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COALSIM - A digital simulation program for the coal production and handling systems at a mechanised colliery

by

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1. The role of simulation at different levels within the coal industry.

Underground coalmining is a complex production activity with strong interactions between operations, so that it would be folly to consider formulating and applying objectives for a limited area of activities without taking into account their effect upon, and feedbacks from, the dynamic behaviour of the rest of the system. Since the situation is such that a close representation of the practical system lies outwith the bounds of straightforward analyses, there is an obvious case for using simulation models to test out strategies.

Modelling on a single level cannot provide predictions in the appropriate degree of detail, or over a sufficiently broad area, to meet all the needs of a planning and control study - instead there is a need for a graded hierarchy of models and it becomes a major task for the engineer to map out the tiers of this structure. I would suggest 4 complementary levels on which one can model coalmining operations, ranked in the following order:-

1. Local models, dealing with individual elements in the production system at a colliery - such as coalfaces, bunkers, or screening plant.

2. Production system simulations, covering the entire extraction and product handling processes at a single colliery.

3. Structure planning models, to assist in deciding how the basic resources in an area should be exploited.

4. Long range planning and policy models for the entire coal industry.

In progressing up the scale from local to industry - wide models, an increasing degree of freedom is coupled with the greater uncertainty which bedevils forecasting at higher levels. Given this hierarchy it is possible to focus down from broad areas of concern towards specific problems and clearly defined objectives.

2. The form of simulation at various levels.

2.1. Higher echelons.

At the highest level, the requirement is to balance the material and financial resources of the industry against the opportunities offered and constraints imposed by the market. In determining future levels of investment and rates of resource exploitation some guide is needed to the future pattern of demand for coal, and it is a study carried out in this area that highlights the pitfalls of modelling at this level.

The Cambridge study (reference 1) describes those elements of projected fuel demand which were included in a fuel economy submodel of a growth model of the British economy. In the climate of 1968 it was reasonable to assume a worsening competitive position for coal in the fuel market, although this involved a myopic view of the shifting balance of oil resources. Subsequently, political acts associated with the furore over a so-called energy crisis are making nonsense of most predictions in this field.

Level 3 deals with the pattern of future exploitation of coal reserves within an area with regard to local financial and labour resources and in the light of area targets derived at a higher level. Here one is again conscious of the interactions between model levels, involving basic flows of, in one direction, demands and, in return, information as to how and to what effect they may be achieved. The National Coal Board's Operational Research Executive has developed techniques (reference 2; Knowles, Tagg, and Thompson) which relate resources and alternative working methods at individual collieries to generate 'action plans' covering forward planning within an area for an 18 month period.

2.2. Simulation, within the context of the Sheffield research programme.

The complementary role of different models at the same level can readily be examined at the second level, that of colliery simulation. Not to put forward too narrow a definition, this level might include situations where a group of collieries are closely coupled to a single customer, as with the Longannet power station, in Fife; or the Lynemouth smelter in Northumberland.

Linear mathematical models are, despite their shortcomings, a needful step towards analysing the system and have been used in this department in a dynamic programming study aimed at optimising system component capacities and methods of control (reference 3, Edwards and Marshall). I have since been trying to extend this approach to examine the relationship of shaft bottom storage and winder throughput, by introducing winding rate as a further manipulable input - and so weakening the coupling between above and below ground activities. Associated with this is a quadratic cost model, embodying the objective function.

Feedback control strategies, evolved in this way, must be translated into functions of real physical variables before they can be tested under conditions approaching those of real life. One needs then a simulation model in which real variables are explicit and subject to the constraints and discontinuities encountered in the colliery. Simulations have been developed in Operational Research (reference 4, Tomlinson), and section 4 includes an appraisal of the N.C.B.'s SIMBELT model together with those features which render it wholly inapplicable to this study. Basically, the established approach to colliery system design involves a considerable acceptance of existing working methods and control systems. Alternative schemes are put forward, based on steady state analysis, and tested against each other in lengthy trials (reference 5, Hunter and Naylor). The control engineer demands the freedom to vary established working methods and create new control structures - including

direct digital control (reference 6, Wilson).

One model which does offer this freedom is that developed by the Mining Research & Development Establishment's Computer Systems Group (reference 7, Chandler). Based on a scaled down mechanical analogue coalface, it is being used to examine various degrees of computer control. A model of this sort, which can include a fairly detailed representation of local problems, transcends the distinction between the 2 lower simulation levels and offers the real life experience of interfacing the control computer to a separate piece of plant. For a general model, digital simulation still appears to offer the greatest degree of flexibility of structure and control, and so I have developed the simulation program, COALSIM, which is described in the following pages.

Inextricably bound up with this is work on local models (level 1 of the hierarchy), which are used to test out new control systems and establish the validity of controls or operating methods implied in the larger simulation. One study, using an analogue coalface model (reference 8, Edwards and Fawcett), has established the feasibility of manipulating a set of basic variables - the rates of production at individual faces, and I am currently modelling a forward traversing bunker. If this work reveals that the departures from the operating ideal implied in coalsim are not inconsequential when viewed against the performance of the remainder of the system, then the bunker characteristics in the larger simulation will be revised accordingly.

3. The colliery system

The area of activities considered within the scope of Coalsim begins with the means of production at the coalface and embraces the system by which the product is transported underground and brought to the surface, together with storage bunkers, including any surface stockpile from which the customer demand (which could be the input to preparation plant) must be met. The associated movements of men and materials are accounted for only insofar as they determine the operating cycle of any part of the system.

In essence, the underground system comprises a series of faces working into one or more coal seams of varying thickness, quality, and water and ash content; with common links to the surface. If the workings are relatively shallow then the product may be drawn to the surface through an inclined roadway, or drift; otherwise the majority of outlets are vertical shafts, up which the product is wound in discrete payloads.

Coal may be transported from the faces either along belt conveyors or by locomotive hauled minecars, running along a railway network, and there are clear differences between the principles and operating philosophies of the two systems. Minecars prove relatively flexible - the coal in transit is split up into discrete loads, with a degree of independence and the possibility of moving at different speeds, so offering a storage capability to smooth out variations in production rates. Conveyors avoid the many transhipment problems associated with minecar working but are relatively inflexible in that the whole belt must run as one unit at the same speed, so a need arises for surge bunkers to combat the effects of production variations. As a result, the event and route decisions, required to control a minecar system, must be replaced by continuous controls over production and bunker operation. In this simulation I have considered only conveyors which tend, nowadays, to be installed in preference to minecar systems.

4. An alternative simulation program.

During the past decade, the N.C.B.'s O.R. Executive has developed, under the names SIMBELT and SIMLOC, two groups of digital simulation programs representing underground coal handling systems employing, respectively, conveyors and locomotive hauled minecars. (References 9, Mitchell and Lee; and 10, Rannyard).

At first sight, Simbelt 2 (reference 11, Price, Szabo, and Holmes) would appear to share the objectives of the model I have been constructing. It allows the user to set up various configurations of faces, conveyors, and bunkers - feeding a single shaft; to specify component capacities and shift patterns, and so to test out the effectiveness of a proposed coal handling system. The user also specifies average breakdown statistics for components in the system, from which the model generates consequent production delays. Simbelt has, however, been designed with a generalised structure, facilitating the input of data by inexperienced users, but without the flexibility needed when trying out novel control strategies. The following are its chief limitations:-

(i) There is no facility for controlling the production rates at individual faces, though it might be possible to simulate an on/off operation. i.e., 'bang - bang' control.

(ii) Certain local control loops are implied in the model, although the user is free to specify one of three bunker operating strategies.

(iii) The winder is represented as a continuous flow, subject to random delays. The exclusion of its discrete loading and winding characteristics limits the scope for examining the detailed effects of changes in the winder payload and duty cycle.

(iv) There is no distinction between different product flows and the outputs of different faces.

5. COALSIM

5.1 The general philosophy.

The objections raised to an existing simulation, in section 4 should be some guide to the rationale underlying the Coalsim program. The aim has been to offer the user as much freedom as possible in constructing colliery layouts and specifying operating modes for their component activities; to which end the model has been designed around a set of subroutines, representing basic elements in the production system. These are called from a master segment in which the user constructs the system framework, specifies production demands and shift patterns, and organises a control structure according to his own requirements. This is not so formidable a task as it might at first seem, since large blocks of this segment remain unaffected by changes in the system, and access to the basic timing loop of the model enables the user to programme parameter changes into the simulation.

Throughout the model, a binary product flow is maintained, which can be used to separately identify the output of one face or group of faces. Normally, however, it is used to distinguish the saleable product, coal, from a waste product, 'stone.'

Before considering the program in any greater detail it would be valuable to examine the operation of a typical mechanised coalface, employing one of the most commonly used longwall cutting systems - the Anderton shearer-loader. (Reference 12, Shepherd and Withers).

5.2 A coalface in operation.

The coalface layout is illustrated in figure 1. The cutting machine, riding on an armoured face conveyor (a.f.c.), may be drawn along either by an external motor, pulling the haulage chain from the gate (reference 13, Dowell and Edwards), or by an internal drive onto a fixed chain. Performance is cyclic - in that the machine carries out a sequence of operations, involving one cut along the face, and then the a.f.c. and roof supports must have been advanced

before the next sequence can begin.

During its shearing run, the machine is hauled against the direction of coal flow along the a.f.c. and picks, lacing the revolving cutting drum, bite into the buttock and dislodge coal. The shearer does not progress steadily but in a series of hops (reference 13, Dowell and Edwards; figure 22) - an average rate of typically 5 metres/minute may be maintained. After reaching the tail end of the face, the shearer flits back at a faster speed (typically in the range 10 to 25 metres/minute) and ploughs onto the a.f.c. any coal remaining in its path, while, behind it, the a.f.c. is snaked forward into the area newly cleared - ready for the next cutting run. The flitting speed will be limited by the capacity of the a.f.c. to clear the coal ploughed onto it.

