (a, b) corresponds to a beta(1, 1) distribution over the same interval. Algorithms to generate random variates from triangular, beta and Weibull distributions are given in APPENDIX D.

4.4.3 Sample Input and Output

CONSIM requires a minimum amount of data to be input by the user. These data are essentially the dimensions of workings, the operational and maintenance characteristics of the equipment. To provide an example for use of CONSIM, a hypothetical three heading continuous mining section was simulated (Figure 9). The pillars are at 90 X 90 feet centers. The widths of headings and breakthroughs are 19 feet. The depth of a cut is 20 feet. The dump is located at the intersection of heading and breakthrough. Two shuttle cars of 7-ton payload are used to haul coal from the miner to dump. One roof bolter is used for roof-bolting. Initially the miner is in the first heading and the bolter in the third heading. The distance of the cut from breakthrough is 80 feet. It was specified to make eleven cuts. The production time in a shift is 430 minutes. The input data for the example are shown in Table 14.

CONSIM was run once and the output is given in Table 15. From Table 15, it may be read that the duration of the first shift is 430.1 minutes of which the miner spent 208.1 minutes loading 829.2 tons of coal, 121.1 minutes on change-out, 0.5 minutes on waiting for shuttle cars, 45.8 minutes on waiting for entry into next cut because the roof bolter has not completed bolting the cut, 25.0 minutes tramming

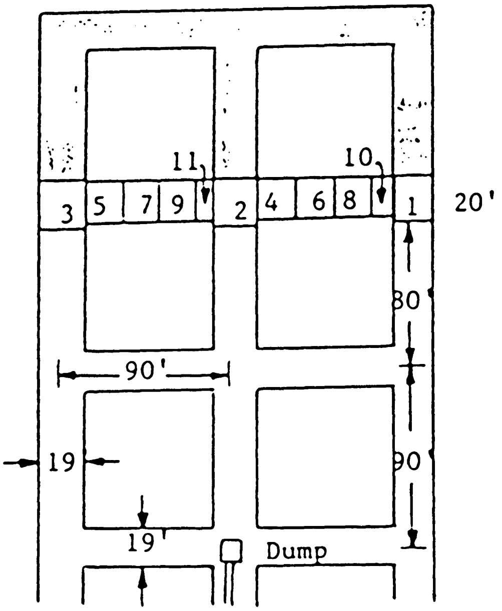

Figure 9
Layout for CONSIM Input Data

Table 14

A Sample Input for CONSIM

```
                              Input Data                                    Card Type

    3    1    2    1    0   22    9    1                                     A  (Table 4)
430.00.043.0094.010600.0000.0000.0000.00                                     B  (Table 5)
    481.10     1462.80       25.10       66.60                               C  (Table 6)
    419.70       10.5                                                        D  (Table 7)
        25     12345      6678      7890                                     E  (Table 8)
 19.0 19.0 19.0 20.0 71.0 71.0 32.0 28.0 80.0 00.0                           F  (Table 9)
   11    1    3    2    3    2    1                                          G  (Table 10)
 0.80 6.0 .0024.0023.0022.0021 0.59  .000 .000 .000 .000 .000 .000 .000
 0.90 7.0 .0025.0024.0023.0025 0.59  .0191.000 .041 .051 .164 .0221.000
 1.00     .0026.0025.0024.0026       .112      .110 .288 .136 .179
 1.10     .0027.0026.0025.0027       .292      .205 .425 .186 .299
 1.20     .0028.0027.0026.0028       .442      .315 .550 .271 .328
 1.30     .0029.0028.0027.0029       .572      .329 .625 .429 .373
 1.40     .0030.0029.0028.0030       .609      .507 .675 .529 .463
 1.50     .0031.0030.0029.0031       .628      .589 .775 .657 .522
 1.60     .0032.0031.0030.0032       .646      .658 .788 .743 .627
 1.70     .0033.0032.0031.0033       .683      .671 .850 .814 .687
 1.80     .0034.0033.0032.0034       .702      .726 .863 .900 .716
 1.90     .0035.0034.0035.0035       .720      .808 .875 .914 .731
 2.00     .0036.0035.0036.0036       .776      .822 .888 .943 .776              H  (Table 11)
 2.10     .0037.0037.0037.0037       .794      .849 .900 .971 .791
 2.20     .0038.0038.0040.0038       .813      .863 .9251.000 .821
 2.40     .0039.0039     .0039       .850      .904 .938      .866
 2.50     .0040.0043     .0040       .887      .959 .950      .925
 2.60     .0041.0047     .0043       .905      .973 .963      .940
 2.80     .0043.0050     .0045       .924      .986 .988      .970
 3.00     .0048.0052     .0047       .961     1.0001.000     1.000
 4.00                                .979
 5.00                               1.000
```

Table 14 (Continued)

A Sample Input for CONSIM

Input Data	Card Type
56.00 00.00 06.00 19.00 20.00	I (Table 12)
56.00 00.00 06.00 19.00 20.00	
56.00 00.00 06.00 19.00 20.00	
56.00 00.00 06.00 19.00 11.00	
56.00 00.00 06.00 19.00 20.00	
56.00 00.00 06.00 19.00 20.00	
56.00 00.00 06.00 19.00 20.00	
56.00 00.00 06.00 19.00 20.00	
00.00 00.00 06.00 19.00 20.00	
/*	
//	

Table 15

A Sample Output from CONSIM

```
                          ANALYSIS OF CONTINUOUS MINING SYSTEM
                          ************************************

                                 ALL TIMES IN MINUTES

              RUN      1 OF     1


SYSTEM PERFORMANCE BY SHIFT
***************************

SHIFT TIME   LOAD  CHANGE  WAIT-   WAIT-   TRAM  REPAIR  HAUL   TONS    T/M   CM  WAIT-  REPAIR  RB
NO.                OUT     CAR     COAL          (CM)    DIST                 AT  RB     RB      AT

 1   430.1  208.1  121.1    0.5    45.8    25.0   29.7   13.0   829.2 1.93   9    0.0    0.0    7

 2   163.4   43.6   32.1    0.0    77.5    10.2    0.0    3.2   161.0 0.99  11    0.0    0.0    9


SYSTEM PERFORMANCE OVER SIMULATION TIME
***************************************

TIME     LOAD     CHANGE   WAIT-   WAIT-    TRAM    REPAIR   HAUL     TONS    T/M    WAIT-   REPAIR   TIME    TONS
                  OUT      CAR     COAL             (CM)     DIST                    RB      RB       RB      /MILE

 593.5   251.6    153.2     0.5    123.3    35.2     29.7    16.2    990.2   1.67    0.0     0.0     596.1    61.3
```

between cuts and 29.7 minutes for repairs. The shuttle cars hauled 13.0 miles between the miner and the dump. The rate of mining was 1.93 tons/minute. At the end of the first shift, the miner is in the ninth cut and the bolter is in the seventh cut. Note that the shift time is more than the specified shift time of 430 minutes. This is because operation in progress at the end of the shift time is allowed to be completed.

4.4.4 Special Features of CONSIM

The special features of CONSIM are the following:

1. It can be run on microcomputers.
2. It is inexpensive to use.
3. It is simple and easy to understand.
4. It can be run interactively or in batch mode.
5. The input data requirements are minimal.
6. It can simulate breakdowns of equipment.
7. It can be used to simulate continuous mining systems with conveyors by specifying tram and discharge rates of shuttle cars as zero. It can also simulate continuous miners with roof bolter mounted on them by

specifying the values of the input variables for the roof bolter as zero.

8. It can be used to simulate development in longwall mining and mining room-and-pillar panels, without the without the need to make extensive data preparation.

The limitations of CONSIM are the following:

1. It can not simulate miner operation in more than one panel simultaneously.
2. It can not be used if pillars are of irregular sizes.
3. It can not be used for more than two shuttle cars.
4. Time study is required to collect data.

If one prefers deterministic simulation to stochastic simulation and wants to avoid time study, it is still possible to use CONSIM by inputting average performance characteristics of equipment instead of empirical probabilistic data. A stochastic simulation model requiring time study, however, is to be preferred to deterministic simulation for the following reasons:

1. The results obtained from a deterministic simulation does not consider the probabilistic nature of the performance measures of the system.

2. When comparing alternatives by performance measures obtained from a deterministic simulation using equipment characteristics, it is understandable that what can be realized with a system of equipment may not be proportional to these performance measures because of human and environmental factors influencing actual system performance. Therefore, incorporation of of these factors in some way in the simulation model is preferable.

Chapter V

MODEL VALIDATION AND CASE STUDIES

5.1 MODEL VERIFICATION

The model verification was done by going through the computer program with the flowchart to determine if the model translation into FORTRAN was correct. Having confirmed that translation into the FORTRAN program was correct, the program was run to see if it performed as intended in different artificially created conditions. The program was checked and found to function as intended in all possible simulation conditions.

5.2 MODEL VALIDATION

To validate CONSIM, the program was run with the same set of data used in FACESIM without simulating the breakdowns of equipment and other changes made in CONSIM that are not in FACESIM. Identical results were obtained from FACESIM and CONSIM. Therefore, CONSIM is validated with respect to FACESIM. FACESIM has been found to produce sufficiently accurate results in the mining industry(Prelaz, et al, 1964). Since the assumptions made in CONSIM are not grossly different from those in FACESIM, CONSIM is expected to produce reasonably accurate results for real mining systems. These arguments lead to the conclusion that CONSIM is a reasonably accurate representation of a real continuous mining system.

5.3 CASE STUDIES

To validate CONSIM with respect to real continuous mining systems, i.e., to check if the results obtained from CONSIM are reasonably close to the actual performance of real system, data were collected from two mining operations in West Virginia. For validation purposes, only the coal production per shift from CONSIM was statistically compared with the actual shift production of the operations.

Since no data were available for the time between breakdowns of equipment and time for each breakdown, the breakdowns of equipment could not be simulated. The production time of the miner in a shift was obtained by subtracting the average breakdown time of the miner per shift from the available face time.

On the advice of the industrial engineer familiar with the operations of the equipment in both of the mines and because of the difficulties involved in making time studies to calculate the travel rates of shuttle cars between different points on their haul between the miner and the dump, and to obtain switch-in, switch-out and change-out times, it was assumed that the haul rates of shuttle cars do not vary significantly whether the shuttle car is loaded or empty and that switch-in, switch-out and change-out times are zero. Since the change-out time was assumed to be zero, the change-out distance is zero. In other words, the shuttle cars change out at the miner and the haul distance is the distance between the miner and the dump change point and any switch-in and switch-out times are included in the time required to haul to and from the miner.

In both the mines, the dump is located at the intersection of the heading and breakthrough. Therefore, the dump change-out distance is zero. Since the discharge rate of shuttle cars is mainly dependent on the belt speed which is kept constant, the discharge rate was assumed constant. The discharge time for a shuttle car was 25 seconds and 35 seconds in the first and second mine respectively.

On the advice of the industrial engineer, the shuttle car load was assumed to be distributed as the shuttle car payload minus uniformly distributed load between zero and one ton.

5.3.1 Case Study I

In the first mining operation, the miner drives six headings in a 42-inch thick seam. The width of the heading and breakthough is 18 feet. The pillars are at 90 x 90 feet centers. The miners makes a 20-foot cut in headings and breakthroughs. Single cuts are made in breakthroughs. The dump is located in heading number three. The layout of the section is shown in Figure 10. Two shuttle cars of 5-ton capacity are used to haul coal from the miner to the dump. One roof bolter is in operation in this section of the mine.

When the time study was made, the miner was driving headings three through six; the miner was initially in heading number six and the roof bolter was waiting to move into heading number six. Headings one and two were not mined. Therefore, for the purpose of validation, it was assumed that there were four headings, the dump being located in heading number four. The miner was assumed to be in heading number four initially, the bolter waiting for the miner. The initial conditions were set to simulate the operations as closely as possible when the time study was made.

The program was run with the data from this mine and the mean and standard deviation of production per shift were obtained. The mean shift production from CONSIM IS 418.5 tons. The 90% confidence interval for production per shift (in tons) is (403.4, 433.6). The actual production of the miner when the time study was made was 420 tons. The 90% confidence interval for production per shift obtained from CONSIM covers the actual production realized.

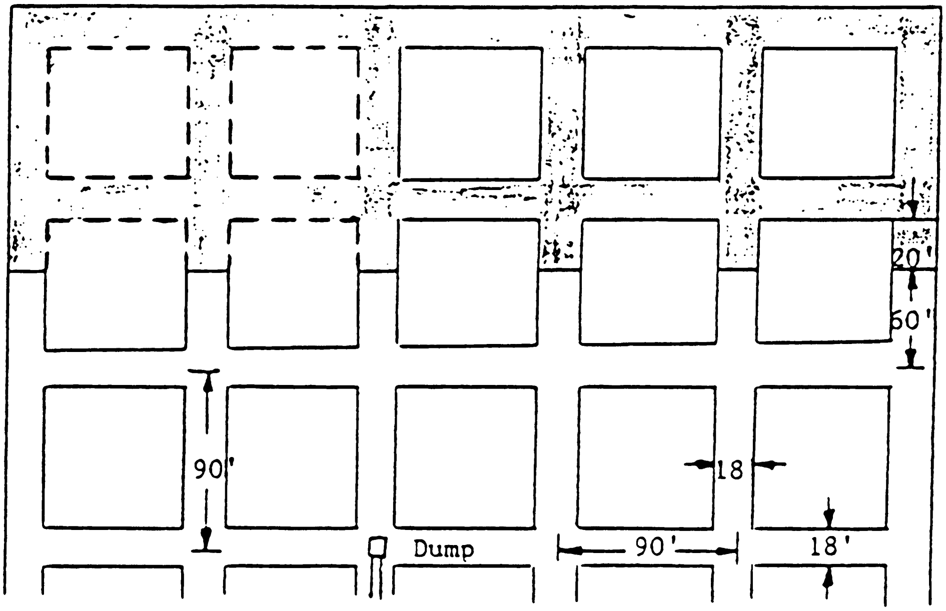

Figure 10
Layout for Case Study I

5.3.2 Case Study II

In the second mining operation, the miner makes chain pillars with three headings in a 6-foot thick seam. The dump is located in the second heading. The width of heading and breakthough is 19 feet. The pillars are at 90 x 90 feet centers. The miner makes 20-foot cut in headings and breakthroughs. Single cuts are made in breakthroughs. The layout of the section is shown in Figure 11. Two shuttle cars of 7-ton capacity are used to haul coal from the miner to the dump. One roof bolter is in operation in this section of the mine. The initial conditions were set to simulate the operations as closely as possible when the time study was made.

The program was run to get statistics on shift production. The mean shift production from CONSIM is 393.7 tons. The 90% confidence interval for production per shift (in tons) was (376.1, 411.3). The actual production of the miner when the time study was made was 400 tons. The 90% confidence interval for production per shift obtained form CONSIM covers the actual production realized.

From the two case studies, it is concluded that CONSIM simulates the continuous mining systems satisfactorily.

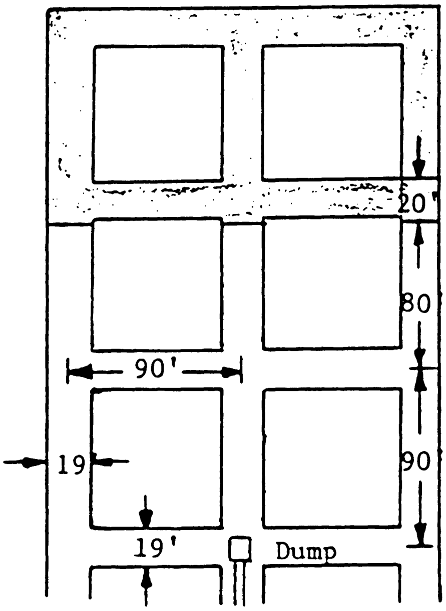

Figure 11

Layout for Case Study II

5.3.3 Analysis of Mining Operations

To illustrate some possible uses of CONSIM in analyzing existing face operations in continuous mining systems, CONSIM was run making changes in the input data collected from case studies and the change in shift production level was noted. No attempt was made to check the technical feasibility of implementing the changes made, or to analyze all possible changes or their combination, since it is only aimed to show a few possible uses of CONSIM. The changes made in input data and the results from CONSIM are shown in Table 16.

For the first mine, the following changes in the face operation were analyzed:

1. Reduce loading time of shuttle car by 25%.
2. Increase the center-line distance between pillars to 110 feet and the width of cut to 25 feet.