Working in a hostile environment, the shearer is prone to delays - one problem arises with the cutting motor stalling when the picks encounter particularly hard material, so that a measure of feedback load control is called for (references 13, Dowell and Edwards; and 8, Edwards and Fawcett). These delays are of a random nature, and some statistics for a longwall face (reference 10, Rannyard) are given in figure 2 - revealing a skew distribution with a preponderance of brief stoppages. An effective load control might be expected to eliminate many of the shorter delays, which are in any case of little consequence in the context of the dynamic performance of the whole system, and so the breakdown generator in Coalsim models a distribution biassed further towards the delay times of greatest significance.

5.3 Model Structure.

Coalsim is based upon 5 major subroutines:

FACE and FLIT; coalface cutting and flitback simulations

CONVEY; a general belt conveyor model

BUNK; a general homogeneous bunker model

COALWIND -2; a vertical winder model, with cyclic behaviour.

These are complemented by a number of subroutines dealing with parameter setting and coalface characteristics, and by routines used to log the simulated

plant performance.

The program timing is based upon a 1 minute computing increment; within which the winder operates asynchronously, on a 1 second base, on its own duty cycle - which can be of any specified duration. To allow, however, for a finer specification of conveyor lengths, Convey is run on a half minute increment basis - thus 2 runs must be made through the conveyor system for each increment of the main program; the way in which this works is illustrated in the master segment example of figure 10. The general structure of a master segment is shown in figure 3.

5.4 The fundamental subroutines.

5.4.1 FACE - figure 4.

In modelling the shearing run, a form of load control has been assumed in that the haulage rate slows down whenever the cutter encounters an increase in face hardness (represented by an increase in the 'stone fraction of the region being cut) while the demanded production tonnage is maintained. The hardness pattern for each face must be programmed into the subroutine CONT, and it is not intended that this should be used to represent local hardness variations but, rather, major changes along the face - or trends such as might result from steering inadequacies allowing the machine to cut into the roof or floor of a seam. Since the specific gravity of 'stone', relative to coal, is a parameter entered into the master segment, the term stone can be used to identify coal produced at a particular face, or group of faces, by giving it a relative s.g. of 1 and making those faces cut 100°/o stone - the haulage speed will then be unaffected, since the load control is based upon this relative s.g.

The haulage speed is calculated on the basis of a 'face rate' parameter, which must be specified by the user. This is that length of face (metres) which must be cut in order to produce 1 tonne of coal if the seam has zero stone content, and would be a function of coal hardness, depth of cut, and face advance distance.

At the input to the model there is a first order lag, of time constant -

2 minutes, between changes in production demand and the consequent production changes. At output, the product flow is subject to a time delay based on the shearer position and a.f.c. speed - this is an integer number of minutes.

At present, the delay generator, FISH, operates on the premise that the beginning and end of a delay are equally probable events which may be generated by the same random sequence - a Poisson process derived from a p.r.b.s., providing the distribution shown in figure 2b. A new delay subroutine is in preparation, using 2 Poisson sequences, which will allow the user to specify the average percentage availability of a shearer, for each face individually.

5.4.2 FLIT - figure 5.

During flitback, a flitting speed is entered into the subroutine at each call, and the coal ploughed out is taken to be a specified fraction of the output during a previous shearing run. The historical tonnage extracted per metre cut is obtained from the logging routine, FASTAT.

Non-productive periods of time are included prior to, and following, flitback and can be used to represent manoeuvring and related operations. These are specified in integer numbers of minutes and, during the first, the a.f.c. continues to clear the coal which has been loaded onto it.

If bidirectional operation is to be simulated then the flitback operation must be eliminated. To do this, the existing logical call statement for FLIT should be replaced by one for the subroutine BIDI.

5.4.3 CONVEY - figure 6.

This subroutine represents an idealised conveyor, in that no allowance has been made for breakdowns or for the lag in accelerating up to speed at start up. It does, however, provide for spillage if the quantity of material fed to a conveyor exceeds its capacity, which is defined as a tonnage rather than volume. The quantity spilled is returned to the master segment.

The conveyor parameters are determined in a routine, CONSETT; the user having specified the length, speed and capacity (tonnes per hour) of the conveyor, this routine calculates a capacity and time delay - rounded up to the nearest half minute.

5.4.4 BUNK - figure 7

This represents a homogeneous bunker with idealised filling and unloading characteristics and zero time delay between inflow and outflow. With the assumption of perfect mixing, the composition of the outflow is the same as the average composition within the bunker. In a case where the inflow and outflow are at opposite extremes of a bunker, partial mixing may be simulated by using a series of small bunkers cascaded to represent one large one.

No control strategy is implied other than that the demanded outflow will be met, providing sufficient material is contained within the bunker. If inflow exceeds capacity then the quantity spilled is returned to the master segment.

5.4.5 COALWIND - 2, figure 8.

The model operates on a cycle in which the winder waits until a full payload has been taken on - it then takes a fixed time to reach the surface and produce an output. This assumes a flexible system of shaft bottom loading, i.e., minecars being filled from the incoming conveyor and, where the rate of coal arriving exceeds the capacity of the winder, forming a queue. The constraints of the real situation, whether it be minecar decking or skip loading, would be applied in the master segment.

5.5 The Capacity of the Model.

As presently dimensioned, Coalsim can deal with up to 5 faces, 20 conveyors (affording a total delay capability of 300 minutes) and 10 bunkers. In practice the number of bunkers and conveyors simulated can be extended simply by redimensioning the associated arrays. This is not so in the case of the face model where any extension affects the length of time for which the simulation may be run before the delay generator sequence is exhausted and the face delays begin to show a correlation. At present a period of just over 27 hours of continuous real time working can be simulated before this happens.

6. Symbols.

6.1 Coal Face.

Integers

i = face identifying number

ts(i) = tail gate manoeuvring time (minutes)

tm(i) = main gate manoeuvring time (minutes)

Non-integers

f(i) = set production rate (tonnes per minute)

fc(i) = coal produced during 1 minute (tonnes)

fs(i) = 'stone' " " 1 " "

x(i) = distance of shearer from main gate end of face (metres)

y(i) = face length (metres)

z(i) = length remaining to be cut (metres)

c(i) = coal fraction = coal extracted/total tonnage extracted

ϕ(i) = motor temperature (normalised)

r(i) = flitback speed (metres per minute)

gc = density of coal (tonnes per cubic metre)

gs = specific gravity of stone relative to that of coal

gf(i) = coal face rate = tonnage produced per metre of face cut

af(i) = coal currently being carried on face conveyor

6.2 Conveyor.

Integers

j = conveyor identifying number

d(j) = delay time (minutes)

Non-integers

l(j) = conveyor distance (metres)

u(j) = speed (metres per minute)

v(j) = capacity (tonnes per minute)

sc(j) = spillage during a half minute (tonnes)

ac(j) = coal currently being carried (tonnes)

e(j) = input capacity (tonnes per half minute)

6.3 Bunker.

Integers

k = bunker identifying number

Non-integers

b(k) = capacity (tonnes)

a(k) = set outflow (tonnes)

sb(k) = spillage (tonnes)

cl(k) = coal level within bunker (tonnes)

sl(k) = stone level (tonnes)

6.4 Winder.

Integers

tw = winding cycle duration (seconds)

Non-integers

p = payload (tonnes)

q = tonnage of material queueing to be wound up shaft

wc = coal reaching surface (tonnes)

ws = stone " " "

7. Using Coalsim.

7.1 Subroutine Call Statements and Common Blocks.

Though many of the data transfers to and from the master segment take place in call statements, where the user is normally free to specify any variable names he cares to, some occur in common statements. In these instances it is more convenient to use the variable names specified in the existing statements and already dimensioned accordingly.

7.1.1 FACE.

CALL FACE(f(i), I,J,K,i, fc(i), fs(i), A, ϕ(i), x(i), z(i), N(i))

I is a two state variable denoting the operating status of the face, i.e., on = 1; off = 0. The appropriate initial value, 1 or 0, must be assigned to this variable prior to the first entry - thereafter its status is determined by the random face delay generator.

J and K are feedback and count parameters for the random face delay generator.

A is a flow variable which must be initialised within the master segment prior to the first entry. For machines starting from rest it must be set to zero - thereafter its value is determined from within.

N is a two state variable indicating the direction in which a bi-directional face is cutting. 1 denotes the forward run from main gate to tail, 2 - the return run.

COMMON Variable names

af(i) is returned as ACV(i)

gf(i) " entered " CRATE(i)

fp(i) " " " FPLOW(i)

gs " " " SHARD

7.1.2 FLIT

CALL FLIT(i,x(i),y(i),JFLIT(i),IFLIT(i),z(i),fc(i),fs(i),r(i))

JFLIT and IFLIT are clock integers stored in arrays in the master segment and must be referred to by these names.

COMMON Variable names

ts(i) is entered as ISF(i)

tm(i) " " " IPF(i)

7.1.3 CONVEY.

CALL CONVEY(A,B,C,D,sc(j),ac(j),CONC(m),CONS(m),d(j),e(j))

A is coal fed onto conveyor during a half minute

B is stone " " " " " " "

C is coal drawn from " " " " "

D is stone " " " " " " "

CONC and CONS are storage arrays and m is the element at which the storage allocated to conveyor j begins:-

$$m = 1 + \sum_{i=1}^{i=j-1} d(i)$$

d(j) and e(j) are derived from the conveyor parameters, specified in the master segment, by the subroutine CONSETT. The call statement for this is:-

CALL CONSETT(l,u,v,d,e,DET)

The variables l, u and v must be entered in arrays, of dimension 5.

7.1.4 BUNK

CALL BUNK(A,B,C,D,sb(k),cl(k),sl(k),a(k),b(k),k)

A = coal accepted by bunker during computing increment

B = stone " " " " " "

C = coal supplied " " " " "

S = stone " " " " " "

7.1.5 COALWIND 2.

CALL COALWIND 2(A,B,q,wc,ws)

A = coal supplied to shaft bottom during 1 minute

B = stone " " " " " " "

7.1.6. BIDI

CALL BIDI (x,JBYE(i), NBYE(i), MBYE(i),i,fc(i),fs(i))

JBYE is the stable manoeuvring clock integer

NBYE is an indicating integer:-

If the machine is cutting along the face - NBYE = 0,

if it is manoeuvring in the stable then NBYE = 1

MBYE is a manoeuvring time integer equal to 1 + the number of minutes required for stable work on turning round.

If MBYE = 1, the machine turns around straight away on reaching the end of the face and begins cutting again at the outset of the next minute.

7.2 Logical Call Statements for FLIT and BIDI

7.2.1. Unidirectional Shearing

IF (EX(i).EQ.0) CALL FLIT (.....)

followed by a test to bypass the FACE call statement when flitting, e.g.:

IF (JFLIT(i).GT.1) GOTO 1.

7.2.2. Bidirectional Cutting

IF (EX(i). EQ.0) CALL BIDI(.....)

followed by a test to bypass FACE when manoeuvring, e.g.

IF (NBYE (i). EQ.1) GOTO 1.

7.3. The Alternative Delay Subroutine

This uses a partitioned p.r.b.s. sequence to generate face delays having unequal average on and off periods. The face characteristics are entered into an array in the master segment :-

ONAV (i) = average working period between breakdown of face i

OFAV (i) = average delay period

NCO (i), MCO (i,1), and MCO (i,2) are integer parameters derived from an initialising subroutine FISHIN, the call statement for which is :-

CALL FISHIN (ONAV(i), OFAV(i), NCO(i), MCO(i,1), MCO(i,2),24.0,10)

Using these values the mark two delay subroutine, FISH, will then generate the required averages, subject to a small rounding off error involved in matching the program timing.

8. Simulation results for the system outlined in Figure 9.

COALFLOW SIMULATION

DEMANDED OUTPUT IS 5.0 TONNES PER MINUTE

CONVEYOR PARAMETERS ARE

C1	DELAY TIME IS 2.5 MINUTES	CAPACITY IS 300.0 TONNES PER HOUR
C2	DELAY TIME IS 5.0 MINUTES	CAPACITY IS 500.0 TONNES PER HOUR
C3	DELAY TIME IS 0.5 MINUTES	CAPACITY IS 500.0 TONNES PER HOUR
C4	DELAY TIME IS 3.0 MINUTES	CAPACITY IS 300.0 TONNES PER HOUR
C5	DELAY TIME IS 2.5 MINUTES	CAPACITY IS 500.0 TONNES PER HOUR

SURGE BUNKER CAPACITY IS 300.0 TONNES
INITIAL BUNKER LEVEL IS 0.0

INITIAL LEVEL OF SURFACE STOCKPILE IS 600.0

START OF RUN

PRODUCTION FIGURES (TONS) AT INTERVALS OF 1 MINUTE

TIME	FIRST FACE			SECOND FACE			WINDER		BUNKER AT SURFACE STOCKS		OUTFLOWS	
	POSITION	COAL	STONE	POSITION	COAL	STONE	QUEUE	LOAD	COAL	STONE	COAL	STONE
0	150.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	400.0	200.0	0.0	0.0
1	152.2	0.0	0.0	2.4	0.0	0.0	0.0	0.0	396.7	198.3	3.3	1.7
2	155.3	0.0	0.0	2.4	0.0	0.0	0.0	0.0	393.3	196.7	3.3	1.7
3	158.7	0.0	0.0	2.4	0.0	0.0	0.0	0.0	390.0	195.0	3.3	1.7
4	162.3	1.2	1.8	2.4	0.0	0.0	0.0	0.0	386.7	193.3	3.3	1.7
5	165.9	1.7	2.5	2.4	0.0	0.0	0.0	0.0	383.3	191.7	3.3	1.7
6	169.9	1.9	2.8	2.4	0.0	0.0	0.0	0.0	380.0	190.0	3.3	1.7
7	173.9	1.9	2.9	2.4	0.0	0.0	0.0	0.0	376.7	188.3	3.3	1.7
8	178.0	2.0	3.0	2.4	0.0	0.0	0.0	0.0	273.3	186.7	3.3	1.7
9	182.0	3.0	2.0	2.4	0.0	0.0	0.0	0.0	370.0	185.0	3.3	1.7
10	186.0	3.0	2.0	2.4	0.0	0.0	0.0	0.0	366.7	183.3	3.3	1.7

PRODUCTION FIGURES AT END OF 1 HOUR

FACE 1

COAL 111.6 TONNES
STONE 45.0 TONNES
PRODUCTION TIME 36 MINUTES
BREAKDOWN TIME 0 MINUTES
NUMBER OF BREAKDOWNS 0
LENGTH CUT 300.0 METRES

MEAN STOPPAGE TIME IS 0.0 MINUTES
MEAN COAL PRODUCTION RATE, EXCLUSIVE OF STOPPAGES, IS 3.1 TONNES PER MINUTE

FACE 2

COAL 141.9 TONNES
STONE 29.6 TONNES
PRODUCTION TIME 39 MINUTES
BREAKDOWN TIME 21 MINUTES
NUMBER OF BREAKDOWNS 1
LENGTH CUT 170.1 METRES

MEAN STOPPAGE TIME IS 21.0 MINUTES
MEAN COAL PRODUCTION RATE, EXCLUSIVE OF STOPPAGES, IS 3.6 TONNES PER MINUTE

TIME	FIRST FACE			SECOND FACE			WINDER		BUNKER AT SURFACE STOCKS		OUTFLOWS	
	POSITION	COAL	STONE	POSITION	COAL	STONE	QUEUE	LOAD	COAL	STONE	COAL	STONE
	FACE 1 IS FLITTING BACK											
61	120.0	1.3	0.5	173.7	2.0	3.0	10.5	14.0	412.6	162.4	3.6	1.4
	FACE 1 IS FLITTING BACK											
62	108.0	1.3	0.5	177.4	2.0	3.0	3.4	0.0	409.0	161.0	3.6	1.4
	FACE 1 IS FLITTING BACK											
63	96.0	1.3	0.5	181.1	2.0	3.0	10.3	14.0	416.5	162.5	3.6	1.4
	FACE 1 IS FLITTING BACK											
64	84.0	1.3	0.5	184.3	2.0	3.0	3.2	0.0	412.9	161.1	3.6	1.4
	FACE 1 IS FLITTING BACK											
65	72.0	1.3	0.5	187.6	2.0	3.0	10.0	14.0	420.2	162.8	3.6	1.4
	FACE 1 IS FLITTING BACK											
66	60.0	1.3	0.5	190.8	2.0	3.0	2.9	0.0	416.5	161.5	3.6	1.4
	FACE 1 IS FLITTING BACK											
67	48.0	1.3	0.5	194.9	0.5	4.5	9.8	14.0	421.7	165.3	3.6	1.4
	FACE 1 IS FLITTING BACK											
68	36.0	1.3	0.5	198.9	0.5	4.5	2.7	0.0	418.1	163.9	3.6	1.4
	FACE 1 IS FLITTING BACK											
69	24.0	1.3	0.5	202.9	0.5	4.5	9.6	14.0	421.3	169.7	3.6	1.4
	FACE 1 IS FLITTING BACK											
70	12.0	1.3	0.5	207.0	0.0	0.0	2.4	0.0	417.7	168.3	3.6	1.4
	FACE 1 IS FLITTING BACK											
71	0.0	1.3	0.5	211.0	3.0	2.0	9.3	14.0	421.0	174.0	3.5	1.5
	FACE 1 IS FLITTING BACK											
72	0.0	1.3	0.5	211.0	3.0	2.0	2.2	0.0	417.5	172.5	3.5	1.5
	FACE 1 IS IN MAIN GATE											
73	0.0	1.3	0.5	211.0	3.0	2.0	9.1	14.0	420.2	178.8	3.5	1.5
	FACE 1 IS IN MAIN GATE											
74	0.0	1.3	0.5	211.0	3.0	2.0	2.0	0.0	416.7	177.3	3.5	1.5
	FACE 1 IS IN MAIN GATE											
75	0.0	1.3	0.5	211.0	3.0	2.0	6.3	14.0	417.3	185.7	3.5	1.5
	FACE 1 IS IN MAIN GATE											
76	0.0	1.3	0.5	211.0	3.0	2.0	10.7	0.0	413.8	184.2	3.5	1.5