In the first case, the miner spent less time loading shuttle cars and more time waiting for them. Only 1% improvement in shift production level was achieved. In the second case, more coal could be mined in a cut because of increased width of cut. This resulted in fewer place changes per shift and lower shift tram time. However, because of longer haulage distance between the miner and the dump, the

TABLE 16

Analysis of Mining Operations

Change analyzed	Shift production (tons) Actual	Mean from CONSIM	Change in shift production
Mine No.1	420.0		
1. Original system		418.5	
2. Load time/S.C. reduced by 25%		426.0	1.4%
3. Width of cut & pillar: 25 & 110 ft		371.6	-11.5%
Mine No.2	400.0		
4. Original system		393.7	
5. S.C. payload: 9t		480.6	20.2%
6. 50% reduction in breakdown time		405.8	1.5%

miner had to wait longer for shuttle car lowering the shift production by 12%. Therefore, increasing the size of pillars and width of cuts is not desirable or reducing the shuttle car loading time is not attractive. Since, in both the cases, the miner spends a lot of time waiting for shuttle car, reducing it by putting more shuttle cars to haul coal or reducing shuttle car hauling time by increasing shuttle car haul rate may improve the shift production.

For the second mine, the following changes were analyzed:

1. Increase the shuttle car payload from 7 tons to 9 tons.

2. Decrease the miner breakdown time by 50%.

Lowering the miner breakdown time per shift by 50%, i.e., 15 minutes does not greatly improve the shift production since the miner already spends a large percentage of its time waiting for shuttle car. There is sharp improvement in shift production in the first and the last case. In the first case, the miner spent more time tramming between cuts per shift while the time the miner spent on other acivities remained essentially the same. The increase tramming time per shift is due to more number of cuts that could be mined. Since only the shuttle car payload was changed in the input data, the increase in the shift production was achieved not only by increased shuttle car payload but faster loading and unloading.

Chapter VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

A computer simulation model was successfully built to simulate continuous mining systems on micro-computers. The computer program was run on an IBM personal computer (with a FORTRAN 77 compiler) and an Ithaca micro-computer (with a FORTRAN 80 compiler) without any problem. Both computer systems have 64K random access memory. The only change required to make in the program when using it on different micro-computers is to check if the input/ouput units are correctly specified because different computers have different unit numbers for the same input/output units. The printer should be able to print 132 characters in a line.

CONSIM is simple and inexpensive to use. It can be used by anyone without much experience in simulation. Input data required are minimum and not much effort is required on the part of the user to prepare the data. CONSIM can also be run interactively.

There are several options available to the CONSIM user. He can specify any number of headings and designate any of them as transport heading. The breakthroughs need not be at right angle to the heading. Single or or multiple cuts may be made in breakthroughs. Simulation of automated miner-bolter, conveyor system and breakdowns of miner, shuttle cars and bolter are possible.

CONSIM can be used to design section layout, to select and evaluate equipment and to establish production standards.

6.2 RECOMMENDATIONS

The recommendations for future research in this area are the following:

1. Modifying CONSIM to simulate the miner operations in more than one panel. This makes possible simulation of all the face mining operations in a mine simultanoeusly.
2. Modifying CONSIM to simulate more than one miner bolter operation in a section.
3. Incorporation of a cost model to aid the user in financial analysis.
4. Development of simulation models of other mine systems such as ventilation systems, etc. and integrating them in CONSIM so that the entire mine system can be simultaneously optimized.

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APPENDIX A

DEFINITION OF VARIABLES

DEFINITION OF VARIABLES

The variables are given in the order they are executed in the program. To avoid repetition, the variable defined previously in the main program or in a subprogram is not defined again in another subprogram. All times are in minutes.

The variables used in the main program are the following:

KT	The first cut to be worked by the roof bolter.
NTSC	Number of mean times between breakdowns or mean breakdown times to be specified for shuttle car(s). This equals one or the number of shuttle cars used, NSC.
NSC	Numbers of shuttle cars to be used with continuous miner.
NDUMP	Type of dump. Enter one for one-way dump, two for two-way dump.
ICBCO	Type of output. Enter -1 for output by cut, 0 for output by shift, 1 for output

	by the time required to mine all the cuts.
NA	Number of input cards used to define empirical distributions for loading rate, shuttle car payload, shuttle car haul rates and discharge rate.
NB	Number of input data cards used to input dimensions of cuts and cycle times and tram functions of roof bolter. It is equal to 9.
NREP	Number of replications to be made.
SHFT	Production time in a shift. This equals the scheduled shift time excluding the times required to start work and to get out of the mine at the end of shift.
DENS	Density of coal in tons/cu.ft.
TL	Tram rate of continuous miner in min/ft.
TR	Tram rate roof bolter in min/ft.
SWI	The time required by an empty shuttle car to provide clearance for a loaded car by tramming into an entry at change point.

SWO	The time required by the shuttle car to return to the haulage road after switch-in.
CL1	The time required for any function other than production done by miner inby the passing point. This is called in-place constant in development. Examples of these functions are gas check, hang brattice.
CR1	Same as above, but for roof bolter.
XM1	Mean time between breakdowns for continuous miner.
XM3	Mean time between breakdowns for roof bolter.
XM4	Mean breakdown time for continuous miner.
XM6	Mean breakdown time for roof bolter.
XM2(I)	Mean time between breakdowns for shuttle car I.
XM5(I)	Mean breakdown time for shuttle car I.
L	Dummy variable for uniform(0, 1) random

	number generator.
IX, IY, IZ	Initial seeds for Uniform(0, 1) random number generator. Their values should lie in the range 1 through 30000. Integer arithmetic upto 30323 is required.
RLA(.)	Upper limit of interval for loading rate.
RLB(.)	Upper limit of interval for shuttle car payload.
RLC(.)	Upper limit of interval for loaded shuttle car haul rate in min/ft -- miner to change point.
RLD(.)	Upper limit of interval for loaded shuttle car haul rate in min/ft -- change point to dump.
RLE(.)	Upper limit of interval for empty shuttle car haul rate in min/ft -- dump to change point.
RLG(.)	Upper limit of interval for empty shuttle car haul rate in min/ft -- change point to miner.
RLH(.)	Upper limit of interval for discharge

	rate in minutes per shuttle car.
RA(.)	Cumulative distribution function for RLA(.).
RB(.)	Cumulative distribution function for RLB(.).
RC(.)	Cumulative distribution function for RLC(.).
RD(.)	Cumulative distribution function for RLD(.).
RE(.)	Cumulative distribution function for RLE(.).
RG(.)	Cumulative distribution function for RLG(.).
RH(.)	Cumulative distribution function for RLH(.).
RNRSUP(I)	Roof bolter cycle time for code I.
RMRSUP(I)	Roof bolter tram function for code I.
HT(I)	Height of cut for code I.
W(I)	Width of cut for code I.

DTH(I)	Depth of cut for code I.
NREPM	Number of replications made so far (A replication is an independent run of the program).
KREST	Internal control variable.
PLACE(I)	Time when cut I available.
SST(I)	Sample standard deviation of TSP(I).
TTSP(I)	Accumulator for TSP(I) over several runs.
SS(I)	Sample standard deviation of SP(I).
TLOAD, TSP(1)	Accumulator for miner loading time.
TCOT, TSP(2)	Accumulator for shuttle car change-out time.
TWL, TSP(3)	Accumulator for miner wait time for shuttle car.
TWP, TSP(4)	Accumulator for miner wait time for coal.
TTON, TSP(5)	Accumulator for coal mined (in tons).
TTPM, TSP(6)	Accumulator for mining rate (in tons/ min).
TWRS, TSP(7)	Accumulator for roof bolter wait time.

TREPTL, TSP(8)	Accumulator for miner breakdown time.
TREPTR, TSP(9)	Accumulator for roof bolter breakdown time.
THD, TSP(10)	Accumulator for haul distance of shuttle car(s).
TCYCLE, TSP(11)	Accumulator for cut cycle time.
ARC, TSP(12)	Clock on roof bolter.
ALC, TSP(13)	Clock on continuous miner.
RATE,TSP(14)	Mining rate over the time reqiured to mine all the cuts.
TPMIL, TSP(15)	Coal hauled (in tons) per mile of shuttle car travel over the time required to mine all the cuts.
TTRAM, TSP(16)	Accumulator for miner tram time.
CLOAD	Loading time in a cycle.
CCOT	Change-out time in a cycle.
WL	Miner wait time for shuttle car in a cycle.

WP	Miner wait time for place in a cycle.
CTON	Coal mined in a cut (tons).
CTPM	Mining rate in a cycle.
CWRS	Roof bolter wait time for place during a miner cycle.
CHD	Shuttle car haul distance in a cycle.
CYCLE	Cycle time.
IDUMP	Switch to route shuttle car in a two-way dump. Its initial value is one.
K	Cut number.
LIN	The first cut to be mined by miner.
M	Number of the shuttle car whose operation is being simulated.
KT1	Storage for initial value of KT.
KE1	Next cut to be made available by roof bolter.
KE	Cut made available by roof bolter.
FALTL	Time at which continuous miner will breakdown. The time between breakdowns is

	obtained by random sampling.
TREPTS(I)	Total breakdown time of shuttle car I when all cuts are mined.
ISUR(I)	Operating status of shuttle car I. Enter zero, if available; one, otherwise.
CREPTS(I)	Time the shuttle car I will be under breakdown at the beginning of the next shift.
FALTS(I)	Time at which shuttle car I will breakdown.
FALTR	Time at which the roof bolter is to breakdown.
IRS	Operating status of roof bolter. Zero if the roof bolter is in operation; if not, one).
NSHFT	Number of shifts simulated.
TPLAC	Coal remaining in cut being mined by the miner (in tons).
REM	Time remaining in shift.
CREPTL	Time the miner will be under breakdown in

the beginning of the next shift due to breakdown in a shift.

CREPTR	Same as CREPTL, but for roof bolter.
CTRAM1	Time required in the next shift to complete tramming.
WP1	Time the miner has to wait in the next shift for entry into the next cut.
WRS1	Time the bolter has to wait in the next shift for entry into the next cut.
TARC	Time to tram the bolter into the cut to be roof-bolted.
SLC	Miner loading time in a shift.
STRAM	Miner tramming time in a shift.
TTIME	Simulation clock, i.e., the variable giving current value of simulated time.
SWRS2	Roof bolter wait time for place in a shift when the miner completes mining the previous cut.
SLOAD, SP(1)	Miner loading time in a shift.
STCOT, SP(2)	Shuttle cars change-out time in a shift.

SWL, SP(3)	Miner wait time for shuttle cars in a shift.
SWP, SP(4)	Miner wait time for place in a shift.
STON, SP(5)	Coal mined in a shift (tons).
STPM, SP(6)	Shift mining rate.
SWRS, SP(7)	Roof bolter wait for place in a shift.
SREPTL, SP(8)	Time the miner was under breakdown in a shift.
SREPTR, sp(9)	Time the roof bolter was under breakdown in a shift.
SHD, SP(10)	Haul distance of shuttle cars in a shift.
SREPTS(I)	Breakdown time of shuttle car I in a shift.
IIRS	Control to read data for the next cut to be roof-bolted.
PTON	Coal initially in a cut (tons).
KODE(I)	Code for dimensions of cuts and roof bolter cycle times and tram functions for cut I.

SWL2	Miner wait time for shuttle car in a shift when it completed mining the previous cut.
SLOAD2	Miner load time in a shift when it completed mining the previous cut.
STON2	Coal mined in a shift when the miner completed mining the previous cut.
SHD2	Distance hauled by shuttle car(s) in a shift when the miner completed mining the previous cut.
STCOT2	Change-out time in a shift when the miner completed mining the previous cut.
SCC(I)	Clock on shuttle car I.
ALC2	Time on miner clock when the miner completed mining the previous cut.
CPCHK	Clock at the change point.
DCPCK, DCPCK2	Clocks at the dump change point.
ALOAD	Continuous miner loading rate obtained by random sampling.

SCAPY	Shuttle car payload obtained by random sampling.
REPTL	Breakdown time of miner obtained by random sampling when it breaks down.
FALTL	Time at which the miner will breakdown.
SREPTL	Time the miner was under breakdown in a shift.
CPD	Change-out distance for cut (ft).
VL1	Haul rate of loaded shuttle car between sampling and dump change point obtained by random sampling.
VL2	Haul rate of loaded shuttle car between dump change point and dump.
VE1	Same as VE1 when the shuttle car is empty.
HD	Distance between change point and dump change point of cut.
DISCH	Discharge rate obtained by random sampling.
DCPD	Dump change-out distance.

REPTS(I)	Breakdown time of shuttle car I obtained by random sampling when it breaks down.
J	Counter for number of shuttle cars checked for operating status.
DMIN	Variable to store the time on shuttle car which will return to operating status the earliest.
VE2	Same as VL2, but when shuttle car is empty.
LT1(I)	Tram distance for cut I from passing point to passing point.
LT2(I)	Tram distance for cut I from face to passing point.
K1	Cut to be mined next by the miner.
CTRAM	Miner tram time in a cycle.
STRAM	Miner tram time in a shift.
ICRS	Number of cuts roof bolter is behind the miner initially.
KG	Cut to be roof-bolted next.

KRS	Storage for KODE(KT).
REPTR	Roof breakdown time obtained by random sampling when the roof bolter breaks down.
SP1(I)	Sample mean of SP(I).

The following are the variables used in subroutine GCARD:

W(I)	Width of cut: in non-transport heading, for I=1; in transport heading, for I=2; in breakthrough, for I=3.
DTH	Depth of cut in development.
WHPIL	Length of pillar along heading.
WPIL	Length of pillar along breakthrough.
ALM	Length of continuous miner.
SCL	Length of shuttle car.
SDIST	Distance of the first cut from the center of the breakthrough in the heading.
NCM	Number of cuts to be made in development.

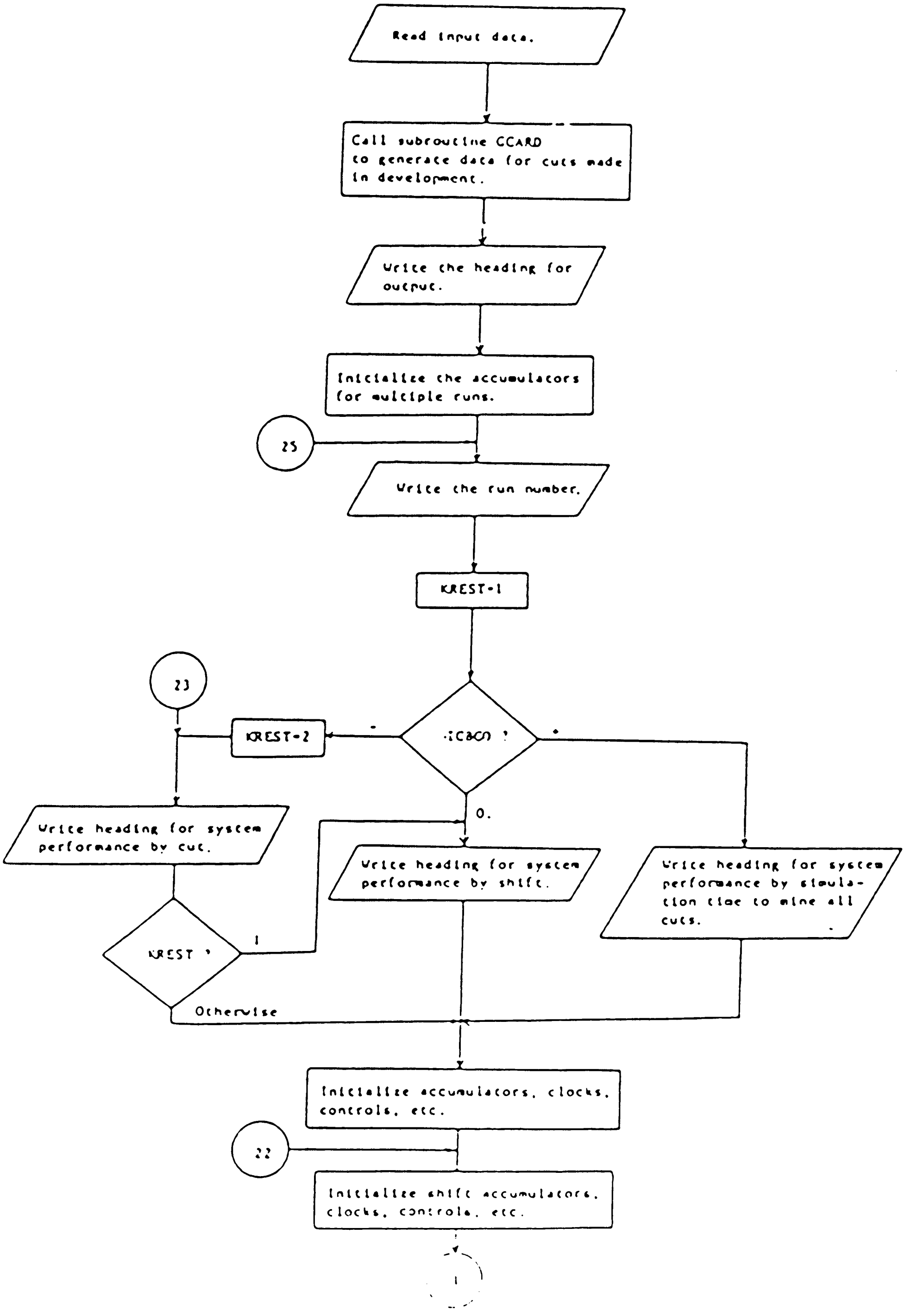
MULTI	Control variable for type of cut to be made in breakthrough. Enter one for single cut; two for multiple cut.
KHEAD	Number of headings in a panel.
NHT	Number of the transport heading.
NPC	Distance to be advanced in development in terms of center-to-center pillar distance.
LPC	Control variable for movement of dump. Enter zero, if the dump is not to be moved; otherwise, any positive number.
KIL, I, J	Internal multipliers for distances.
MIL	Control for calculation of distances.
TLT2	Storage for LT2(.).
TD1	Storage for change-out distance.
NP	Counter for number of center-to-center pillar distance advanced.
DIST1	=WHPIL+W(3)
DIST2	=DIST1-SCL
DIST3	=WPIL+W(1)