	FACE 1 IS IN MAIN GATE											
77	0.0	1.3	0.5	211.0	3.0	2.0	3.6	0.0	410.3	182.7	3.5	1.5
	FACE 1 IS IN MAIN GATE											
78	0.0	1.3	0.5	211.0	3.0	2.0	10.5	14.0	413.9	188.1	3.4	1.6
	FACE 1 IS IN MAIN GATE											
79	0.0	1.3	0.5	211.0	3.0	2.0	3.3	0.0	410.5	186.5	3.4	1.6
	FACE 1 IS IN MAIN GATE											
80	0.0	1.3	0.5	211.0	3.0	2.0	10.2	14.0	415.9	190.1	3.4	1.6
	FACE 1 IS IN MAIN GATE											
81	0.0	1.3	0.5	211.0	3.0	2.0	3.1	0.0	412.5	188.5	3.4	1.6
82	4.4	1.3	2.5	211.0	3.0	2.0	10.0	14.0	417.9	192.1	3.4	1.6
83	9.1	0.0	1.7	211.0	3.0	2.0	2.9	0.0	414.4	190.6	3.4	1.6
84	14.0	4.4	0.0	211.0	3.0	2.0	9.7	14.0	419.9	194.1	3.4	1.6
85	19.0	4.7	0.0	211.0	3.0	2.0	2.6	0.0	416.4	192.6	3.4	1.6
86	23.9	4.9	0.0	211.0	3.0	2.0	9.5	14.0	421.9	196.1	3.4	1.6
87	28.9	5.0	0.0	211.0	3.0	2.0	2.4	0.0	418.4	194.6	3.4	1.6
88	33.9	5.0	0.0	211.0	3.0	2.0	9.3	14.0	423.9	198.1	3.4	1.6
89	38.9	5.0	0.0	211.0	3.0	2.0	2.1	0.0	420.5	196.5	3.4	1.6
90	43.9	5.0	0.0	211.0	3.0	2.0	9.0	14.0	425.9	200.1	3.4	1.6
91	48.9	5.0	0.0	211.0	3.0	2.0	1.9	0.0	422.5	198.5	3.4	1.6
92	53.9	5.0	0.0	211.0	3.0	2.0	9.5	14.0	427.9	202.1	3.4	1.6
93	58.4	5.0	0.0	211.0	3.0	2.0	3.0	0.0	424.5	200.5	3.4	1.6
94	62.9	5.0	0.0	211.0	3.0	2.0	10.5	14.0	428.7	205.3	3.4	1.6
95	67.3	4.0	1.0	211.0	3.0	2.0	4.9	0.0	425.3	203.7	3.4	1.6
96	71.8	4.0	1.0	211.0	3.0	2.0	13.2	14.0	430.8	207.2	3.4	1.6
97	76.2	4.0	1.0	211.0	3.0	2.0	7.5	0.0	427.5	205.5	3.4	1.6
98	80.7	4.0	1.0	211.0	3.0	2.0	1.9	14.0	435.2	206.8	3.4	1.6
99	85.2	4.0	1.0	213.4	3.0	2.0	10.2	14.0	443.0	208.0	3.4	1.6
100	89.6	4.0	1.0	216.8	3.0	2.0	4.5	0.0	439.6	206.4	3.4	1.6
101	94.1	4.0	1.0	220.5	3.0	2.0	12.9	14.0	447.4	207.6	3.4	1.6
102	98.8	4.0	1.0	224.4	0.0	0.0	7.2	0.0	444.0	206.0	3.4	1.6
103	103.5	4.0	1.0	228.4	1.8	1.2	1.5	14.0	451.7	207.3	3.4	1.6
104	108.3	1.3	2.5	233.4	2.5	1.7	9.9	14.0	459.5	208.5	3.4	1.6
105	113.0	4.5	0.5	238.4	2.8	1.9	4.2	0.0	456.0	207.0	3.4	1.6
106	117.7	4.5	0.5	243.4	2.9	1.9	12.5	14.0	463.6	208.4	3.4	1.6
107	122.4	4.5	0.5	248.4	3.0	2.0	5.2	0.0	460.1	206.9	3.4	1.6
108	127.1	4.5	0.5	253.4	5.0	0.0	11.7	14.0	466.8	209.2	3.5	1.5
109	131.8	4.5	0.5	258.4	5.0	0.0	5.9	0.0	463.3	207.7	3.5	1.5
110	131.8	4.5	0.5	263.4	5.0	0.0	0.2	14.0	470.2	209.8	3.5	1.5
111	131.8	4.5	0.5	268.4	5.0	0.0	8.5	14.0	476.7	212.3	3.5	1.5
112	131.8	4.5	0.5	273.4	5.0	0.0	2.9	0.0	473.3	210.7	3.5	1.5
113	131.8	4.5	0.5	278.4	5.0	0.0	11.2	14.0	479.6	213.4	3.5	1.5
114	131.8	4.5	0.5	283.4	5.0	0.0	5.5	0.0	476.2	211.8	3.5	1.5
115	131.8	4.5	0.5	288.4	5.0	0.0	13.9	14.0	483.6	213.4	3.5	1.5
116	131.8	4.5	0.5	293.4	5.0	0.0	8.2	0.0	480.2	211.8	3.5	1.5
117	131.8	4.5	0.5	298.4	5.0	0.0	2.5	14.0	488.2	212.8	3.5	1.5
FACE 2 HAS REACHED STABLE												
118	131.8	4.5	0.5	300.0	5.0	0.0	10.9	14.0	498.0	212.0	3.5	1.5
	FACE 2 IS IN TAIL GATE											
119	131.8	4.5	0.5	300.0	0.0	0.0	5.2	0.0	494.5	210.5	3.5	1.5
	FACE 2 IS IN TAIL GATE											
120	131.8	4.5	0.5	300.0	0.0	0.0	13.5	14.0	504.3	209.7	3.5	1.5

PRODUCTION FIGURES AT END OF 2 HOURS

FACE 1

COAL 276.2 TONNES
STONE 68.7 TONNES
PRODUCTION TIME 64 MINUTES
BREAKDOWN TIME 11 MINUTES
NUMBER OF BREAKDOWNS 1
LENGTH CUT 431.8 METRES

MEAN STOPPAGE TIME IS 11.0 MINUTES
MEAN COAL PRODUCTION RATE, EXCLUSIVE OF STOPPAGES, IS 4.3 TONNES PER MINUTE

FACE 2

COAL 316.4 TONNES
STONE 131.8 TONNES
PRODUCTION TIME 70 MINUTES
BREAKDOWN TIME 48 MINUTES
NUMBER OF BREAKDOWNS 2
LENGTH CUT 300.0 METRES

MEAN STOPPAGE TIME IS 24.0 MINUTES
MEAN COAL PRODUCTION RATE, EXCLUSIVE OF STOPPAGES, IS 4.5 TONNES PER MINUTE

PRODUCTION FIGURES AT END OF 5 HOURS

FACE 1

COAL 644.4 TONNES
STONE 178.9 TONNES
PRODUCTION TIME 116 MINUTES
BREAKDOWN TIME 94 MINUTES
NUMBER OF BREAKDOWNS 4
LENGTH CUT 641.8 METRES

MEAN STOPPAGE TIME IS 23.5 MINUTES
MEAN COAL PRODUCTION RATE, EXCLUSIVE OF STOPPAGES, IS 5.6 TONNES PER MINUTE

FACE 2

COAL 782.5 TONNES
STONE 271.0 TONNES
PRODUCTION TIME 140 MINUTES
BREAKDOWN TIME 108 MINUTES
NUMBER OF BREAKDOWNS 4
LENGTH CUT 600.0 METRES

MEAN STOPPAGE TIME IS 27.0 MINUTES
MEAN COAL PRODUCTION RATE, EXCLUSIVE OF STOPPAGES, IS 5.6 TONNES PER MINUTE

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FIGURE 1

COAL FACE

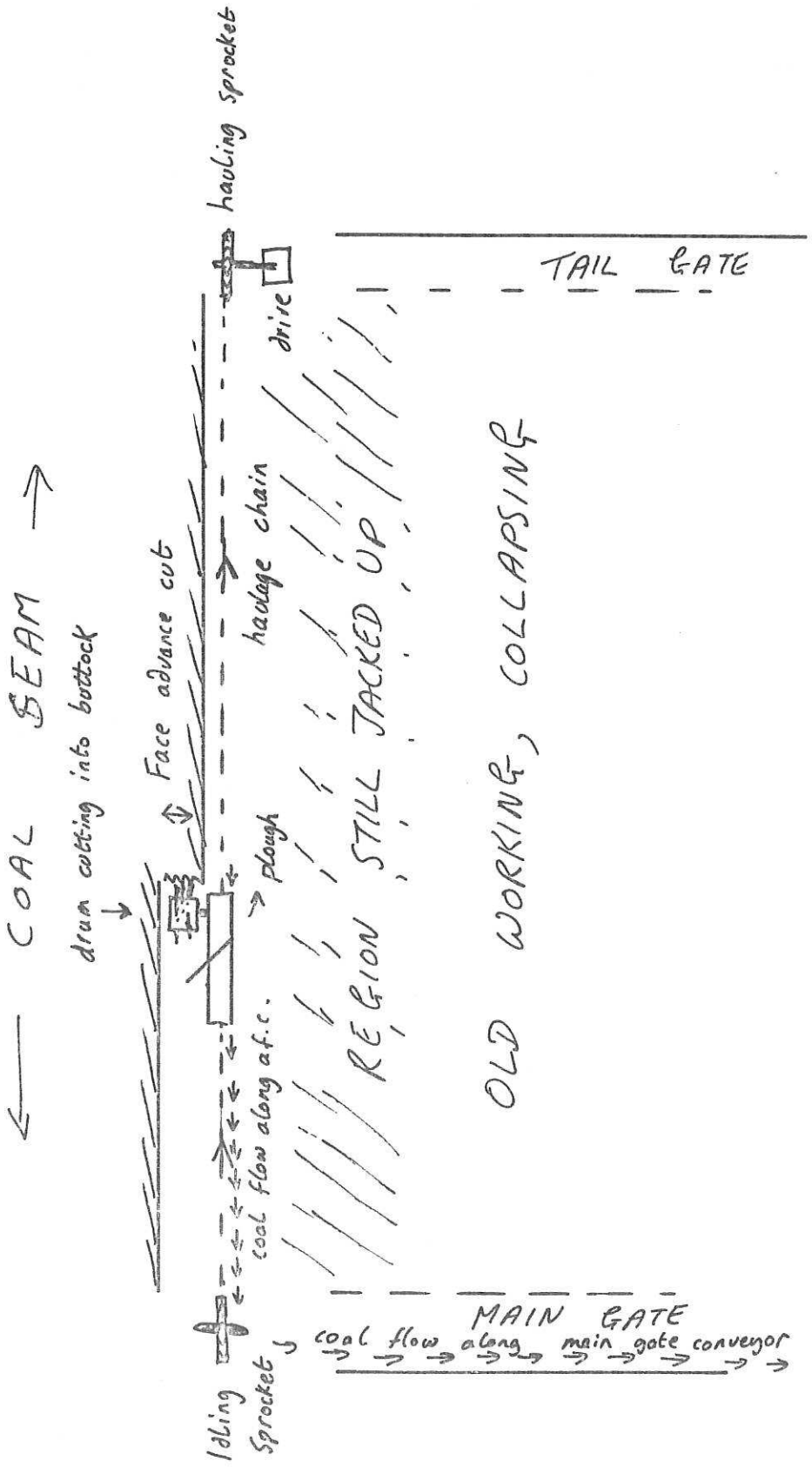
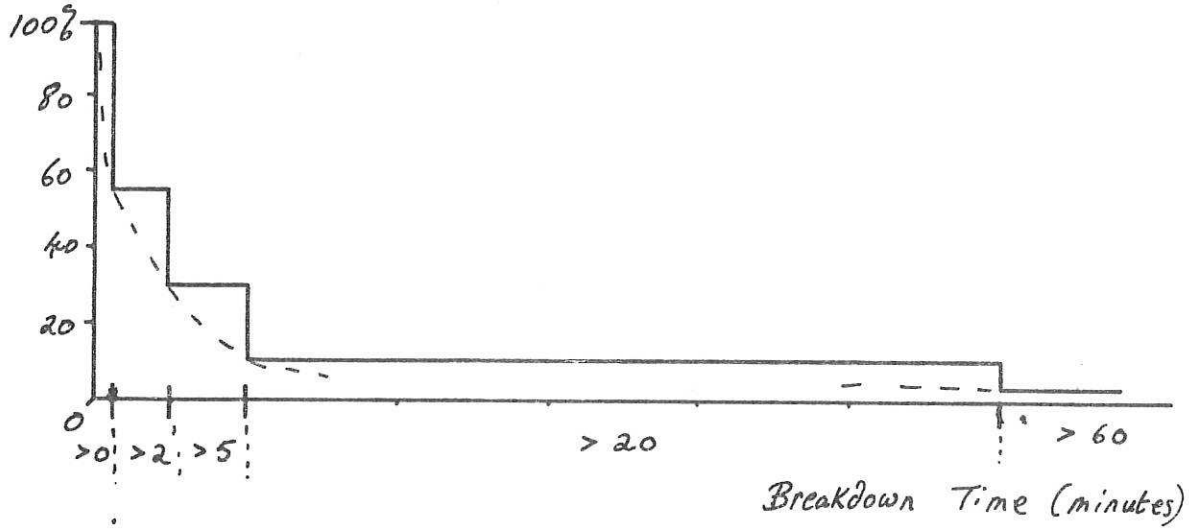
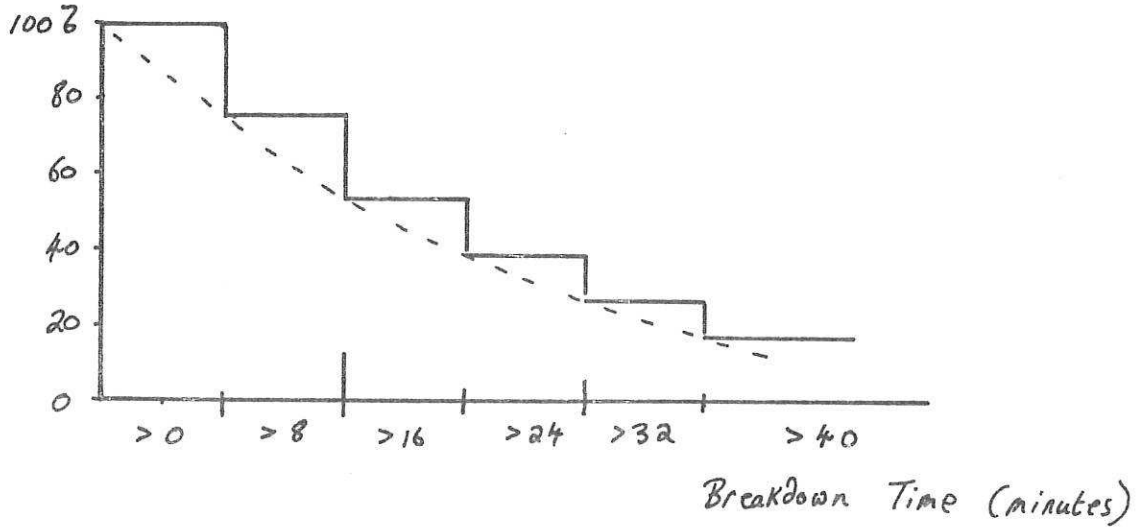