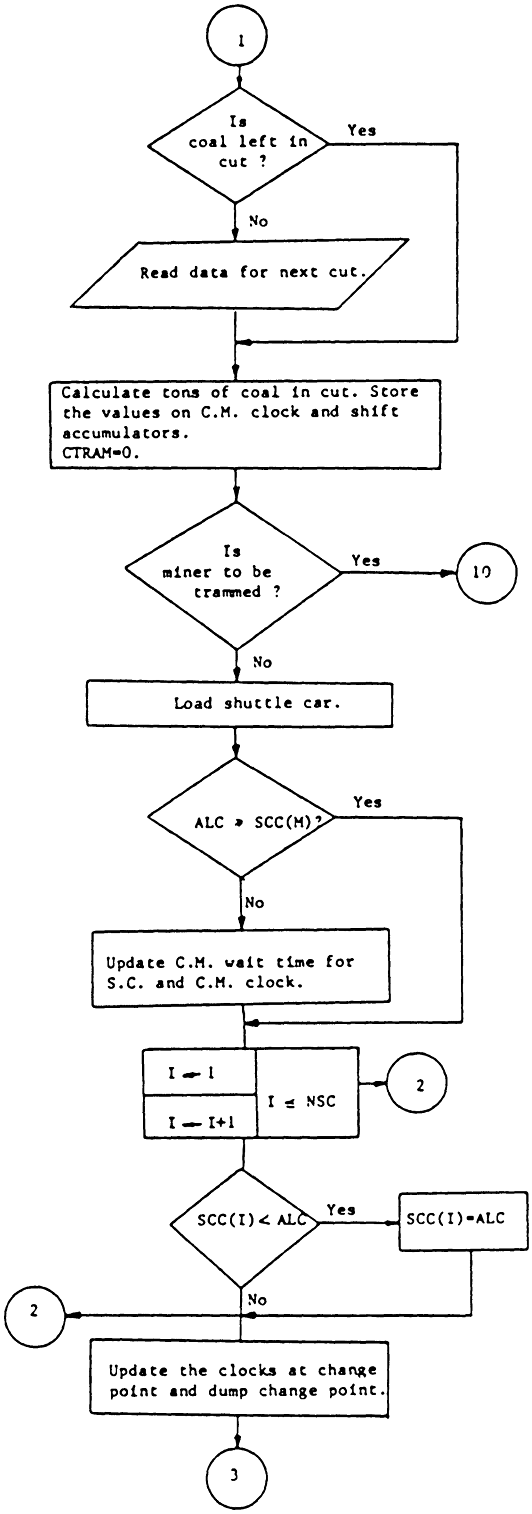
KK	Number of cuts to be made in each heading for advancement of a minimum of DIST1 distance.
SDIST2	storage for SDIST.
KK1	Number of single cuts to be made before another cut in the same breakthrough.
CLAST	Width of the last cut in a breakthrough.
KK2	Same as KK1, but when multiple cuts are made.

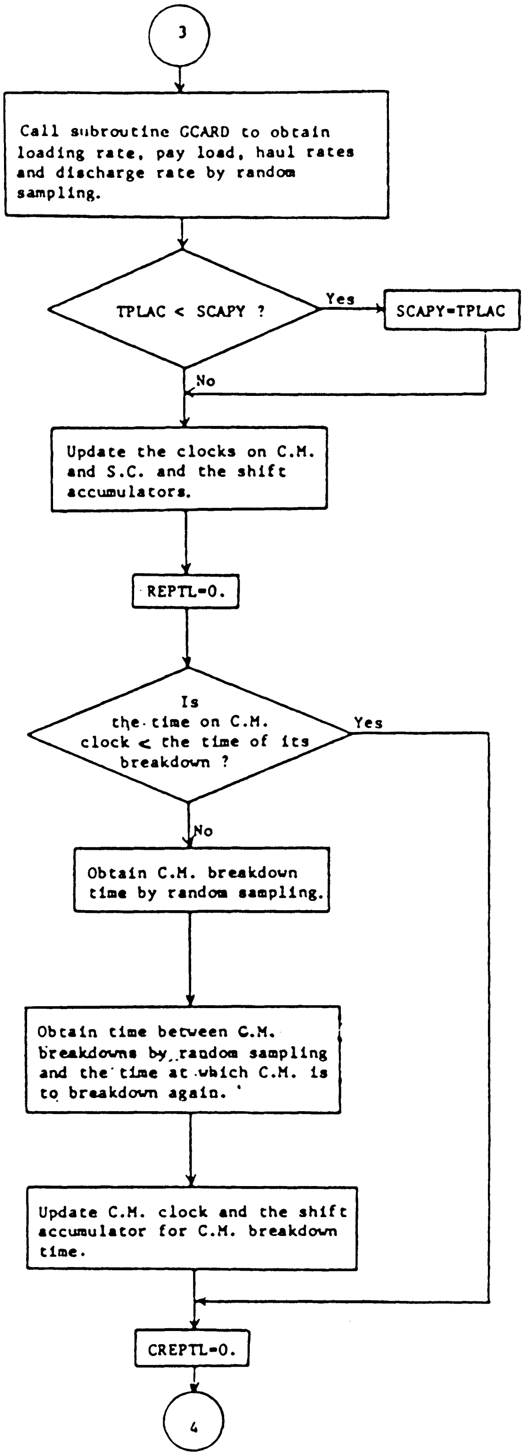
APPENDIX B

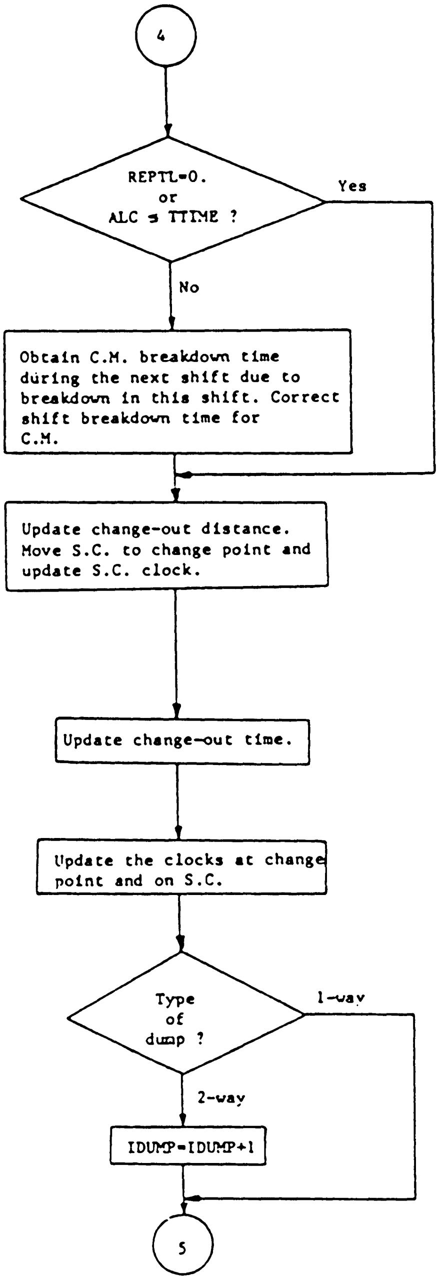
FLOWCHART FOR CONSIM

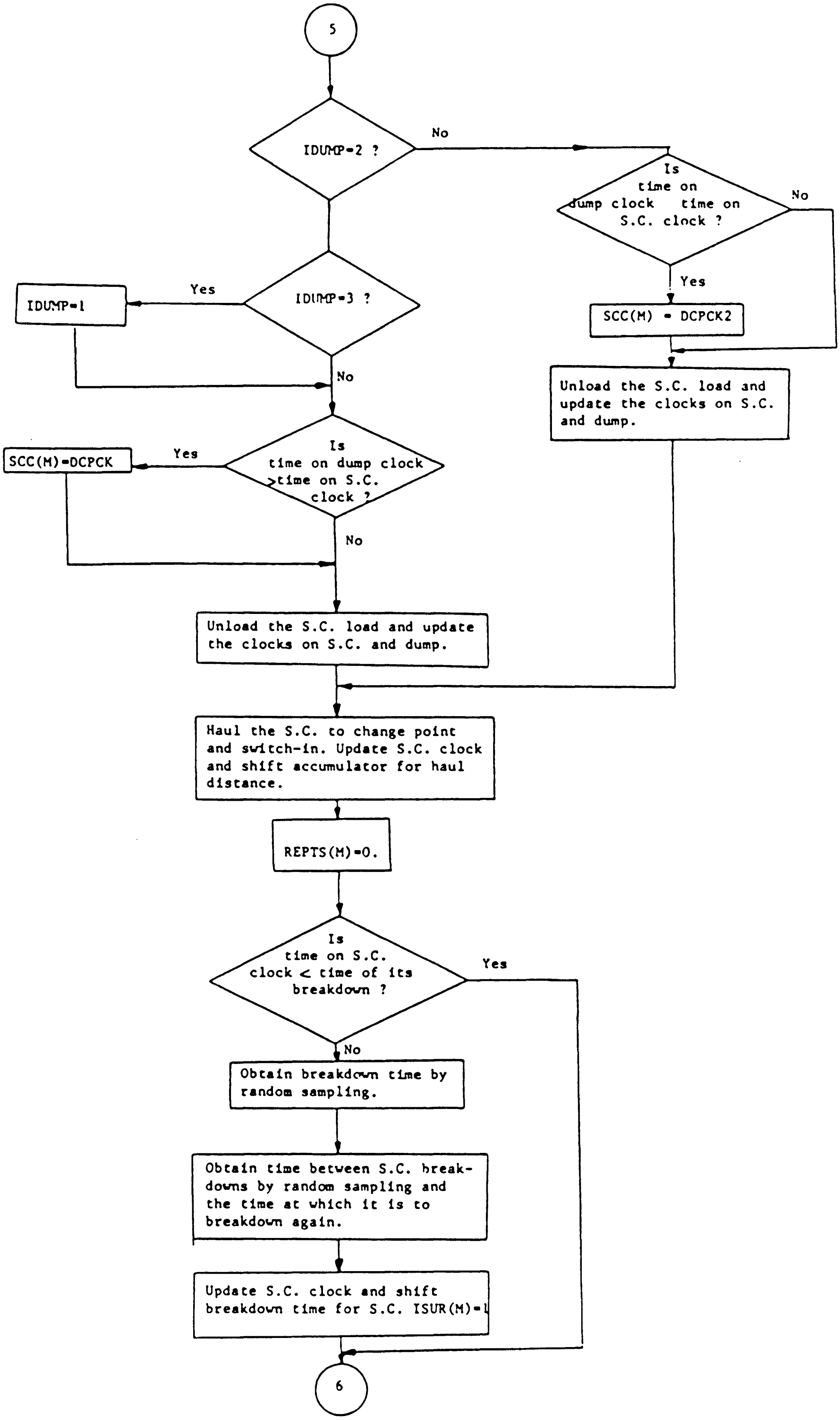
(1) Flowchart for Main Program

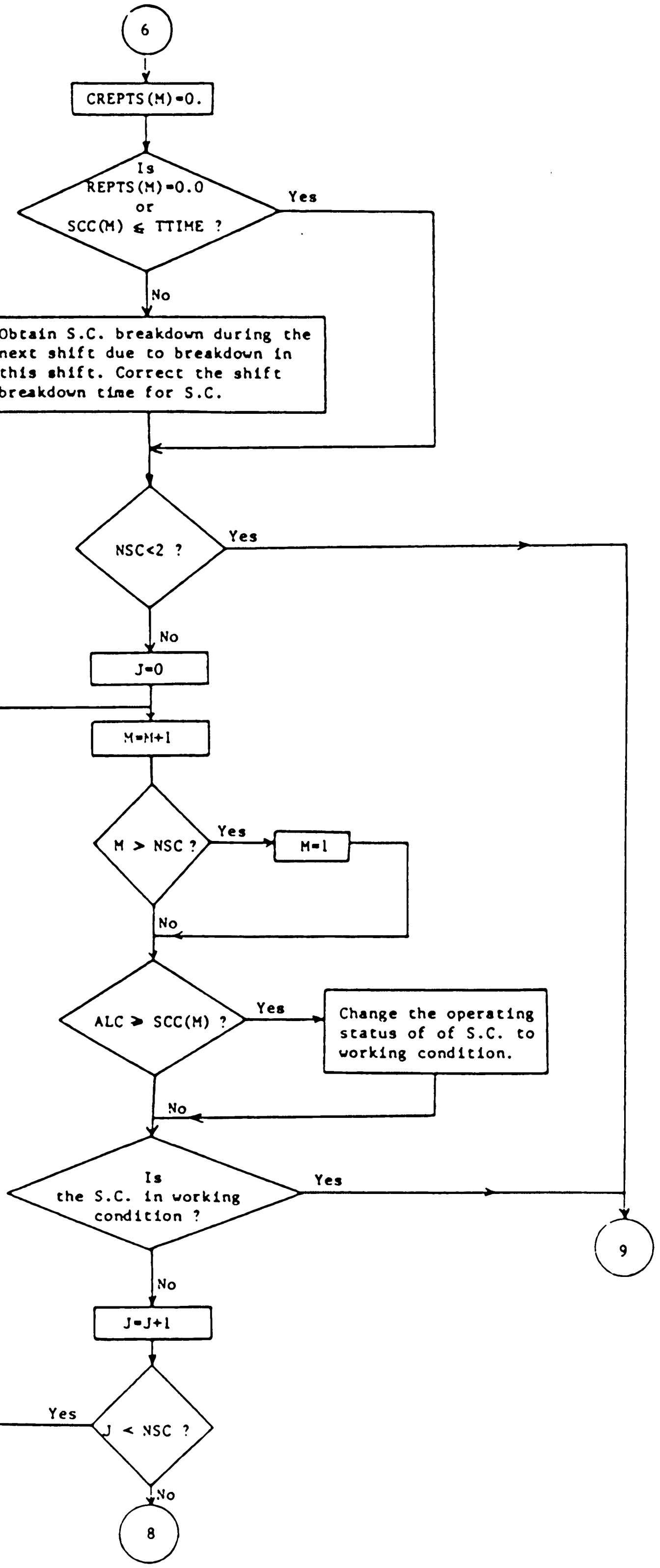


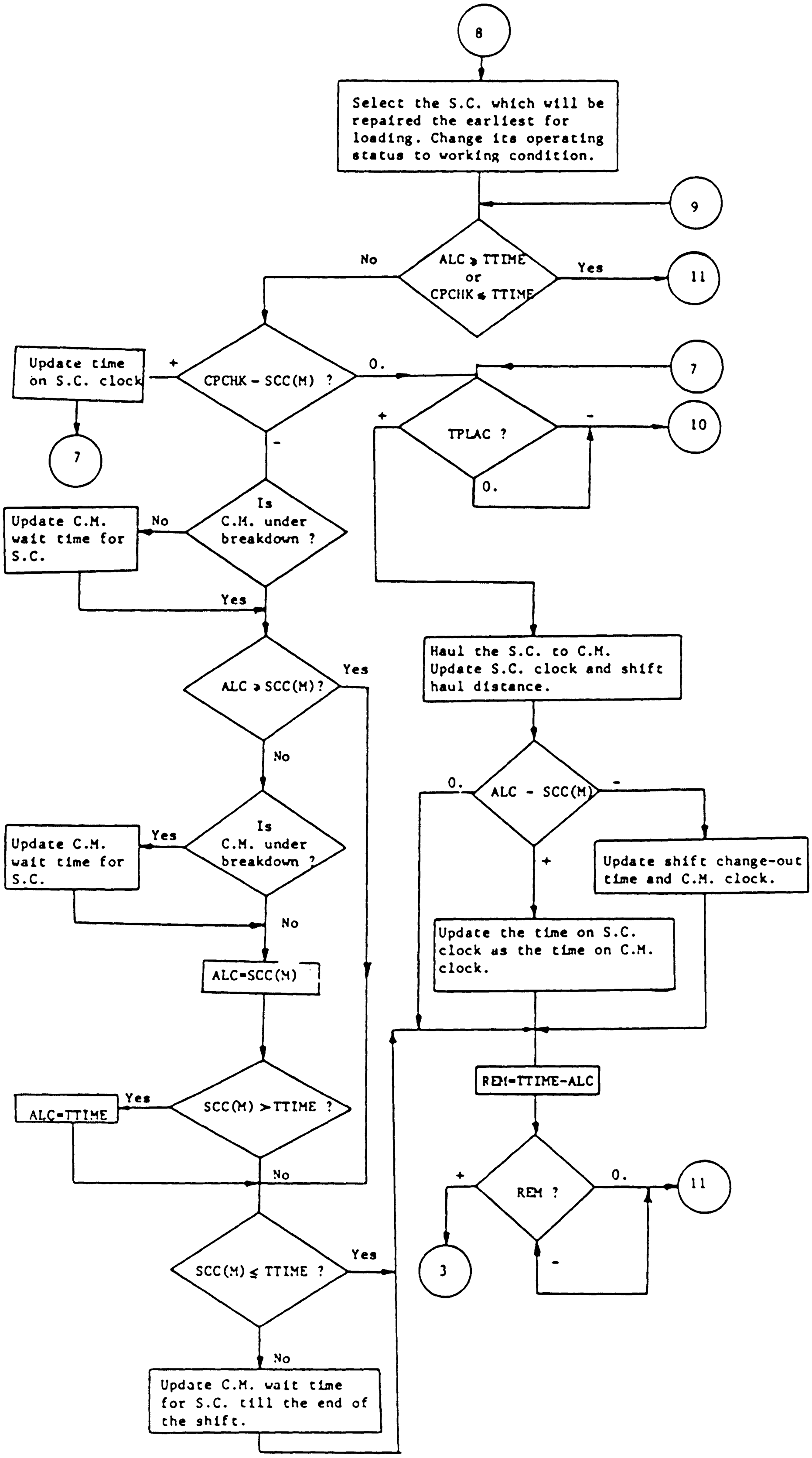

1
Is coal left in cut ?
Yes
No
Read data for next cut.
Calculate tons of coal in cut. Store the values on C.M. clock and shift accumulators.
CTRAM=0.
Is miner to be trammed ?
Yes
10
No
Load shuttle car.
ALC ≥ SCC(M)?
Yes
No
Update C.M. wait time for S.C. and C.M. clock.
I ← 1
I ← I+1
I ≤ NSC
2
SCC(I) < ALC
Yes
SCC(I)=ALC
No
2
Update the clocks at change point and dump change point.
3

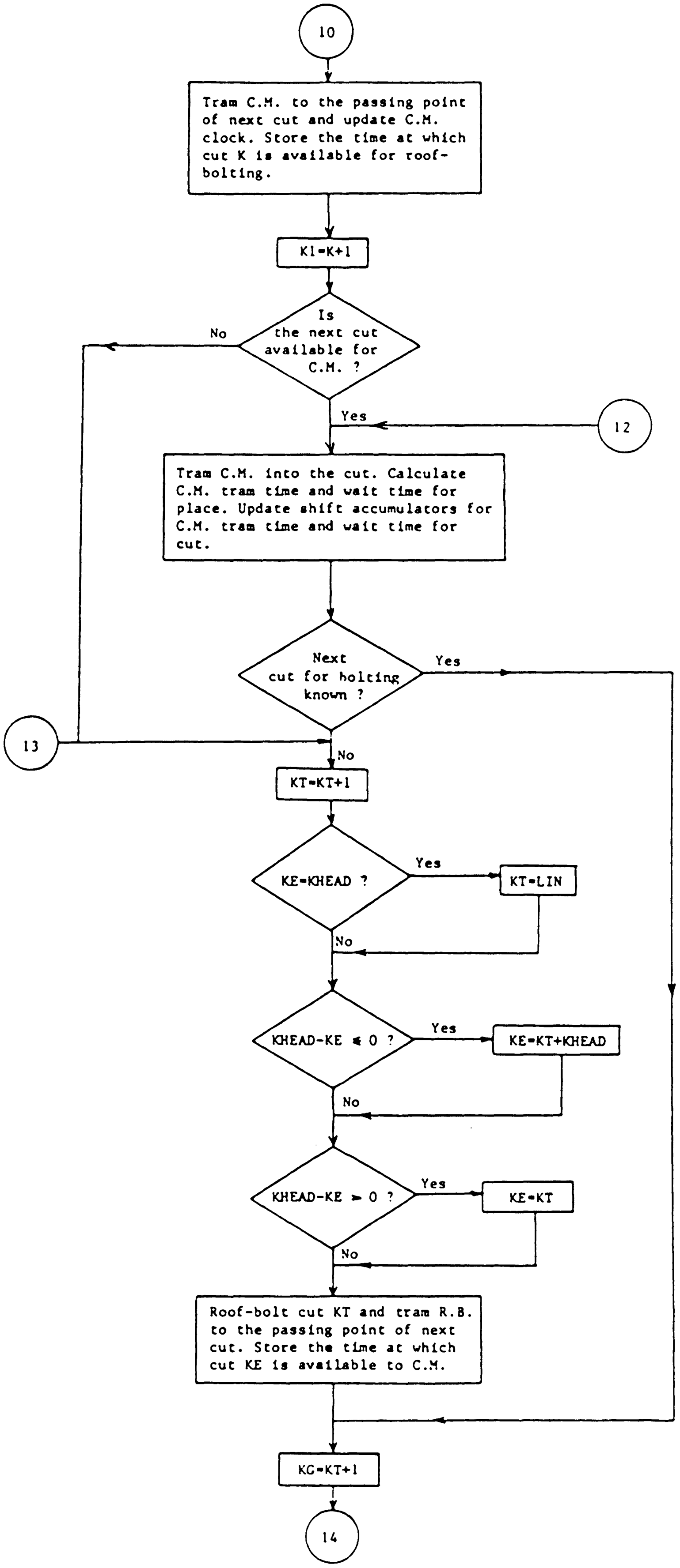

3
Call subroutine GCARD to obtain loading rate, pay load, haul rates and discharge rate by random sampling.
TPLAC < SCAPY ?
Yes
SCAPY=TPLAC
No
Update the clocks on C.M. and S.C. and the shift accumulators.
REPTL=0.
Is the time on C.M. clock < the time of its breakdown ?
Yes
No
Obtain C.M. breakdown time by random sampling.
Obtain time between C.M. breakdowns by random sampling and the time at which C.M. is to breakdown again.
Update C.M. clock and the shift accumulator for C.M. breakdown time.
CREPTL=0.
4

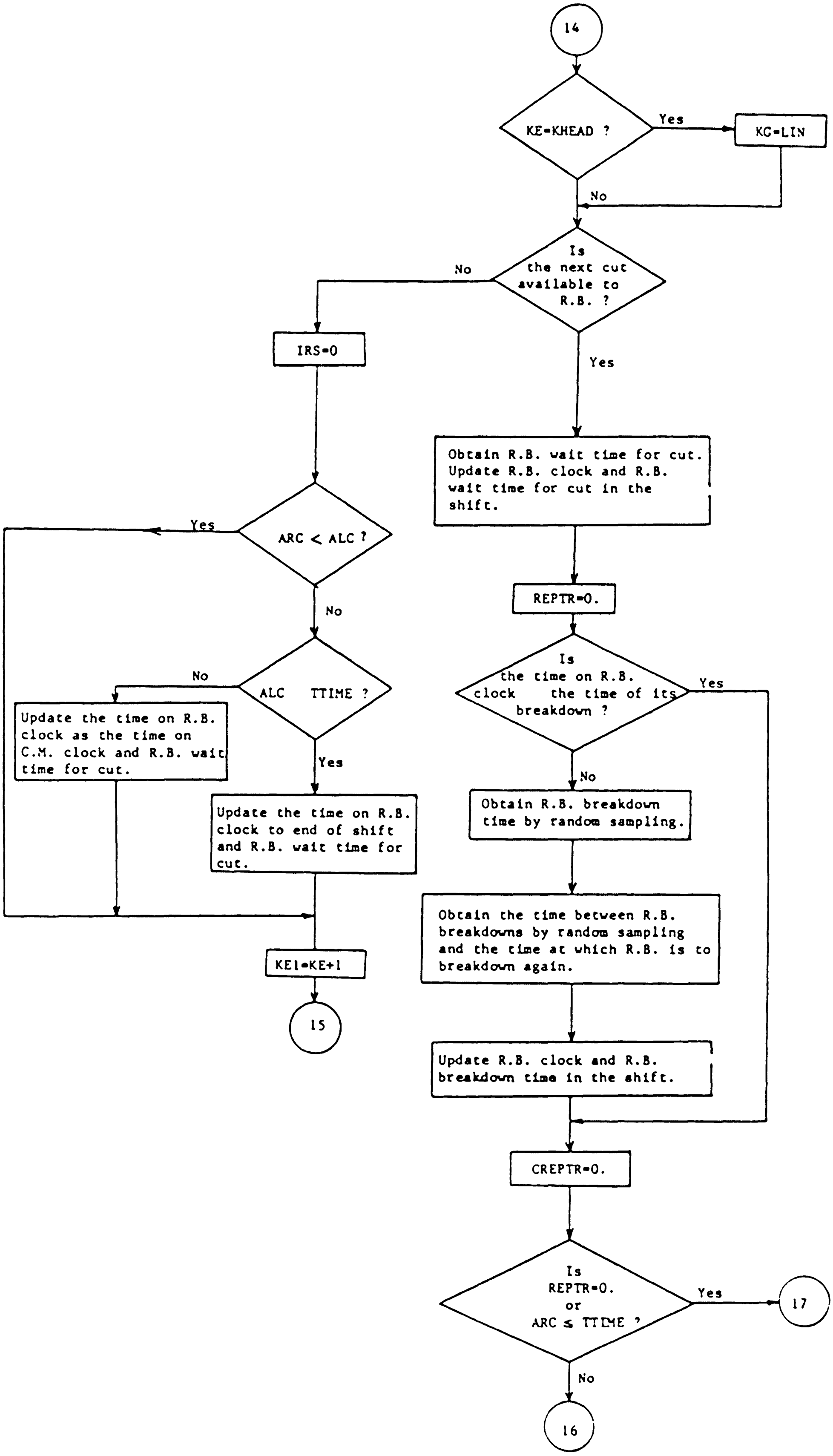

4
REPTL=0.
or
ALC ≤ TTIME ?
Yes
No
Obtain C.M. breakdown time during the next shift due to breakdown in this shift. Correct shift breakdown time for C.M.
Update change-out distance. Move S.C. to change point and update S.C. clock.
Update change-out time.
Update the clocks at change point and on S.C.
Type of dump ?
1-way
2-way
IDUMP=IDUMP+1
5

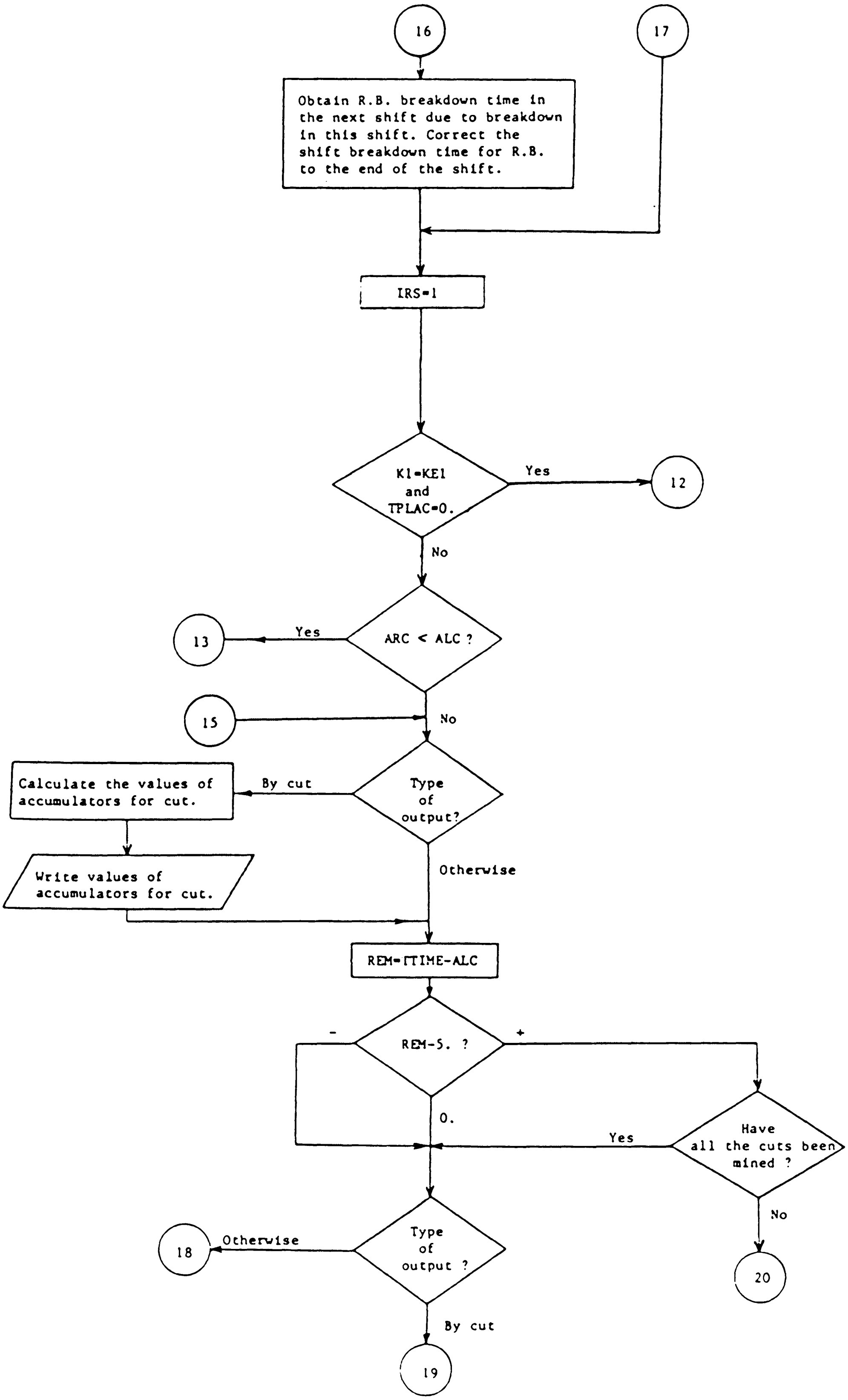

5
IDUMP=2 ?
No
Is time on dump clock time on S.C. clock ?
No
Yes
SCC(M) = DCPCK2
Unload the S.C. load and update the clocks on S.C. and dump.
Yes
IDUMP=3 ?
IDUMP=1
No
Is time on dump clock ≥ time on S.C. clock ?
Yes
SCC(M)=DCPCK
No
Unload the S.C. load and update the clocks on S.C. and dump.
Haul the S.C. to change point and switch-in. Update S.C. clock and shift accumulator for haul distance.
REPTS(M)=0.
Is time on S.C. clock < time of its breakdown ?
Yes
No
Obtain breakdown time by random sampling.
Obtain time between S.C. breakdowns by random sampling and the time at which it is to breakdown again.
Update S.C. clock and shift breakdown time for S.C. ISUR(M)=1
6