FIGURE 2

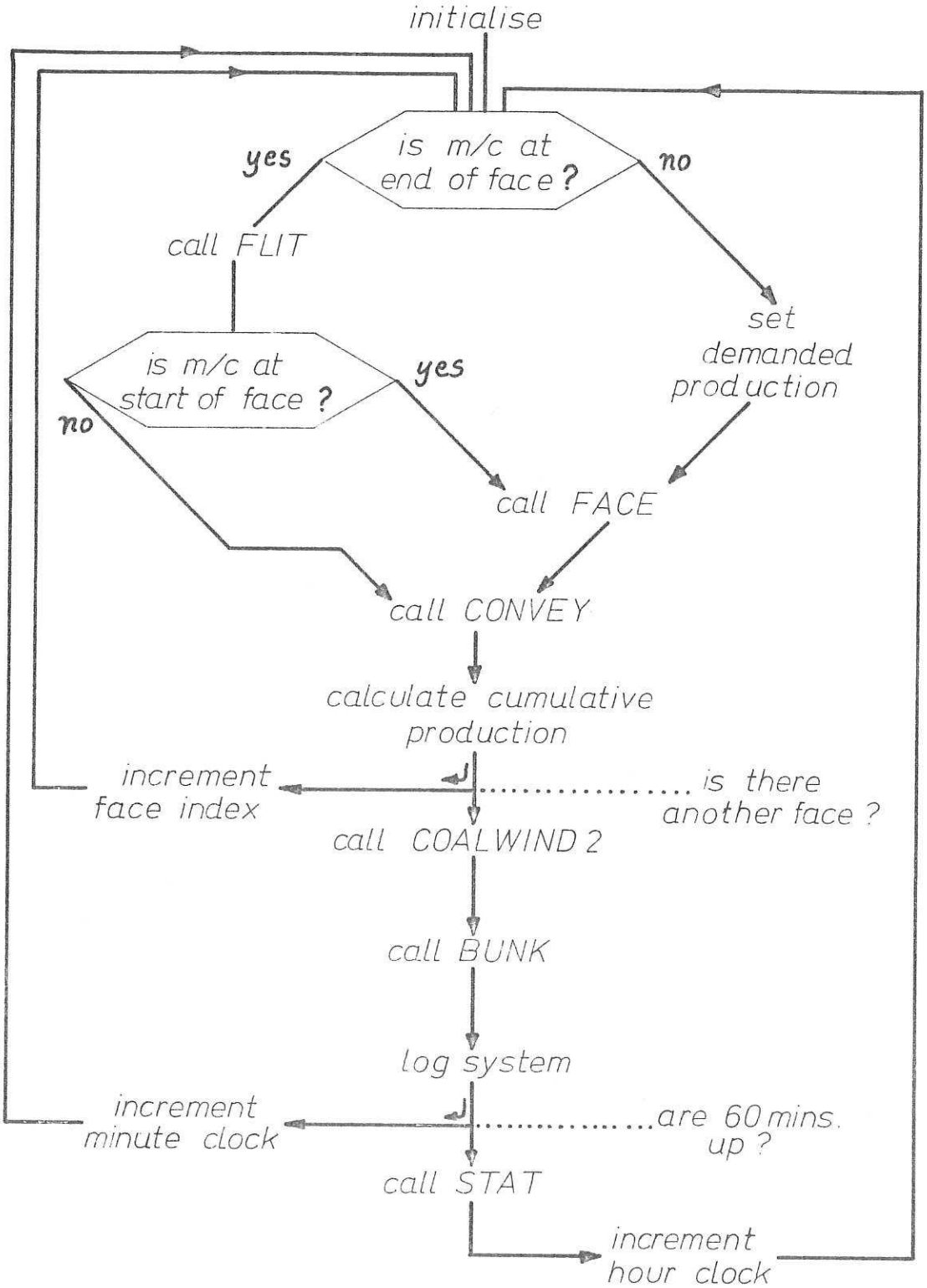
CUMULATIVE DISTRIBUTIONS OF
RANDOM FACE DELAYS



a. From N.C.B. Statistics

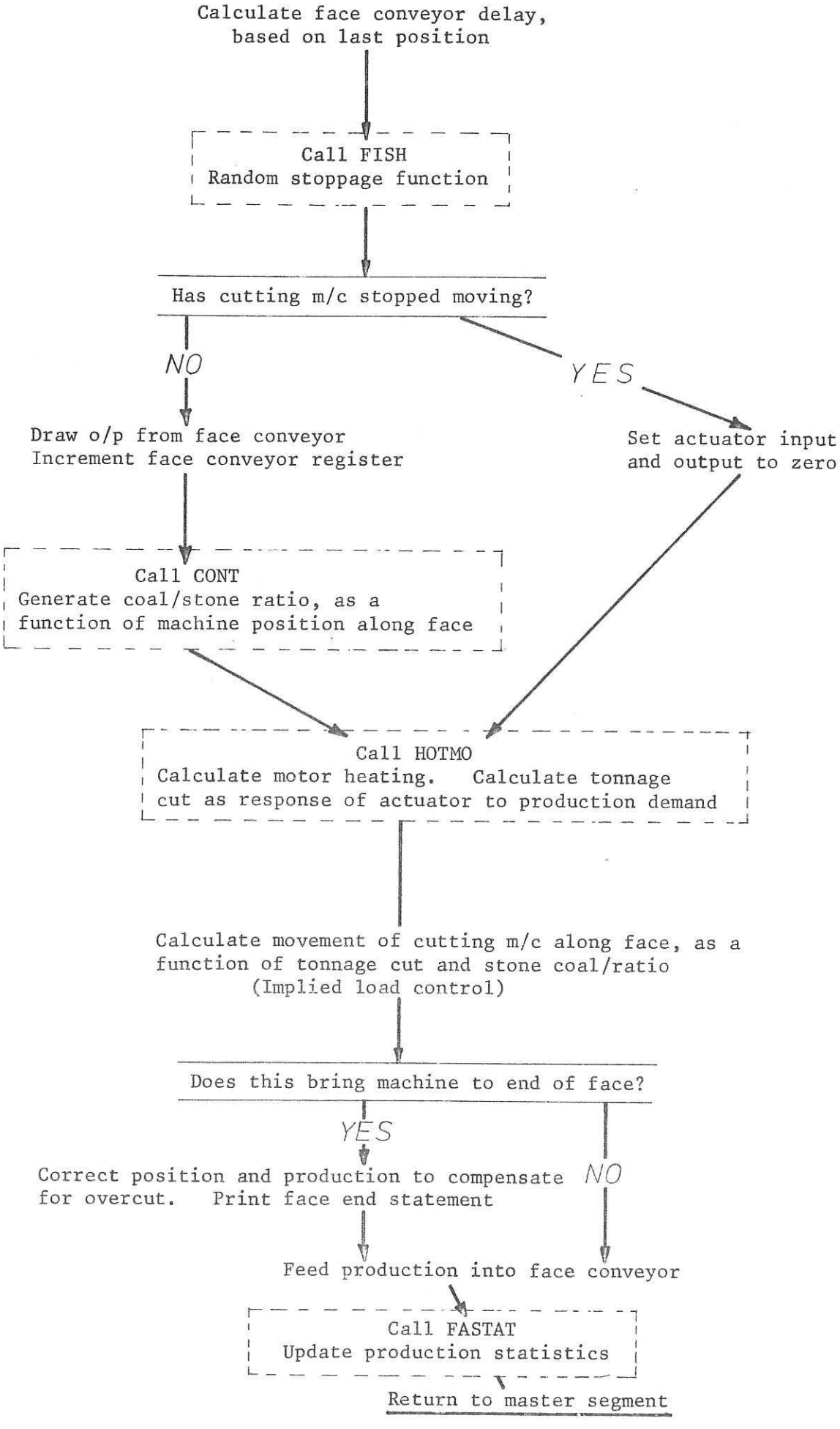


b. Generated within Coalsim



Master Segment for simple 2 Face Colliery Simulation

FIGURE 4


Calculate face conveyor delay, based on last position
Call FISH
Random stoppage function
Has cutting m/c stopped moving?
NO
YES
Draw o/p from face conveyor
Increment face conveyor register
Set actuator input and output to zero
Call CONT
Generate coal/stone ratio, as a function of machine position along face
Call HOTMO
Calculate motor heating. Calculate tonnage cut as response of actuator to production demand
Calculate movement of cutting m/c along face, as a function of tonnage cut and stone coal/ratio (Implied load control)
Does this bring machine to end of face?
YES
NO
Correct position and production to compensate for overcut. Print face end statement
Feed production into face conveyor
Call FASTAT
Update production statistics
Return to master segment

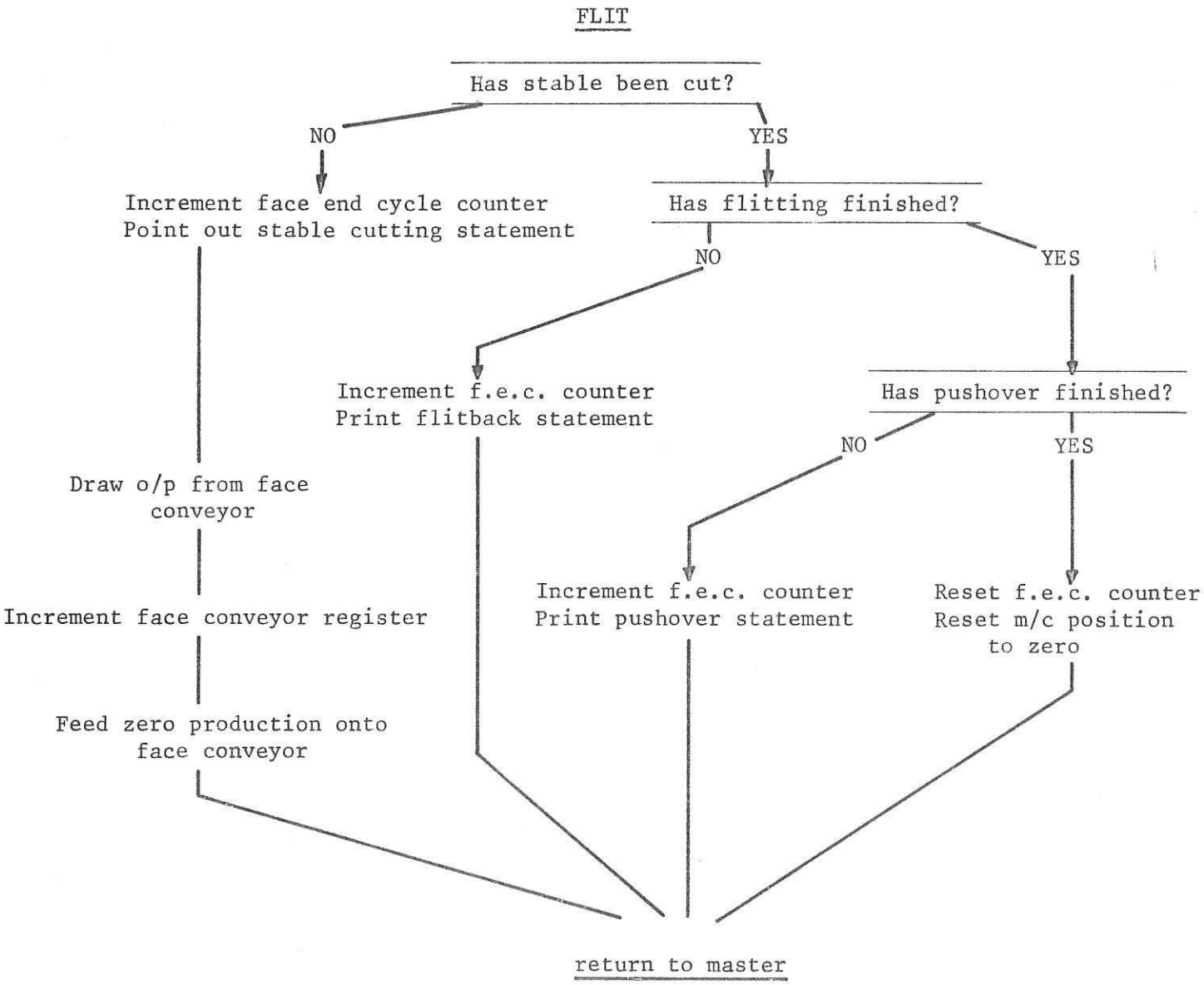

FLIT
Has stable been cut?
NO
YES
Increment face end cycle counter
Point out stable cutting statement
Has flitting finished?
NO
YES
Increment f.e.c. counter
Print flitback statement
Has pushover finished?
NO
YES
Draw o/p from face conveyor
Increment face conveyor register
Feed zero production onto face conveyor
Increment f.e.c. counter
Print pushover statement
Reset f.e.c. counter
Reset m/c position to zero
return to master