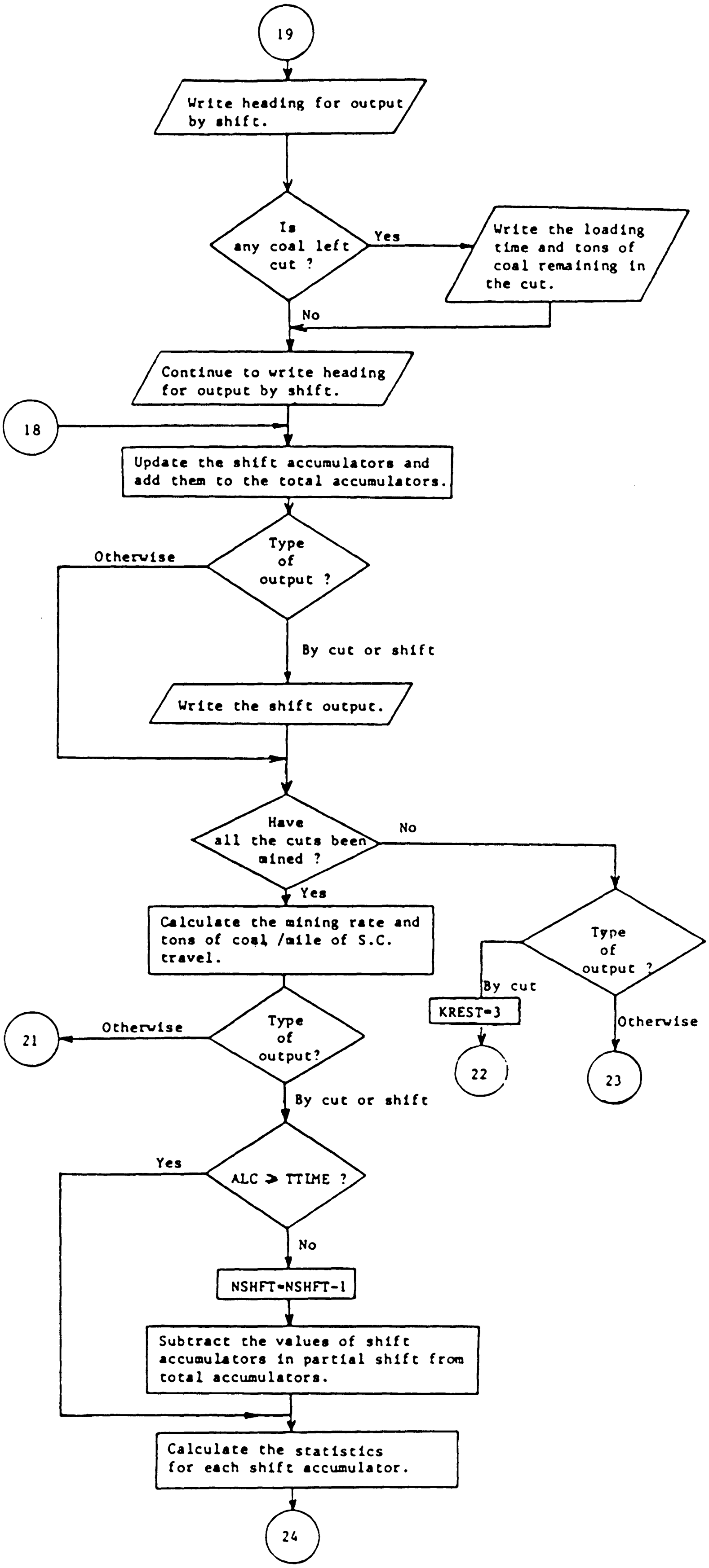

6
CREPTS(M)=0.
Is REPTS(M)=0.0 or SCC(M) ≤ TTIME ?
Yes
No
Obtain S.C. breakdown during the next shift due to breakdown in this shift. Correct the shift breakdown time for S.C.
NSC<2 ?
Yes
No
J=0
M=M+1
M > NSC ?
Yes
M=1
No
ALC ≥ SCC(M) ?
Yes
Change the operating status of of S.C. to working condition.
No
Is the S.C. in working condition ?
Yes
9
No
J=J+1
J < NSC ?
Yes
No
8

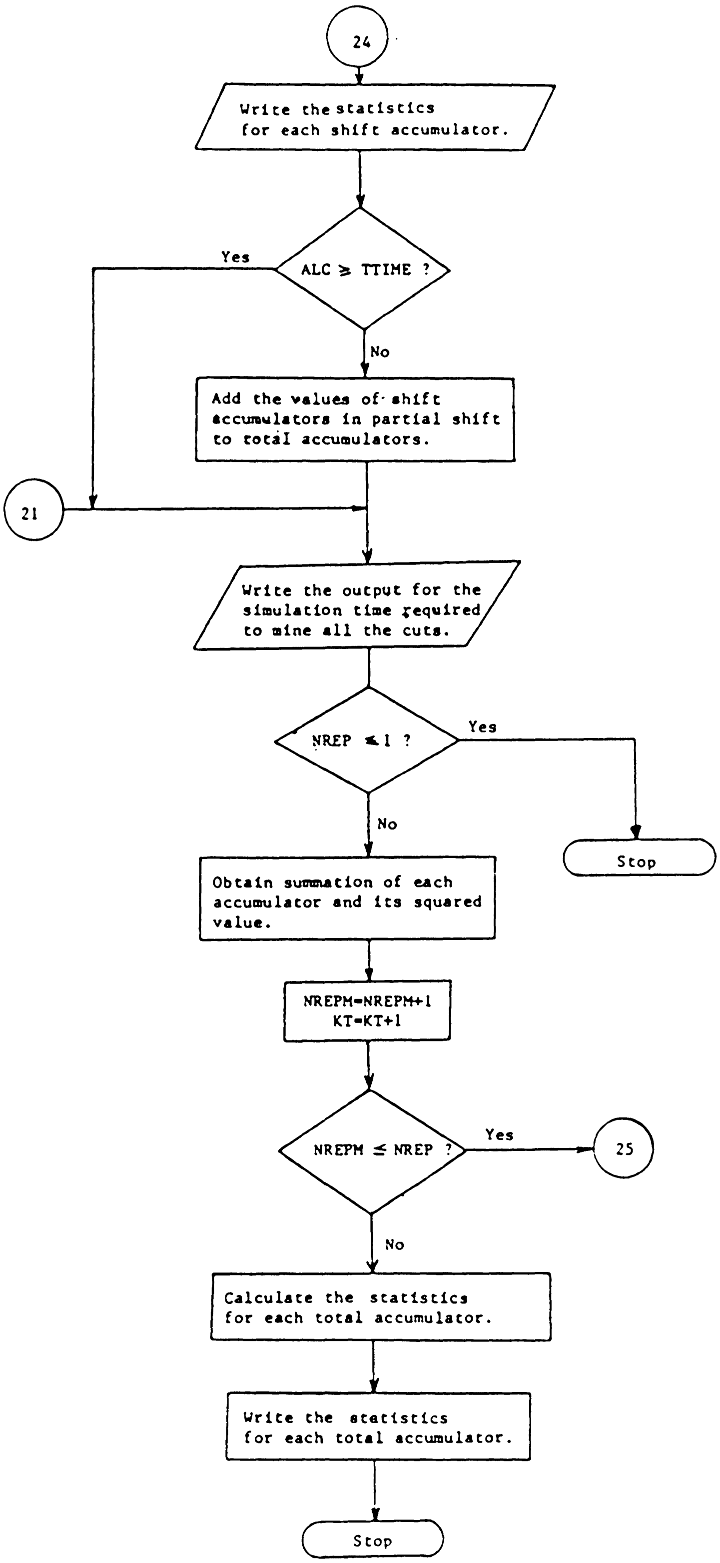

8
Select the S.C. which will be repaired the earliest for loading. Change its operating status to working condition.
9
ALC ≥ TTIME or CPCHK ≤ TTIME
No
Yes
11
Update time on S.C. clock
+
CPCHK - SCC(M) ?
0.
7
-
7
+
TPLAC ?
-
10
0.
Update C.M. wait time for S.C.
No
Is C.M. under breakdown ?
Yes
Haul the S.C. to C.M. Update S.C. clock and shift haul distance.
ALC ≥ SCC(M)?
Yes
No
0.
ALC - SCC(M)
-
Update C.M. wait time for S.C.
Yes
Is C.M. under breakdown ?
+
Update shift change-out time and C.M. clock.
No
Update the time on S.C. clock as the time on C.M. clock.
ALC=SCC(M)
REM=TTIME-ALC
ALC=TTIME
Yes
SCC(M) >TTIME ?
No
+
REM ?
0.
11
-
SCC(M) ≤ TTIME ?
Yes
3
No
Update C.M. wait time for S.C. till the end of the shift.


10
Tram C.M. to the passing point of next cut and update C.M. clock. Store the time at which cut K is available for roof-bolting.
K1=K+1
Is the next cut available for C.M. ?
No
Yes
12
Tram C.M. into the cut. Calculate C.M. tram time and wait time for place. Update shift accumulators for C.M. tram time and wait time for cut.
Next cut for bolting known ?
Yes
13
No
KT=KT+1
KE=KHEAD ?
Yes
KT=LIN
No
KHEAD-KE < 0 ?
Yes
KE=KT+KHEAD
No
KHEAD-KE > 0 ?
Yes
KE=KT
No
Roof-bolt cut KT and tram R.B. to the passing point of next cut. Store the time at which cut KE is available to C.M.
KG=KT+1
14

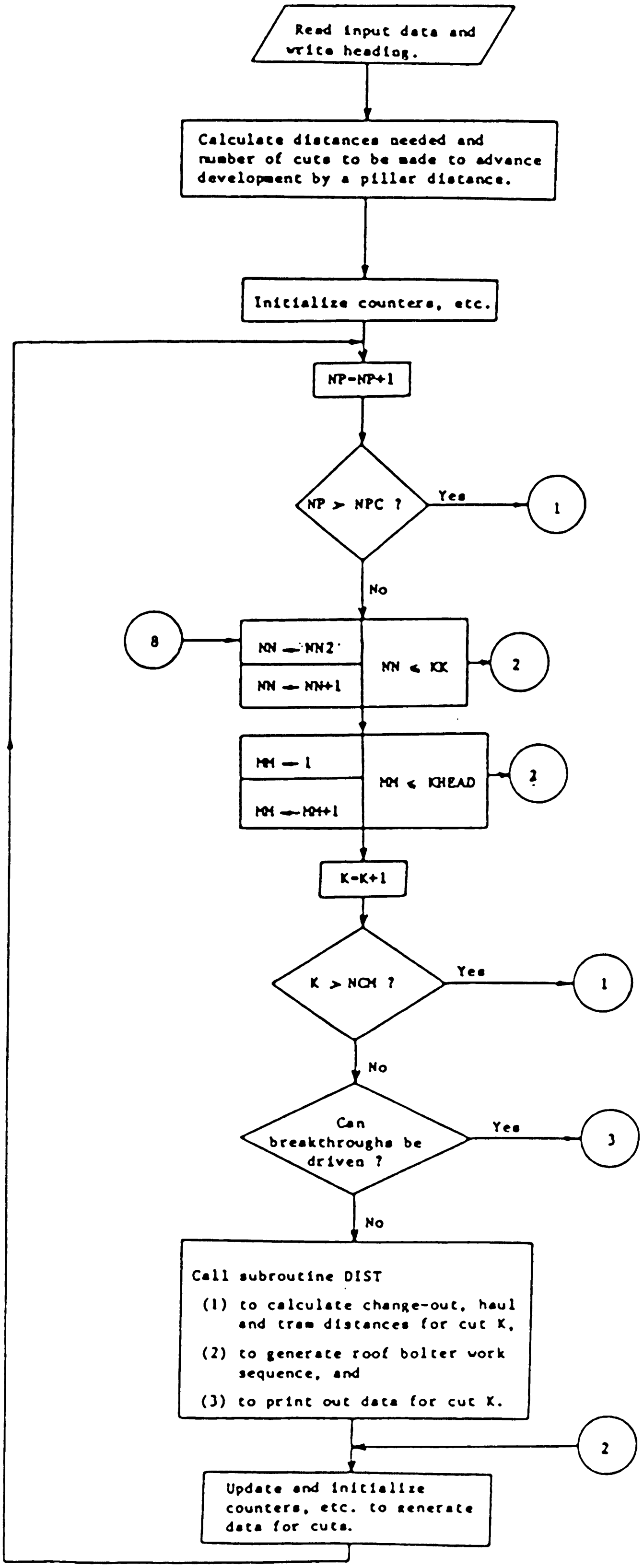

14
KE=KHEAD ?
Yes
KG=LIN
No
Is
the next cut
available to
R.B. ?
No
IRS=0
Yes
Obtain R.B. wait time for cut.
Update R.B. clock and R.B.
wait time for cut in the
shift.
Yes
ARC < ALC ?
No
REPTR=0.
No
ALC TTIME ?
Is
the time on R.B.
clock the time of its
breakdown ?
Yes
Update the time on R.B.
clock as the time on
C.M. clock and R.B. wait
time for cut.
Yes
No
Update the time on R.B.
clock to end of shift
and R.B. wait time for
cut.
Obtain R.B. breakdown
time by random sampling.
Obtain the time between R.B.
breakdowns by random sampling
and the time at which R.B. is to
breakdown again.
KE1=KE+1
15
Update R.B. clock and R.B.
breakdown time in the shift.
CREPTR=0.
Is
REPTR=0.
or
ARC ≤ TTIME ?
Yes
17
No
16

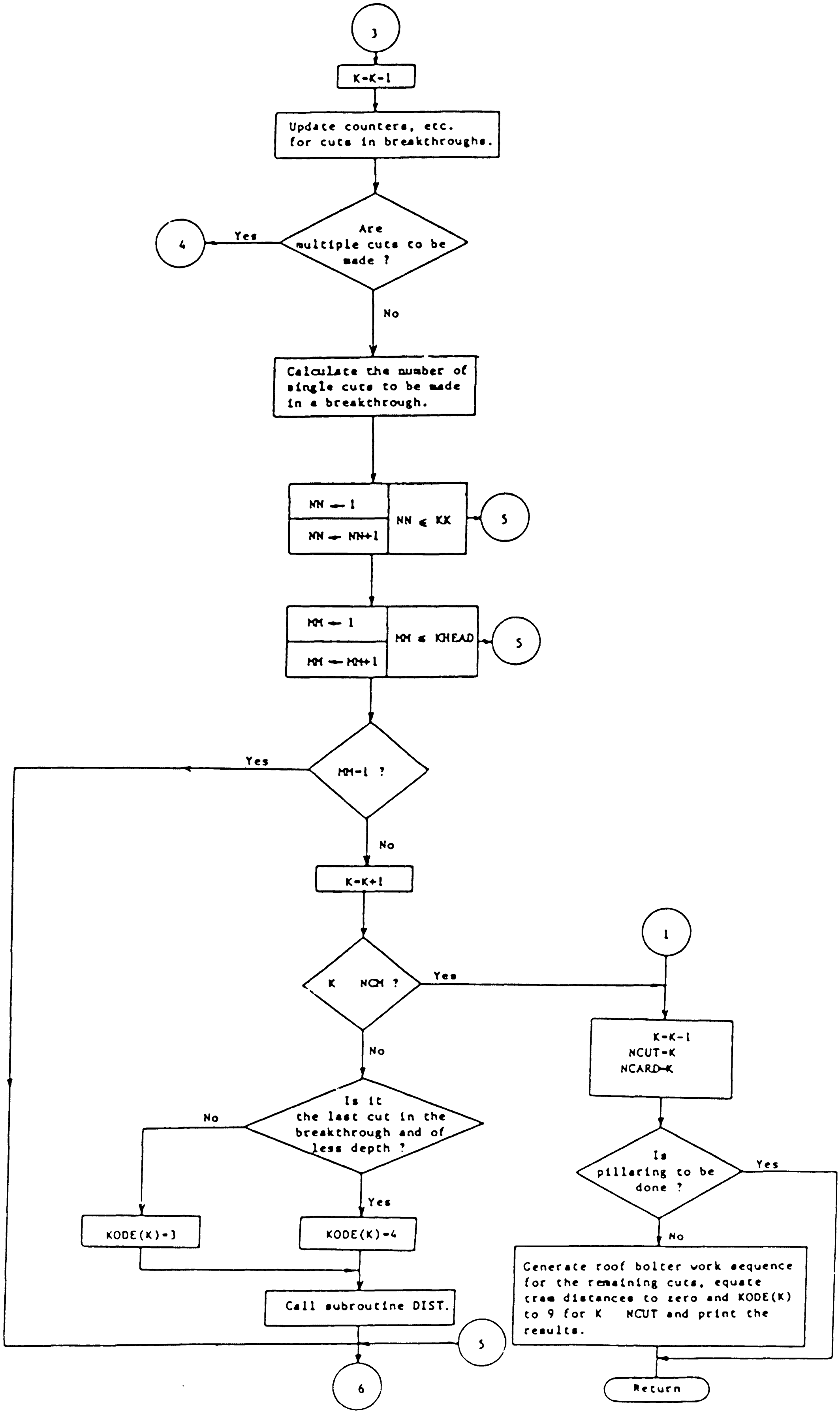

16
17
Obtain R.B. breakdown time in the next shift due to breakdown in this shift. Correct the shift breakdown time for R.B. to the end of the shift.
IRS=1
K1=KE1 and TPLAC=0.
Yes
12
No
ARC < ALC ?
Yes
13
15
No
Type of output?
By cut
Calculate the values of accumulators for cut.
Write values of accumulators for cut.
Otherwise
REM=ITIME-ALC
REM-5. ?
-
+
0.
Have all the cuts been mined ?
Yes
No
20
Type of output ?
Otherwise
18
By cut
19

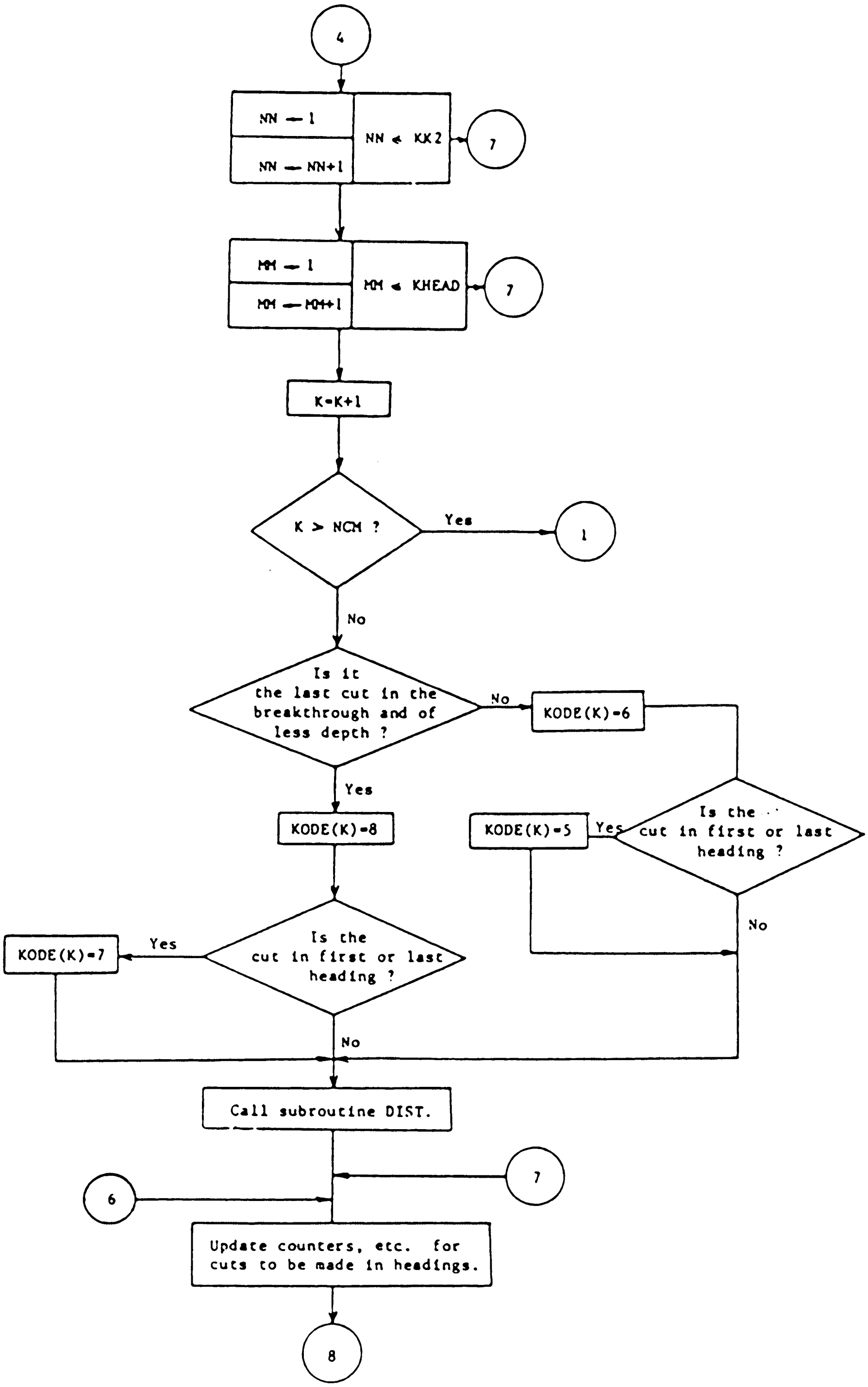

19
Write heading for output by shift.
Is any coal left cut ?
Yes
Write the loading time and tons of coal remaining in the cut.
No
Continue to write heading for output by shift.
18
Update the shift accumulators and add them to the total accumulators.
Type of output ?
Otherwise
By cut or shift
Write the shift output.
Have all the cuts been mined ?
No
Yes
Calculate the mining rate and tons of coal /mile of S.C. travel.
Type of output ?
By cut
KREST=3
22
Otherwise
23
21
Otherwise
Type of output?
By cut or shift
Yes
ALC > TTIME ?
No
NSHFT=NSHFT-1
Subtract the values of shift accumulators in partial shift from total accumulators.
Calculate the statistics for each shift accumulator.
24


24
Write the statistics for each shift accumulator.
ALC ≥ TTIME ?
Yes
No
Add the values of shift accumulators in partial shift to total accumulators.
21
Write the output for the simulation time required to mine all the cuts.
NREP ≤ 1 ?
Yes
No
Stop
Obtain summation of each accumulator and its squared value.
NREPM=NREPM+1
KT=KT+1
NREPM ≤ NREP ?
Yes
25
No
Calculate the statistics for each total accumulator.
Write the statistics for each total accumulator.
Stop

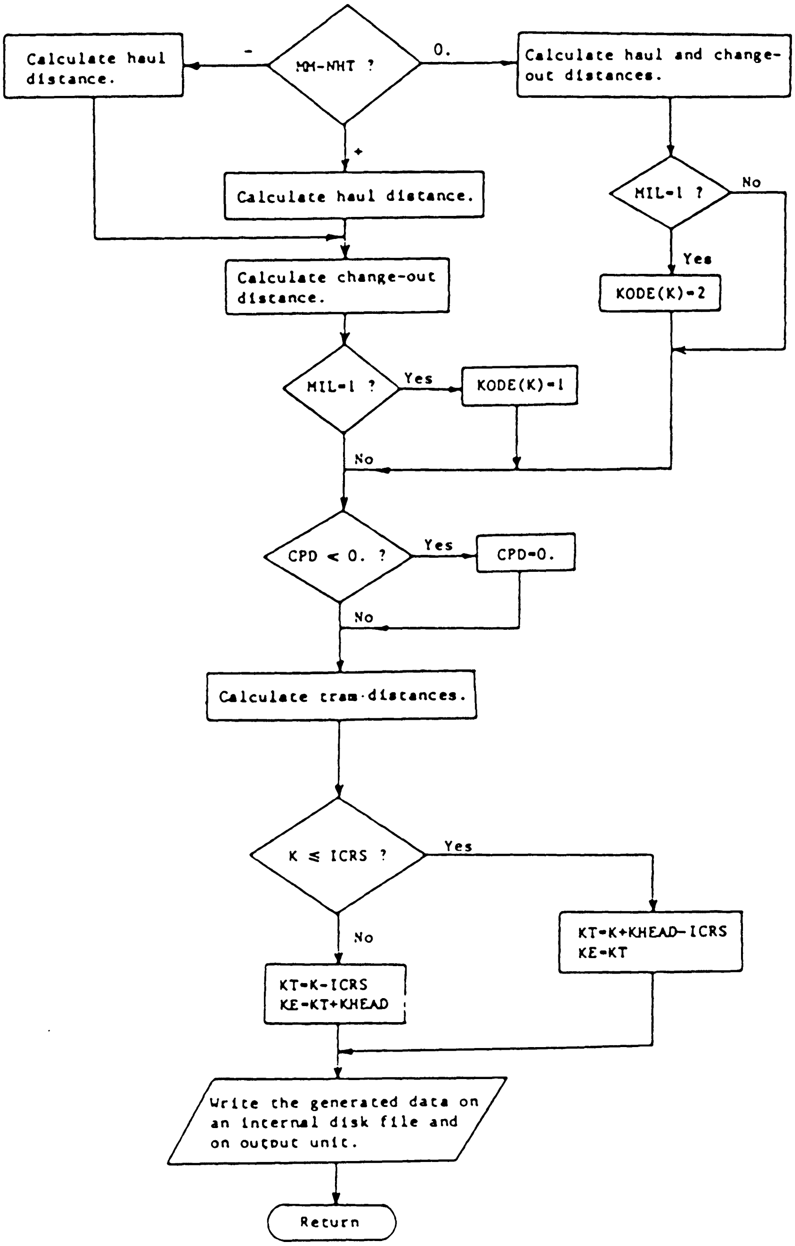
(2) Flowchart for Subroutine GCARD




3
K=K-1
Update counters, etc.
for cuts in breakthroughs.
Are
multiple cuts to be
made ?
Yes
4
No
Calculate the number of
single cuts to be made
in a breakthrough.
NN ← 1
NN ← NN+1
NN ≤ KK
5
MM ← 1
MM ← MM+1
MM ≤ KHEAD
5
MM=1 ?
Yes
No
K=K+1
K NCM ?
Yes
1
No
K=K-1
NCUT=K
NCARD=K
Is it
the last cut in the
breakthrough and of
less depth ?
No
Yes
KODE(K)=3
KODE(K)=4
Call subroutine DIST.
5
6
Is
pillaring to be
done ?
Yes
No
Generate roof bolter work sequence
for the remaining cuts, equate
tram distances to zero and KODE(K)
to 9 for K NCUT and print the
results.
Return


4
NN ← 1
NN ← NN+1
NN ≤ KK2
7
MM ← 1
MM ← MM+1
MM ≤ KHEAD
7
K=K+1
K > NCM ?
Yes
1
No
Is it the last cut in the breakthrough and of less depth ?
No
KODE(K)=6
Yes
KODE(K)=8
Is the cut in first or last heading ?
Yes
KODE(K)=5
No
Is the cut in first or last heading ?
Yes
KODE(K)=7
No
Call subroutine DIST.
7
6
Update counters, etc. for cuts to be made in headings.
8