FIGURE 6

CONVEY

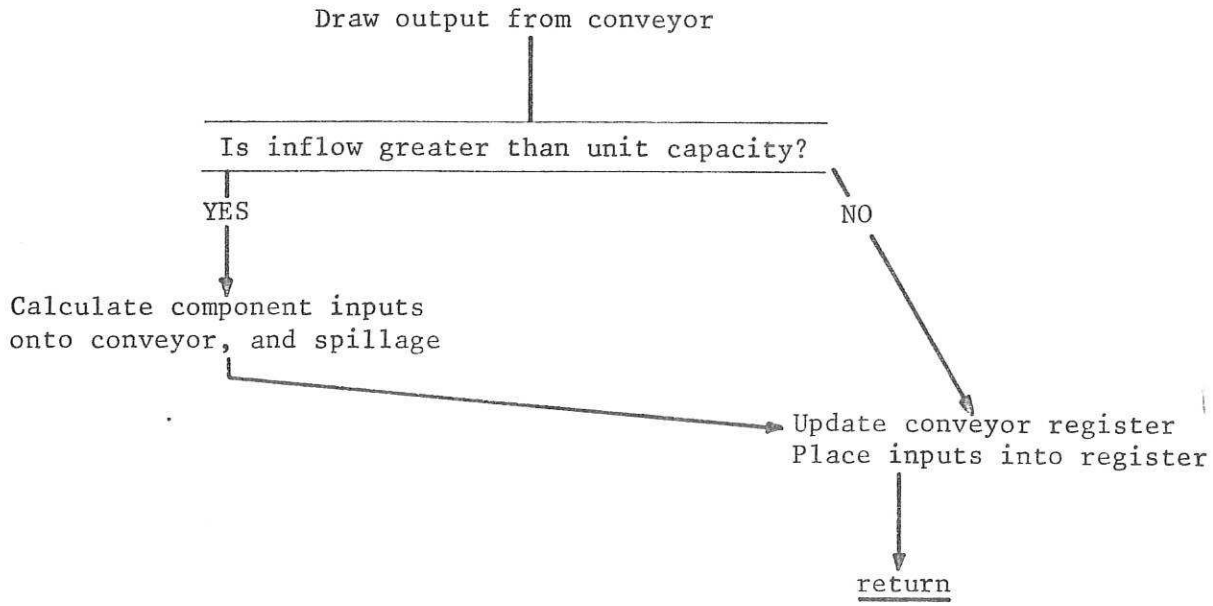
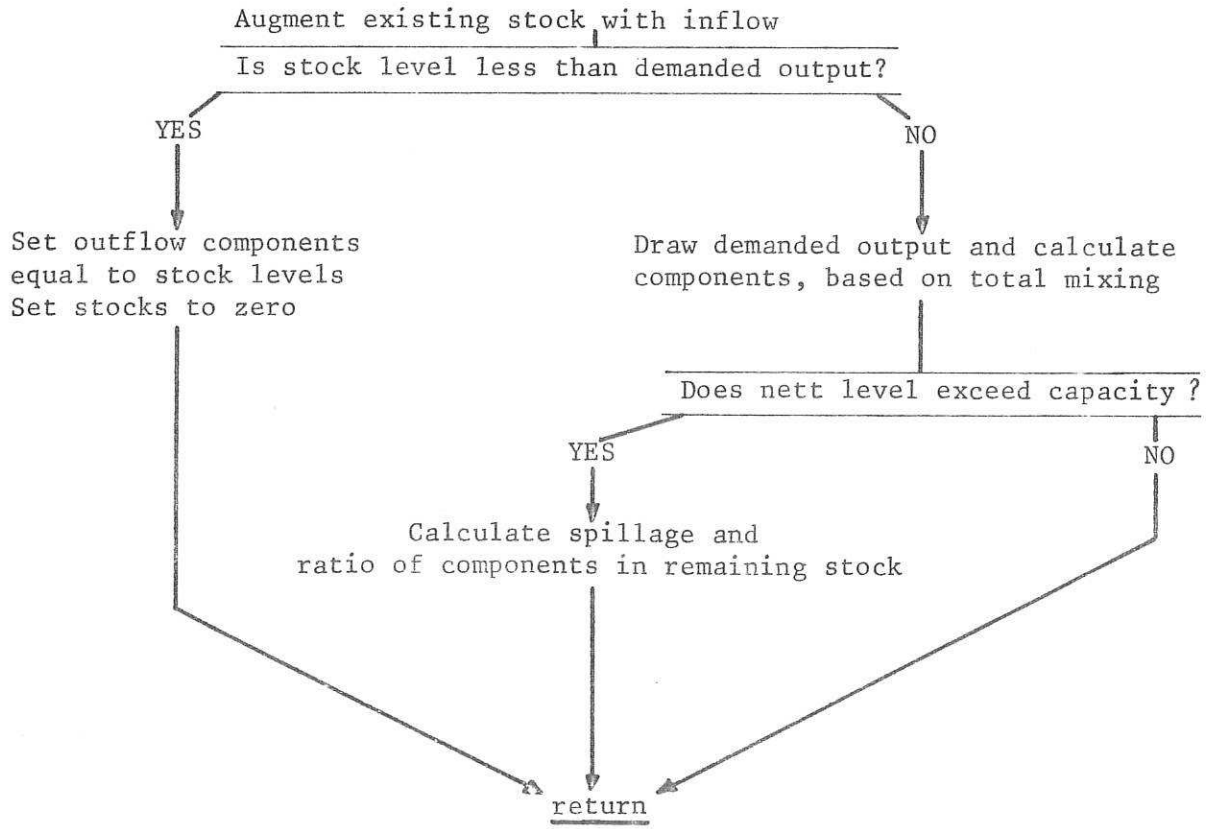
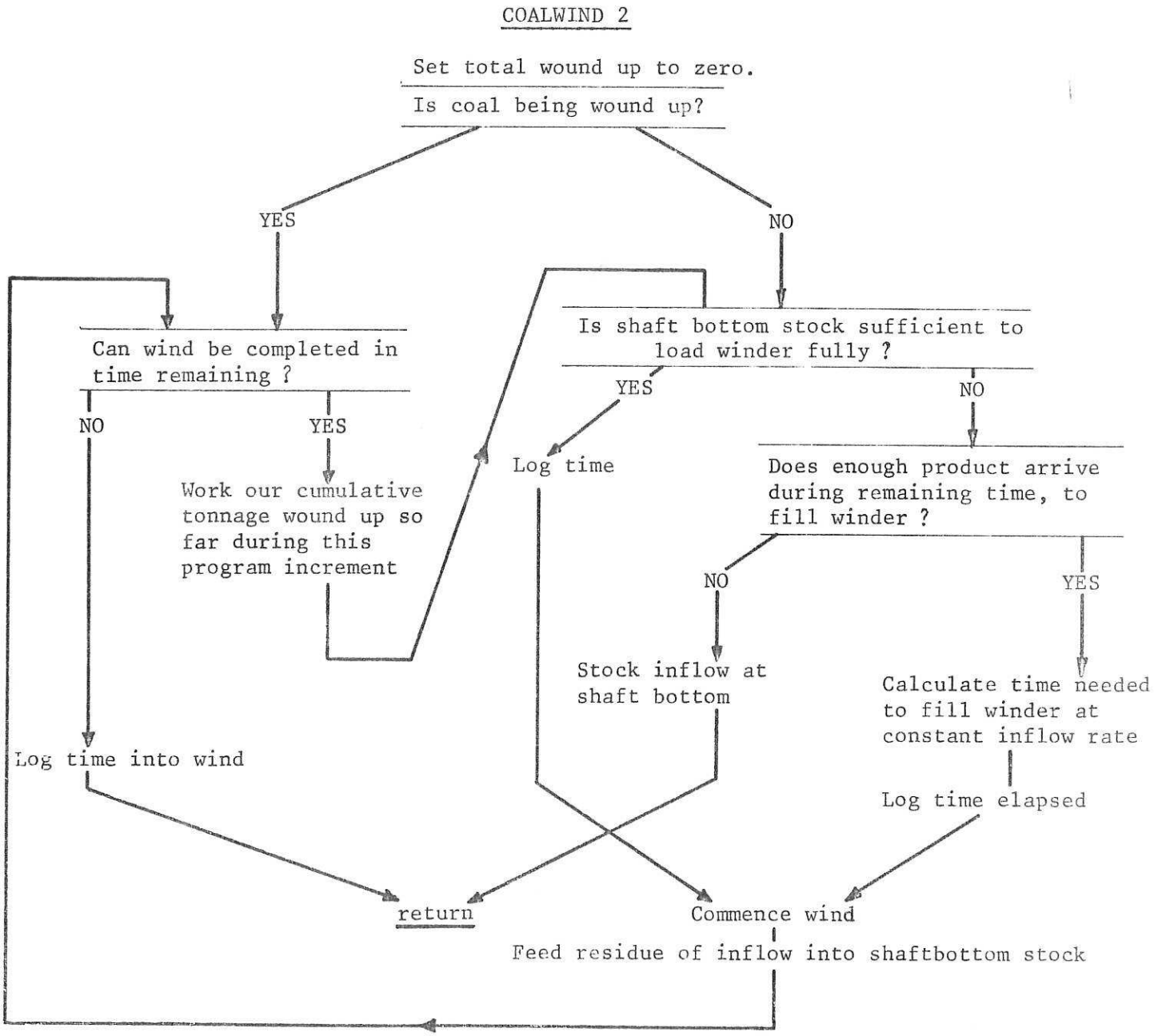
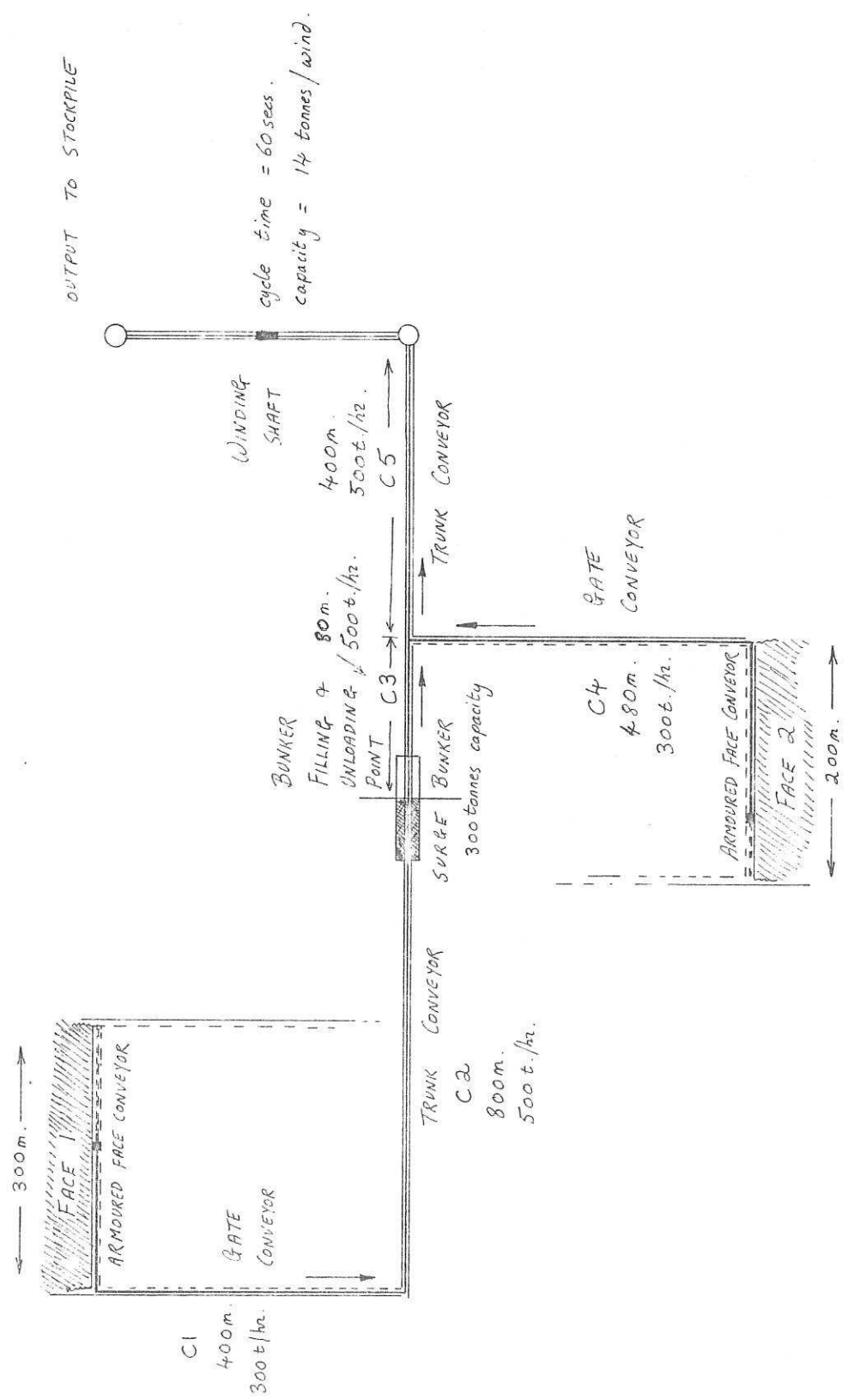