(3) Flowchart for Subroutine DIST



APPENDIX C

LISTING OF CONSIM

```
C
C           CONSIM, A SIMULATOR FOR CONTINUOUS MINING SYSTEMS.
C
      COMMON DCPD,NCUT,KHEAD,LT1(400),LT2(400),KODE(400)
      COMMON/RAND/IX,IY,IZ
      COMMON/GEN1/ RLA(25),RA(25),RLB(25),RB(25),RLC(25),RC(25),RLD(25),
     +RD(25),RLE(25),RE(25),RLG(25),RG(25),RLH(25),RH(25),VL1,VL2,VE1,
     +VE2,DISCH,SCAPY,ALOAD,NA,L
      DIMENSION PLACE(400),RNRSUP(30),RMRSUP(30),HT(30),W(30),DTH(30),
     +SCC(9),ISUR(9),FALTS(9),SFALTS(9),SREPTS(9),TREPTS(9),CREPTS(9),
     +REPTS(9),SP(16),TSP(16),TTSP(16),SST(16),SS(16),SP1(16),
     +XM2(9),XM5(9)
      EQUIVALENCE(TLOAD,TSP(1)),(TCOT,TSP(2)),(TWL,TSP(3)),(TWP,TSP(4)),
     +(TTON,TSP(5)),(TTPM,TSP(6)),(TWRS,TSP(7)),(TREPTL,TSP(8)),(TREPTR,
     +TSP(9)),(THD,TSP(10)),(TCYCLE,TSP(11)),(RATE,TSP(14)),(TPMIL,TSP(1
     +5)),(SLOAD,SP(1)),(STCOT,SP(2)),(SWL,SP(3)),(SWP,SP(4)),(STON,SP(5
     +)),(STPM,SP(6)),(SWRS,SP(7)),(SREPTL,SP(8)),(SREPTR,SP(9)),(SHD,SP
     +(10))
      REWIND 1
C
C           READ CARD TYPE A
C
      READ(5,708)KT,NTSC,NSC,NDUMP,ICBCO,NA,NB,NREP
C
C           READ CARD TYPE B
C
      READ(5,710)SHFT,DENS,TL,TR,SWI,SWO,CL1,CR1
C
C           READ CARD TYPE C
C
      READ(5,738)XM1,XM3,XM4,XM6
C
C           READ CARD TYPE D
C
      READ(5,739)(XM2(I),XM5(I),I=1,NTSC)
C
C           READ CARD TYPE E
C
      READ(5,737)L,IX,IY,IZ
C
C           CALL SUBROUTINE GCARD TO GENERATE DATA FOR CUTS MADE
C            IN DEVELOPMENT
```

```
C
      CALL GCARD
C
C           READ CARD TYPE H (IN NA NUMBER OF CARDS) TO DEFINE EMPIRICAL
C           DISTRIBUTIONS FOR LOADING RATE, PAYLOAD, HAUL RATES AND
C           DISCHARGE TIME
C
      DO 30 N=1,NA
   30 READ(5,701)RLA(N),RLB(N),RLC(N),RLD(N),RLE(N),RLG(N),RLH(N),
     1RA(N),RB(N),RC(N),RD(N),RE(N),RG(N),RH(N)
C
C           READ CARD TYPE I (IN NB NUMBER OF CARDS) -- ROOF BOLTER
C           CYCLE TIMES AND TRAM FUNCTIONS AND CUT DIMENSIONS
C
      DO 40 N=1,NB
   40 READ(5,705)RNRSUP(N),RMRSUP(N),HT(N),W(N),DTH(N)
C
C           INITIALIZE CLOCKS, ACCUMULATORS, ETC. WRITE HEADING
C
      WRITE(6,1)
      NREPM=1
      DO 904 I=1,16
      SST(I)=0.
  904 TTSP(I)=0.
 1098 WRITE(6,605) NREPM,NREP
      REWIND 1
      KREST=1
      IF(ICBCO)146,151,148
  146 KREST=2
  153 WRITE(6,3)
      WRITE(6,4)
      GO TO(151,147,125),KREST
  151 WRITE(6,6)
      WRITE(6,7)
      GO TO 147
  148 WRITE(6,17)
  147 DO 45 N=1,400
   45 PLACE(N)=0.
      DO 905 I=1,16
      SS(I)=0.
  905 TSP(I)=0.
      IDUMP=1
```

```
      K=0
      L=1
      LIN=1
      M=1
      KT1=KT
      KE1=KT
      KT=KT-1
      KE=KT
      ARC=0.0
      ALC=0.0
      FALTL=EXPON(XM1)
      DO 800 I=1,NSC
      SCC(I)=0.
      TREPIS(I)=0.
      ISUR(I)=0
      CREPTS(I)=0.
      IF(NTSC.NE.1) GO TO 800
      XM2(I)=XM2(1)
      XM5(I)=XM5(1)
  800 FALTS(I)=EXPON(XM2(M))
      FALTR=EXPON(XM3)
      IRS=1
      NSHFT=0
      TTIME=0.
      TTRAM=0.
      TPLAC=0.
      REM=0.
      CREPTL=0.
      CREPTR=0.
      CTRAM1=0.
      WP1=0.
      WRS1=0.
      TARC=0.
C
C        INITIALIZE SHIFT ACCUMULATORS, ETC.
C
  125 SLC=ALC
      IF(CREPTL.GT.0) SLC=TTIME
      IF(ARC.LT.TTIME) ARC=TTIME
      IF(TARC.GT.0) ARC=ARC+TARC
      DO 810 I=1,NSC
      IF(SCC(I).LT.TTIME) SCC(I)=TTIME
```

```
  810 SREPTS(I)=CREPTS(I)
      TTIME=TTIME+SHFT
      STRAM=0.
      SWRS2=0.
      DO 910 I=1,10
  910 SP(I)=0.
      IF(CTRAM1.GT.0.0) STRAM=STRAM+CTRAM1
      IF(WP1.GT.0.0) SWP=SWP+WP1
      IF(ALC.GT.TTIME.AND.ALC.GT.ARC) SWRS=ALC-ARC
      IF(WRS1.GT.0.0) SWRS=SWRS+WRS1
      SREPTL=CREPTL
      SREPTR=CREPTR
      IIRS=0
      IF(TPLAC.GT.0.) GO TO 117
C
C        READ DATA FOR THE NEXT CUT -- HAUL, CHANGE-OUT AND
C        DISCHARGE CHANGE-OUT DISTANCES
C
  120 READ(1,75)K,HD,CPD,DCPD
      PTON=HT(KODE(K))*W(KODE(K))*DTH(KODE(K))*DENS
      TPLAC=PTON
      IIRS=1
C
C        CALCULATE TONS OF COAL IN CUT
C
C        INITIALIZE ACCUMULATORS, ETC. FOR CUT
C
  117 SWL2=SWL
      SLOAD2=SLOAD
      STON2=STON
      SHD2=SHD
      STCOT2=STCOT
      ALC2=ALC
      CTRAM=0.
      WP=0.
      IF(TPLAC.EQ.1.E-10) GO TO 400
      IF(ALC.GE.SCC(M)) GO TO 900
      SWL=SWL+SCC(M)-ALC
      ALC=SCC(M)
  900 DO 855 I=1,NSC
      IF(SCC(I).LT.ALC) SCC(I)=ALC
  855 CONTINUE
```

```
      CPCHK=ALC
      DCPCK=ALC
C
C       LOAD SHUTTLE CAR
C
  200 CALL RANDG
      IF(TPLAC.LT.SCAPY) SCAPY=TPLAC
      SCC(M)=SCC(M)+ALOAD
      SLOAD=SLOAD+ALOAD
      STON=STON+SCAPY
      TPLAC=TPLAC-SCAPY
      ALC=ALC+ALOAD
      REM=TTIME-ALC
C
C       SIMULATE BREAKDOWN OF MINER
C
      REPTL=0.
      IF(ALC.LT.FALTL) GO TO 2060
      REPTL=EXPON(XM4)
      FALTL=FALTL+REPTL+EXPON(XM1)
      SREPTL=SREPTL+REPTL
      ALC=ALC+REPTL
 2060 CREPTL=0.
      IF(REPTL.EQ.0.OR.ALC.LE.TTIME) GO TO 2061
      CREPTL=ALC-TTIME
      IF(ALC-REPTL.GT.TTIME) CREPTL=REPTL
      SREPTL=SREPTL-CREPTL
C
C        HAUL SHUTTLE CAR TO CHANGE POINT
C
 2061 CPD=CPD+(1.-TPLAC/PTON)*DTH(KODE(K))
      SCC(M)=SCC(M)+VL1*CPD
      IF(REPTL.LT.VL1*CPD) STCOT=STCOT+VL1*CPD-REPTL
      CPCHK=SCC(M)
      IF(ALC.LT.CPCHK) ALC=CPCHK
C
C        HAUL SHUTTLE CAR TO DISCHARGE CHANGE POINT
C
      SCC(M)=SCC(M)+VL2*HD
      IF(NDUMP.EQ.1) GO TO 215
      IDUMP=IDUMP+1
      IF(IDUMP.EQ.2) GO TO 216
```

```
      IF(IDUMP.EQ.3) IDUMP=1
  215 IF(DCPCK.GT.SCC(M)) SCC(M)=DCPCK
C
C        HAUL SHUTTLE CAR TO DUMP AND UNLOAD IT
C
      SCC(M)=SCC(M)+(VL2+VE1)*DCPD+DISCH
      DCPCK=SCC(M)
      GO TO 224
  216 IF(DCPCK2.GT.SCC(M)) SCC(M)=DCPCK2
      SCC(M)=SCC(M)+(VL2+VE1)*DCPD+DISCH
      DCPCK2=SCC(M)
  224 SCC(M)=SCC(M)+VE1*HD+SWI
      SHD=SHD+(HD+DCPD)*2+CPD
C
C        EMPTY CAR BACK AT CHANGE POINT
C        SIMULATE BREAKDOWN OF SHUTTLE CAR
C
      REPTS(M)=0.
      IF(SCC(M).LT.FALTS(M)) GO TO 2248
      REPTS(M)=EXPON(XM5(M))
      FALTS(M)=FALTS(M)+REPTS(M)+EXPON(XM2(M))
      SREPTS(M)=SREPTS(M)+REPTS(M)
      SCC(M)=SCC(M)+REPTS(M)
      ISUR(M)=1
 2248 CREPTS(M)=0.
      IF(REPTS(M).EQ.0.0.OR.SCC(M).LE.TTIME) GO TO 2249
      CREPTS(M)=SCC(M)-TTIME
      IF(SCC(M)-REPTS(M).GT.TTIME) CREPTS(M)=REPTS(M)
      SREPTS(M)=SREPTS(M)-CREPTS(M)
C
C        SELECT THE NEXT SHUTTLE CAR TO BE LOADED.
C
 2249 IF(NSC.LT.2) GO TO 228
      J=0
  820 M=M+1
      IF(M.GT.NSC) M=1
      IF(ALC.GE.SCC(M)) ISUR(M)=0
      IF(ISUR(M).EQ.0) GO TO 228
      J=J+1
      IF(J.LT.NSC) GO TO 820
      DMIN=1.E+10
      DO 830 I=1,NSC
```

```
      IF(SCC(I).GE.DMIN) GO TO 830
      DMIN=SCC(I)
      M=I
  830 CONTINUE
      ISUR(M)=0
C
C        UPDATE ACCUMULATORS, ETC.  CHECK FOR AVAILABLE SHIFT TIME
C
  228 IF(ALC.GE.TTIME.OR.CPCHK.GE.TTIME) GO TO 4000
      IF(CPCHK-SCC(M))229,233,230
  229 IF(REPTL.EQ.0.) SWL=SWL+SCC(M)-CPCHK
      IF(ALC.GE.SCC(M)) GO TO 231
      IF(REPTL.NE.0.) SWL=SWL+SCC(M)-ALC
      ALC=SCC(M)
      IF(SCC(M).GT.TTIME) ALC=TTIME
  231 IF(SCC(M).LE.TTIME) GO TO 233
      SWL=SWL-SCC(M)+TTIME
      IF(TPLAC.EQ.0.0) TPLAC=1.E-10
      GO TO 237
  230 SCC(M)=CPCHK
C
C        HAUL EMPTY CAR TO MINER
C
  233 IF(TPLAC) 400,400,2251
 2251 SCC(M)=SCC(M)+VE2*CPD+SWO
      SHD=SHD+CPD
      IF(ALC-SCC(M)) 235,237,236
  235 STCOT=STCOT+SCC(M)-ALC
      ALC=SCC(M)
      GO TO 237
  236 SCC(M)=ALC
C
C        CHECK FOR AVAILABLE SHIFT TIME
C
  237 REM=TTIME-ALC
  238 IF(REM)4000,4000,200
C
C        TRAM THE MINER TO THE NEXT CUT
C
  400 TPLAC=0.
      ALC=ALC+CL1+TL*(LT1(K)+LT2(K)+DTH(KODE(K)))
      PLACE(K)=ALC-TL*LT1(K)
```

```
      K1=K+1
      IF(K1.EQ.KE1) GO TO 4001
C
C        CALCULATE MINER WAIT TIME FOR PLACE
C
  850 WP=PLACE(K1)-ALC
      IF(PLACE(K1).LT.ALC) WP=0.
      WP1=0.0
      IF(ALC+WP.LE.TTIME) GO TO 851
      WP1=WP
      WP=0.
      IF(ALC.GE.TTIME) GO TO 851
      WP1=ALC+WP1-TTIME
      WP=TTIME-ALC
  851 ALC=ALC+WP+TL*LT2(K1)
      SWP=SWP+WP
      CTRAM=TL*(LT1(K)+LT2(K)+LT2(K1)+DTH(KODE(K)))+CL1
      CTRAM1=0.0
      IF(WP1.LE.0.0) GO TO 853
      CTRAM=CTRAM-TL*LT2(K1)
      ALC=ALC-TL*LT2(K1)
      CTRAM1=TL*LT2(K1)
  853 STRAM=STRAM+CTRAM
 4000 IF(IIRS.EQ.0) GO TO 841
      IF(IRS.EQ.0) GO TO 845
C
C        OBTAIN CUT TO BE ROOF-BOLTED AND CUT MADE AVAILABLE
C
 4001 KT=KT+1
      IF(KE.EQ.KHEAD) KT=LIN
      IF(KHEAD-KE.LE.0) KE=KT+KHEAD
      IF(KHEAD-KE.GT.0) KE=KT
 4209 KRS=KODE(KT)
C
C        ROOF-BOLT AND TRAM THE ROOF BOLTER TO NEXT CUT
C
      ARC=ARC+CR1+TR*(LT1(KT)+LT2(KT)+DTH(KODE(K)))+RNRSUP(KRS)+
     +RMRSUP(KRS)
C
C        CALCULATE ROOF BOLTER WAITING TIME FOR CUT
C
      PLACE(KE)=ARC-TR*LT1(KT)-RMRSUP(KRS)
```

```
 4210 KG=KT+1
      IF(KE.EQ.KHEAD) KG=LIN
      IF(KG.EQ.K) GO TO 840
  845 TRAR3=LT2(KG)
      WRS=0.0
      IF(PLACE(KG).GT.ARC) WRS=PLACE(KG)-ARC
      WRS1=0.0
      TARC=0.0
      IF(ARC+WRS.LE.TTIME) GO TO 854
      WRS1=WRS
      WRS=0.0
      IF(ARC.GE.TTIME) GO TO 856
      WRS1=ALC+WRS-TTIME
      WRS=TTIME-ARC
  856 IF(WRS1.LE.0) GO TO 854
      TARC=TR*TRAR3
      ARC=ARC-TR*TRAR3
  854 ARC=ARC+WRS+TR*TRAR3
      SWRS=SWRS+WRS
C
C         SIMULATE BREAKDOWN OF ROOF BOLTER
C
      REPTR=0.
      IF(ARC.LT.FALTR) GO TO 869
      REPTR=EXPON(XM6)
      FALTR=FALTR+REPTR+EXPON(XM3)
      SREPTR=SREPTR+REPTR
      ARC=ARC+REPTR
  869 CREPTR=0.
      IF(REPTR.EQ.0.OR.ARC.LE.TTIME) GO TO 870
      CREPTR=ARC-TTIME
      IF(ARC-REPTR.GT.TTIME) CREPTR=REPTR
      SREPTR=SREPTR-CREPTR
  870 IRS=1
      IF(K1.EQ.KE1.AND.TPLAC.EQ.0.0) GO TO 850
      GO TO 835
  840 IRS=0
C
C         UPDATE ROOF BOLTER CLOCK
C
  841 IF(ARC.GE.ALC) GO TO 4239
      IF(ALC.GT.TTIME) GO TO 4238
```

```
      SWRS=SWRS+ALC-ARC
      ARC=ALC
      GO TO 4239
 4238 SWRS=SWRS+TTIME-ARC
      ARC=ALC
      GO TO 4239
  835 IF(ARC.LT.ALC) GO TO 4001
 4239 KE1=KE+1
      IF(ICBCO)4240,154,154
C
C        CALCULATE VALUES OF OUTPUT VARIABLES FOR CUT
C
 4240 CYCLE=ALC-ALC2-CREPTL
      CLOAD=SLOAD-SLOAD2
      CCOT=STCOT-STCOT2
      WL=SWL-SWL2
      CHD=(SHD-SHD2)/5280.
      CTON=STON-STON2
      CTPM=CTON/CYCLE
      CWRS=SWRS-SWRS2
      SWRS2=SWRS
C
C        WRITE OUTPUT FOR CUT
C
      WRITE(6,5) K,CYCLE,CLOAD,CCOT,WL,WP,CTRAM,CHD,ALC,CTON,CTPM,KE,PLA
     +CE(KE),KT,ARC
C
C                 IF TIME IS AVAILABLE BEGIN MINING NEXT CUT
C
  154 REM=TTIME-ALC
      IF(REM-5.0)648,648,425
  425 IF(K.GE.NCUT) GO TO 648
      GO TO 120
C
C        WRITE OUTPUT FOR A PARTIAL CUT
C
  648 IF(ICBCO.GE.0) GO TO 650
      WRITE(6,6)
      IF(TPLAC.GT.0.) WRITE(6,9)CLOAD,TPLAC
C
C        UPDATE TOTAL ACCUMULATORS, ETC.
C        WRITE SHIFT OUTPUT
```

```
C
      WRITE(6,7)
  650 SLC=ALC-SLC
C     IF(CREPTL.GT.0.) SLC=SHFT
      DO 860 I=1,NSC
  860 TREPTS(I)=TREPTS(I)+SREPTS(I)
      NSHFT=NSHFT+1
      STPM=STON/SLC
      SHD=SHD/5280.
      DO 920 I=1,10
      TSP(I)=TSP(I)+SP(I)
  920 SS(I)=SS(I)+SP(I)**2
      TTRAM=TTRAM+STRAM
      IF(ICBCO.GT.0.) GO TO 6755
      WRITE(6,8) NSHFT,SLC,SLOAD,STCOT,SWL,SWP,STRAM,SREPTL,SHD,STON,STP
     1M,K,SWRS,SREPTR,KT
 6755 IF(K.GE.NCUT.AND.TPLAC.EQ.0.0) GO TO 666
      IF(ICBCO)665,125,125
  665 KREST=3
      GO TO 153
C
C        WRITE THE OUTPUT OVER SIMULATION TIME, STATISTICS
C        FOR SHIFT OUTPUT AND THE OUTPUT OVER SIMULATION TIME.
C
  666 RATE=TTON/ALC
      TPMIL=TTON/THD
      IF(ICBCO.GT.0) GO TO 939
      IF(ALC.GE.TTIME) GO TO 936
      NSHFT=NSHFT-1
      IF(NSHFT.EQ.1) GO TO 941
      DO 937 I=1,10
      SS(I)=SS(I)-SP(I)**2
  937 TSP(I)=TSP(I)-SP(I)
  936 DO 940 I=1,10
      SS(I)=(SS(I)-TSP(I)**2/FLOAT(NSHFT))/FLOAT(NSHFT-1)
      IF(SS(I).LT.0.0) SS(I)=0.
      SS(I)=SQRT(SS(I))
  940 SP1(I)=TSP(I)/FLOAT(NSHFT)
      WRITE(6,14) (SP1(I),I=1,10)
      WRITE(6,16) (SS(I),I=1,10)
      IF(ALC.GE.TTIME) GO TO 941
      DO 938 I=1,10
```

```
  938 TSP(I)=TSP(I)+SP(I)
  941 CONTINUE
      WRITE(6,17)
  939 WRITE(6,18)ALC,TLOAD,TCOT,TWL,TWP,TTRAM,TREPTL,THD,TTON,RATE,TWRS,
     +TREPTR,ARC,TPMIL
      IF(NREP.LE.1) STOP
      TSP(16)=TTRAM
      TSP(13)=ALC
      TSP(12)=ARC
      DO 950 I=1,16
      SST(I)=SST(I)+TSP(I)**2
  950 TTSP(I)=TTSP(I)+TSP(I)
      NREPM=NREPM+1
      KT=KT1
C
C        CHECK IF MORE RUNS TO BE MADE
C
      IF(NREPM.LE.NREP) GO TO 1098
C
C        CALCULATE AND WRITE STATISTICS FOR OUTPUT OVER SIMULATION
C        TIME
C
      DO 960 I=1,16
      SST(I)=(SST(I)-TTSP(I)**2/FLOAT(NREP))/FLOAT(NREP-1)
      IF(SST(I).LT.0.0) SST(I)=0.
      SST(I)=SQRT(SST(I))
  960 TTSP(I)=TTSP(I)/FLOAT(NREP)
      WRITE(6,19)TTSP(13),(TTSP(I),I=1,4),TTSP(16),TTSP(8),TTSP(10),TTSP
     +(5),TTSP(14),TTSP(7),TTSP(9),TTSP(12),TTSP(15)
      WRITE(6,20)SST(13),(SST(I),I=1,4),SST(8),SST(10),SST(14),SST(7),
     +SST(9),SST(12),SST(15)
C
C         FORMAT STATEMENTS
C
  701 FORMAT(2F5.2,4F5.4,F5.2,1X,7F5.3)
  705 FORMAT(5F6.2)
  708 FORMAT(8I5)
  710 FORMAT(F5.1,F5.3,2F5.4,4F5.2)
  737 FORMAT(4I10)
  738 FORMAT(4(F10.2,2X))
  739 FORMAT(2(F10.2,2X))
  605 FORMAT(1H1,20X,'RUN  ',I4,' OF ',I4,/////)
```

```
    1 FORMAT(1H1,35X,'ANALYSIS OF CONTINUOUS MINING SYSTEM',/35X,' *****
     +*******************************',////42X,'ALL TIMES IN MINUTES',/)
    3 FORMAT(' SYSTEM PERFORMANCE BY CUT',/' *************************')
    4 FORMAT(/' CUT ',' CYCLE ',' LOAD',3X,'CHANGE',' WAIT- ',' WAIT- ',
     +' TRAM   ','HAUL  ','TIME',4X,'TONS',3X,'T/M',2X,'CUT MADE AVAIL '
     +,' RB',2X,'TIME',/' NO. ',15X,'OUT',4X,'CAR',4X,'COAL',9X,'DIST',3
     +X,'(CM)',17X,'NO.',5X,'AT',5X,'AT',2X,'RB')
    5 FORMAT(/I4,5F7.1,F5.1,F7.1,F9.1,F7.1,F5.2,I5,F9.1,I5,F9.1)
    6 FORMAT(///' SYSTEM PERFORMANCE BY SHIFT',/' **********************
     1*****',/)
    7 FORMAT(' SHIFT',' TIME ',' LOAD  ','CHANGE ',' WAIT- ',' WAIT- ','
     + TRAM  ','REPAIR',3X,'HAUL',3X,'TONS',3X,'T/M  ',' CM  ',' WAIT- '
     +,' REPAIR','   RB',/' NO.',15X,'OUT',5X,'CAR',4X,'COAL',9X,'(CM)
     +',3X,'DIST',15X,' AT',4X,'RB',5X,'RB',6X,'AT  ',/)
    8 FORMAT(/I3,1X,F7.1,1X,F6.1,1X,F6.1,5F7.1,1X,F7.1,F5.2,I4,2F8.1,I5,
     +/)
    9 FORMAT(' PARTIAL CUT',//'   LOAD   ','TONS REM.',//2F7.1,/)
   14 FORMAT(//' OVERALL SYSTEM PERFORMANCE BY SHIFT',/' ***************
     +********************',//1X,'LOAD',4X,'CHANGE OUT',2X,'WAIT-CAR',3X
     +,'WAIT-COAL',2X,'TONS',3X,'TONS/MIN',2X,'WAIT(RB)',2X,'REPAIR(CM)'
     +,2X,'REPAIR(RB)',2X,'HAUL DIST',//' SAMPLE MEAN',//5(F7.1,3X),F7.2
     +,3X,4(F7.1,3X),//)
   16 FORMAT(' SAMPLE STANDARD DEVIATION',//10(F9.1,1X),///)
   17 FORMAT(//' SYSTEM PERFORMANCE OVER SIMULATION TIME',/' ***********
     +****************************',//' TIME',6X,'LOAD',4X,'CHANGE',4X,'
     +WAIT-',3X,'WAIT-',3X,'TRAM',4X,'REPAIR',4X,'HAUL',5X,'TONS',5X,'T/
     +M',5X,'WAIT-',4X,'REPAIR',4X,'TIME',5X,'TONS  ',/19X,'OUT',7X,'CAR
     +',5X,'COAL',12X,'(CM)',6X,'DIST',22X,'RB',7X,'RB',8X,'RB ',6X,'/MI
     +LE',//)
   18 FORMAT(7(F7.1,2X),F6.1,3X,F7.1,2X,F5.2,2X,4(F7.1,2X),//)
   19 FORMAT(' SAMPLE MEAN',//7(F7.1,2X),F6.1,3X,F7.1,2X,F5.2,2X,3(F7.1,
     +2X),F7.1,///)
   20 FORMAT(' SAMPLE STANDARD DEVIATION',//4(F7.1,2X),F7.1,8X,2(F7.1,2
     +X),6X,F9.2,2X,4(1X,F8.1))
   75 FORMAT(I4,3F4.0)
      STOP
      END
C
C        SUBROUTINE TO OBTAIN RANDOM VARIATES FROM
C        EMPIRICAL DISTRIBUTIONS
C
      SUBROUTINE RANDG
```

```
      COMMON/GEN1/ RLA(25),RA(25),RLB(25),RB(25),RLC(25),RC(25),RLD(25),
     +RD(25),RLE(25),RE(25),RLG(25),RG(25),RLH(25),RH(25),VL1,VL2,VE1,
     +VE2,DISCH,SCAPY,ALOAD,NA,L
      NVAR=1
  518 U=RANDOM(L)
      DO 516 N=2,NA
      GO TO(501,503,505,507,509,511,513,517),NVAR
C
C         LOADING RATE
C
  501 IF(RA(N)-U) 516,502,502
  502 ALOAD=RLA(N-1)+(U-RA(N-1))*(RLA(N)-RLA(N-1))/(RA(N)-RA(N-1))
      GO TO 515
C
C         PAYLOAD
C
  503 IF(RB(N)-U) 516,504,504
  504 SCAPY=RLB(N-1)+(U-RB(N-1))*(RLB(N)-RLB(N-1))/(RB(N)-RB(N-1))
      GO TO 515
C
C         HAUL RATE -- MINER TO CHANGE POINT
C
  505 IF(RC(N)-U) 516,506,506
  506 VL1=RLC(N-1)+(U-RC(N-1))*(RLC(N)-RLC(N-1))/(RC(N)-RC(N-1))
      GO TO 515
C
C         HAUL RATE -- CHANGE POINT TO DUMP
C
  507 IF(RD(N)-U) 516,508,508
  508 VL2=RLD(N-1)+(U-RD(N-1))*(RLD(N)-RLD(N-1))/(RD(N)-RD(N-1))
      GO TO 515
C
C         HAUL RATE -- DUMP TO CHANGE POINT
C
  509 IF(RE(N)-U) 516,510,510
  510 VE1=RLE(N-1)+(U-RE(N-1))*(RLE(N)-RLE(N-1))/(RE(N)-RE(N-1))
      GO TO 515
C
C         HAUL RATE -- CHANGE POINT TO MINER
C
  511 IF(RG(N)-U) 516,512,512
  512 VE2=RLG(N-1)+(U-RG(N-1))*(RLG(N)-RLG(N-1))/(RG(N)-RG(N-1))
```

```
      GO TO 515
C
C        DISCHARGE TIME
C
  513 IF(RH(N)-U) 516,514,514
  514 DISCH=RLH(N-1)+(U-RH(N-1))*(RLH(N)-RLH(N-1))/(RH(N)-RH(N-1))
  515 NVAR=NVAR+1
      GO TO 518
  516 CONTINUE
  517 RETURN
      END
C
C        FUNCTION TO GENERATE EXPONENTIAL RANDOM VARIATES.
C
      FUNCTION EXPON(XM)
      EXPON=-XM*ALOG(RANDOM(L))
      RETURN
      END
C
C        FUNCTION TO GENERATE U(0,1) RANDOM NUMBER SEQUENCE.
C
      FUNCTION RANDOM(L)
      COMMON/RAND/IX,IY,IZ
      IX=171*MOD(IX,177)-2*(IX/177)
      IY=172*MOD(IY,176)-35*(IY/176)
      IZ=170*MOD(IZ,178)-63*(IZ/178)
      IF(IX.LT.0) IX=IX+30269
      IF(IY.LT.0) IY=IY+30307
      IF(IZ.LT.0) IZ=IZ+30323
      RANDOM=AMOD(FLOAT(IX) / 30269.0 + FLOAT(IY) / 30307.0 + FLOAT(IZ)
     + / 30323.0, 1.0)
      RETURN
      END
C
C        SUBROUTINE TO GENERATE DATA FOR CUTS MADE IN DEVELOPMENT.
C
      SUBROUTINE GCARD
      COMMON DCPD,NCUT,KHEAD,LT1(400),LT2(400),KODE(400)
      COMMON/GEN2/W(5),MULTI,NHT,WPIL,WHPIL,SCL,ALM,DTH,TLT2,TD1,SDIST,
     +DIST1,DIST2,DIST3,KK2,KT,NPC,LPC,ICRS,K,J,KIL,NN,MM,MIL
C
C        READ CARD TYPE F
```

```
C
      READ(5,10) (W(I),I=1,3),DTH,WHPIL,WPIL,ALM,SCL,SDIST,DCPD
C
C        READ CARD TYPE G
C
      READ(5,19) NCM,MULTI,KHEAD,NHT,KT,NPC,LPC
C
C     WRITE HEADING. INITIALIZE VARIABLES
C
      WRITE(6,73)
      WRITE(6,74)
      ICRS=KHEAD-KT+1
      KTL=0
      K=0
      NP=0
      DIST1=WHPIL+W(3)
      DIST2=DIST1-SCL
      DIST3=WPIL+W(1)
      KK=DIST1/DTH
      RK=KK
      IF(RK.LT.DIST1/DTH) KK=KK+1
   56 J=0
      NP=NP+1
      I=1
      IF(NP.GT.NPC) GO TO 55
      IF(LPC.EQ.0.) I=NP
      NN2=1
   44 MTL=1
      TLT2=0.
      TD1=0.
      KK2=0
      DO 20 NN=NN2,KK
      DO 20 MM=1,KHEAD
C
C        MAKE CUTS IN HEADINGS.
C
      K=K+1
      IF(K.GT.NCM) GO TO 55
C
C        CHECK IF CUTS CAN BE MADE IN BREAKTHROUGHS
C
      IF(SDIST+(NN-1)*DTH-J*DIST1.GE.DIST1+W(3)/2.) GO TO 21
```

```
C
C         CALL SUBROUTINE DIST TO CALCULATE DISTANCES AND ROOF
C         BOLTER WORK SEQUENCE
C
      CALL DIST
   20 CONTINUE
      IF(LPC.EQ.0) KIL=KIL+1
      SDIST=SDIST+KK*DTH-DIST1
      GO TO 56
   21 SDIST2=SDIST
      NN2=NN
      SDIST=0.
      K=K-1
      TLT2=DIST1
      TD1=DIST1+ALM
      IF(MULTI.GT.1) GO TO 41
C
C         MAKE SINGLE CUTS IN BREAKTHROUGHS.
C
      KK1=WPIL/DTH
      RK1=KK1
      IF(RK1.LT.WPIL/DTH) KK1=KK1+1
      MIL=2
      DO 45 NN=1,KK1
      DO 45 MM=1,KHEAD
      IF(MM.EQ.1) GO TO 45
      K=K+1
      IF(K.GT.NCM) GO TO 55
      IF(NN.LT.KK1.AND.RK1.NE.FLOAT(KK1)) GO TO 50
C
C         CODE FOR LAST CUT OF SMALLER DEPTH
C
   51 KODE(K)=4
      GO TO 46
   50 KODE(K)=3
   46 CALL DIST
   45 CONTINUE
      GO TO 62
C
C         MAKE MULTIPLE CUTS IN BREAKTHOUGHS.
C
   41 KK2=WPIL/(2.*DTH)
```

```
      RK2=KK2
      IF(RK2.LT.WPIL/(2.*DTH)) KK2=KK2+1
      MIL=3
      DO 61 NN=1,KK2
      DO 61 MM=1,KHEAD
      K=K+1
      IF(K.GT.NCM) GO TO 55
      IF(NN.LT.KK2.AND.RK2.NE.FLOAT(KK2)) GO TO 320
      KODE(K)=8
C
C        CODE FOR CUT IN FIRST OR LAST HEADING
C
      IF(MM.EQ.1.OR.MM.EQ.KHEAD) KODE(K)=7
      GO TO 61
C
C        CODE FOR LAST CUT OF SMALLER DEPTH
C
  320 KODE(K)=6
C
C        CODE FOR LAST CUT OF SMALLER DEPTH IN FIRST OR LAST HEADING
C
      IF(MM.EQ.1.OR.MM.EQ.KHEAD) KODE(K)=5
   61 CALL DIST
C
C        UPDATE VARIABLES FOR CUTS IN HEADINGS
C
   62 KIL=KIL+1
      IF(LPC.NE.0) KIL=0
      J=J+1
      IF(MULTI.GT.1) NN2=NN2+1
      SDIST=SDIST2
      GO TO 44
   55 CONTINUE
      K=K-1
      NCUT=K
C
C        GENERATE ROOF BOLTER OPERATING SEQUENCE FOR THE REMAINING
C        CUTS.GENERATE DATA FOR DUMMY CUTS
C
      IICRS=0
   86 IICRS=IICRS+1
      KT=KT+1
```

```
      KE=KT+KHEAD
      K=K+1
      LT1(K)=0
      LT2(K)=0
      KODE(K)=9
      WRITE(6,85)K,LT1(K),LT2(K),KODE(K),KT,KE
      IF(IICRS.LT.ICRS) GO TO 86
   85 FORMAT(I4,14X,3I6,4X,2I3)
   10 FORMAT(10F5.1)
   19 FORMAT(7I5)
   73 FORMAT(1H1,42X,'DATA GENERATED BY SUBROUTINE GCARD',///)
   74 FORMAT(3X,'K',2X,'HD ',' CPD ',' DCPD',' LT1(K)',' LT2(K) ',
     +'KODE(K)',' KT ','KE',//)
      RETURN
      END
C
C         SUBROUTINE TO GENERATE DISTANCES ROOF BOLTER WORK SEQUENCE
C
      SUBROUTINE DIST
      COMMON DCPD,NCUT,KHEAD,LT1(400),LT2(400),KODE(400)
      COMMON/GEN2/W(5),MULTI,NHT,WPIL,WHPIL,SCL,ALM,DTH,TLT2,TD1,SDIST,
     +DIST1,DIST2,DIST3,KK2,KT,NPC,LPC,ICRS,K,J,KIL,NN,MM,MIL
      IF(MM-NHT) 22,23,24
C
C          CALCULATE HAUL AND CHANGE OUT DISTANCES.
C
   22 HD=W(2)/2.+(NHT-MM)*DIST3-W(1)/2.+DIST2+KIL*DIST1
      GO TO 25
   23 HD=KIL*DIST1+DIST2
      CPD=TD1+SDIST+(NN-1)*DTH-ALM
      IF(MIL.NE.1) CPD=CPD+W(2)/2.
      IF(NN.EQ.KK2) CPD=(3.*CPD-W(2)/2.-(KK2-1)*DTH)/3.
      IF(MIL.EQ.1) KODE(K)=2
      GO TO 26
   24 HD=W(2)/2.+(MM-NHT)*DIST3-W(1)/2.+DIST2+KIL*DIST1
   25 CPD=TD1+SDIST+(NN-1)*DTH-ALM
      IF(MIL.EQ.1) GO TO 90
      CPD=CPD+W(1)/2.
      IF(NN.NE.KK2) GO TO 26
      IF(MM.EQ.1.OR.MM.EQ.KHEAD) CPD=(2.*CPD+W(1)/2.-FLOAT(KK2-1)*DTH)/2
     +.
      IF(MM.NE.1.AND.MM.NE.KHEAD) CPD=(3.*CPD+W(1)-FLOAT(KK2-1)*DTH)/3.
```

```
      GO TO 26
   90 KODE(K)=1
   26 IF(CPD.LT.0.) CPD=0.
C
C            CALCULATE TRAM DISTANCES.
C
      LT2(K)=TLT2+SDIST+(NN-1)*DTH-J*DIST1
      IF(MH.EQ.1) GO TO 31
      LT2(K)=LT2(K)+W(1)/2.
      IF(MM.EQ.NHT) LT2(K)=LT2(K)-W(1)/2.+W(2)/2.
   31 LT1(K)=DIST3
      IF(MM.EQ.KHEAD) LT1(K)=LT1(K)*(KHEAD-1)
      IF(MH.EQ.2.AND.MM.EQ.KHEAD) LT1(K)=LT1(K)-INT(DIST3)
C
C           OBTAIN ROOF BOLTER WORK SEQUENCE
C
      IF(K.LE.ICRS) GO TO 32
      KT=K-ICRS
      KE=KT+KHEAD
      GO TO 36
   32 KT=KHEAD+K-ICRS
      KE=KT
   36 WRITE(1,75)K,HD,CPD,DCPD
      WRITE(6,76)K,HD,CPD,DCPD,LT1(K),LT2(K),KODE(K),KT,KE
   75 FORMAT(I4,3F4.0)
   76 FORMAT(I4,2X,3F4.0,3I6,4X,2I3)
      RETURN
      END
```

APPENDIX D

RANDOM NUMBER GENERATORS

```
      FUNCTION TRIAG(A,B,C)
C
C        A AND B ARE THE LOWER AND UPPER ENDS OF THE DISTRIBUTION.
C        C IS THE MODE.
C
      U=RANDOM(L)
      IF(U.LE.(C-A)/(B-A)) GO TO 2
      TRIAG=B-SQRT(1.0-U)*(B-C)*(B-A))
      RETURN
    2 TRIAG=A+SQRT((B-A)*(C-A)*U)
      RETURN
      END
```

FUNCTION TO GENERATE RANDOM VARIATES FROM TRIANGULAR DISTRIBUTION

```
      FUNCTION WEIBL(ALPHA,BETA)
C
C         THE FOLLOWING STATEMENT CAN BE OMITTED, IF IT IS
C         EXTERNALLY INSURED THAT ALPHA AND BETA ARE
C         POSITIVE NUMBERS.
C
      IF(ALPHA.LE.0.0.OR.BETA.LE.0.0) GO TO 7
      U=RANDOM(L)
      WEIBL=(BETA/(-ALOG(U)))**(1./ALPHA)
      RETURN
    7 WRITE(6,10)
   10 FORMAT(' ALPHA OR BETA IS LESS THAN OR EQUAL TO ZEO')
      STOP
      END
```

FUNCTION TO GENERATE RANDOM VARIATES FROM WEIBULL DISTRIBUTION

```
      FUNCTION BETA(ALPHA1, ALPHA2)
C
C        COMPUTE A, B AND C PRIOR TO EXECUTION OF THE PROGRAM
C        USING THE FOLLOWING EQUATIONS.
C        A=ALPHA1+ALPHA2
C        B=1.0/AMIN(ALPHA1,ALPHA2)
C        IF(AMIN(ALPHA1,ALPHA2).GT.0.) B=(A-2.)/SQRT(2.ALPHA1*
C       +ALPHA2-A))
C        D=-1.3862944
C        C=ALPHA1+1.0/B
C
C        THE FOLLOWING STATEMENT CAN BE OMITTED, IF IT IS
C        EXTERNALLY INSURED THAT ALPHA1, ALPHA2, A AND C
C        ARE POSITIVE NUMBERS.
C
      IF(ALPHA1.LT.0.0.OR.ALPHA2.LT.0.0.OR.A.LT.0.0.OR.C.LT.0.0) GO TO 7
    2 U1=RANDOM(L)
      U2=RANDOM(L)
      V=B*ALOG(U1/(1.-U1)
      W=ALPHA1*EXP(V)
      IF(A*ALOG(A/(ALPHA2+W))+C*V+D.GE.ALOG(U1*U1*U2)) GO TO 2
      X=W/(B+W)
      RETURN
C
C        IF THE FIRST STATEMENT IS OMITTED, OMIT THE
C        FOLLOWING THREE STATEMENTS TOO.
C
    7 WRITE(6,10)
   10 FORMAT(' ALPHA1, ALPHA2, A OR B IS LESS THAN ZERO')
      STOP
      END
```

FUNCTION TO GENERATE RANDOM DEVIATES FROM BETA DISTRIBUTION