FIGURE 7

BUNK




COALWIND 2
Set total wound up to zero.
Is coal being wound up?
YES
NO
Can wind be completed in time remaining ?
NO
YES
Work our cumulative tonnage wound up so far during this program increment
Is shaft bottom stock sufficient to load winder fully ?
YES
NO
Log time
Does enough product arrive during remaining time, to fill winder ?
NO
YES
Stock inflow at shaft bottom
Calculate time needed to fill winder at constant inflow rate
Log time into wind
Log time elapsed
return
Commence wind
Feed residue of inflow into shaftbottom stock



Simulated 2 Face Colliery

General Dimensions and Parameter Setting

```
      MASTER COALSIM2
      DIMENSION IIA(5),IIB(5),IIC(5),IID(5),AIA(5),AIB(5),AIC(5),AID(5)
C  DIMENSION FACES
      DIMENSION X(5),EX(5),FL(5),IFF(5),ICO(5),IFB(5),JFLIT(5),IFLIT(5)
      DIMENSION FUR(5),CRATE(5),FPLOW(5),ACV(5),FLOE(5)
      DIMENSION FLOWC(5),FLOWS(5),FI(5),DEM(5)
C     RANDOM BREAKDOWN REGISTERS
      DIMENSION IP(15,5)
C     A.F.C. REGISTERS
      DIMENSION FLOC(10,5),FLOS(10,5)
C  DIMENSION CONVEYORS
      DIMENSION COL(20),COC(20),COSP(20),DET(20),ID(20),CC(20),
     1SC(20),AC(20)
C     CONVEYOR REGISTERS
      DIMENSION CONC(600),CONS(600)
C  DIMENSION REFERENCES TO BUNKERS
      DIMENSION JS(10),BC(10),BS(10),SB(10)
      COMMON/FACO/ CRATE,FPLOW,SHARD
      COMMON/FSTAT/IIA,IIB,IIC,IID,AIA,AIB,AIC,AID
      COMMON IP/FIERIE/FLOC,FLOS,ACV
      COMMON/WINDUP/JT,W,IW,JW,QC,QS
      COMMON/FLITIN/IPF,ISF
      WRITE(2,101)
C  DEFINE WINDER PARAMETERS
      W=14.0
      IT = 60
C  INITIALISE WINDER VARIABLES
      QC=0
      QS=0
      Q=QC+QS
      JT=60
      JW=0
      IW=0
C  DEFINE CONVEYOR PARAMETERS
      DATA COL/400.0,800.0,80.0,480.0,400.0,15*0/,
     1 COSP/20*160.0/,COC/300.0,2*500.0,300.0,500.0,15*0/
      CALL CONSETT(COL,COSP,COC,ID,CC,DET)
C  DEFINE BUNKER PARAMETERS
      BCAP=300.0
      FRATE = 3.0
C     INITIAL LEVELS IN PITHEAD STOCKPILE
      CL=600.0
      SL=200.0
      BLEVEL=CL+SL
C  INITIAL VALUES OF CONVEYOR AND BUNKER ARGUMENTS
      DATA AC,SC,BC,BS,SB/70*0/
```

FIGURE 10/2

Setting up Faces

```
C  DEFINE FACE PARAMETERS
      SHARD = 1.6                  = STONE  HARDNESS
      IFB(1)=1
      IFB(2)=4
      ICO(1)=2
      ICO(2)=2
      FL(1)=300.0
      FL(2)=300.0
      IPF=10
      ISF=10
      FUR(1)=12.0                  } FLITBACK  SPEED  (METRES/MINUTE)
      FUR(2)=12.0                  }   "    "    "    "
      CRATE(1)=1.0                 } COAL  FACE  RATE  (TONNES / METRE)
      CRATE (2)=1.0                }   "    "    "
      FPLOW(1)=0.3                 } COAL & STONE PLOUGHED DURING FLITBACK
      FPLOW(2)=0.3                 }   "    "    "    "
C  INITIALISE FACES
      ACV(1)=0
      ACV(2)=0
      IFF(1)=1
      IFF(2)=1
      X(1)=150.0
      X(2)=0
      DO 3 J=1,2
      FUR(J)=12.0
      CRATE(J)=1.0
      FPLOW(J)=0.3
      IFLIT(J)=0
      JFLIT(J)=1
      EX(J)=FL(J)-X(J)
      DEM(J)=5.0
      FLOE(J)=0
      FI(J)=0
      DO 2 I=1,15
2     IP(I,J)=0
3     IP(1,J)=1
C  FOR FURTHER INITIALISATION SEE BLOCK DATA SEGMENT
C  ENTER CUSTOMER DEMAND
      CLOUT = 5.0
      WRITE(2,102) CLOUT,(I,DET(I),COC(I),I=1,5)
      WRITE(2,103) BCAP,BU,BLEVEL
      WRITE(2,104)
      WRITE(2,108)
```

Colliery Structure

```
C       COMMENCE OPERATION
        WRITE(2,106) K,(X(I),FLOWC(I),FLOWS(I),FI(I),I=1,2),
     1 Q,FLOWO,CL,SL,COUT,SOUT
        DO 10 KC=1,5
        DO 9 KM=1,60
        K=KM+(KC-1)*60
C   PRODUCTION FACES, TIMEBASE 1 MINUTE
        DO 1 JF=1,2
        IF(EX(JF).EQ.0) CALL FLIT(JF,X(JF),FL(JF),JFLIT(JF),
     1IFLIT(JF),EX(JF),FLOWC(JF),FLOWS(JF),FUR(JF))
        IF(JFLIT(JF).GT.1) GOTO 1
        FPROD=DEM(JF)
        CALL FACE(FPROD,IFF(JF),IFB(JF),ICO(JF),JF,FLOWC(JF),FLOWS(JF),
     1FLOE(JF),FI(JF),X(JF),EX(JF))
1       CONTINUE
        CFF=0
        SFF=0
C   UNDERGROUND TRANSPORT SYSTEM, TIMEBASE 0.5 MINUTES
        DO 4 I=1,2
        CA=FLOWC(1)/2
        SA=FLOWS(1)/2
        CB=FLOWC(2)/2
        SBO=FLOWS(2)/2
        CALL CONVEY(CA,SA,CA1,SA1,SC(1),AC(1),CONC(1),CONS(1),ID(1),CC(1))
        CALL CONVEY(CA1,SA1,CA2,SA2,SC(2),AC(2),CONC(21),CONS(21),
     1ID(2),CC(2))
C   SURGE BUNKER
        CALL BUNK(CA2,SA2,CAB,SAB,SB(1),CLU,SLU,FRATE,300.0,1)
        CALL CONVEY(CAB,SAB,CA3,SA3,SC(3),AC(3),CONC(41),CONS(41),
     1ID(3),CC(3))
        CALL CONVEY(CB,SBO,CB4,SB4,SC(4),AC(4),CONC(61),CONS(61),
     1ID(4),CC(4))
        CF=CA3+CB4
        SF=SA3+SB4
        CALL CONVEY(CF,SF,CF5,SF5,SC(5),AC(5),CONC(81),CONS(81),
     1ID(5),CC(5))
C   SHAFT BOTTOM
        CFF=CFF+CF5
4       SFF=SFF+SF5
        CALL COALWIND2(CFF,SFF,Q,CO,SO)
        FLOWO=CO+SO
C   PITHEAD STOCKPILE
        CALL BUNK(CO,SO,COUT,SOUT,SB(2),CL,SL,CLOUT,2000.0,2)
        BLEVEL = CL+SL
        WRITE(2,106) K,(X(I),FLOWC(I),FLOWS(I),FI(I),I=1,2),
     1Q,FLOWO,CL,SL,COUT,SOUT
9       CONTINUE
        CALL STAT(KC)
10      CONTINUE
```

Logging Statements

```
      WRITE(2,107)
101   FORMAT(////2X,19HCOALFLOW SIMULATION)
102   FORMAT(//2X,'DEMANDED OUTPUT IS ',F4.1,' TONNES PER MINUTE'//
     12X,'CONVEYOR PARAMETERS ARE ',5(/4X,'C',I1,4X,'DELAY TIME IS ',
     2F5.1,' MINUTES',4X,'CAPACITY IS ',F5.1,' TONNES PER HOUR'))
103   FORMAT(//2X,'SURGE BUNKER CAPACITY IS ',F5.1,' TONNES'/2X,
     1'INITIAL BUNKER LEVEL IS ',F5.1,//2X,
     2'INITIAL LEVEL OF SURFACE STOCKPILE IS ',F7.1)
104   FORMAT(////2X,12HSTART OF RUN//2X,
     450HPRODUCTION FIGURES (TONS) AT INTERVALS OF 1 MINUTE//)
106   FORMAT(2X,I3,4X,2(1X,F5.1,4X,F4.1,2X,2(F4.1,3X)),
     1F5.1,2X,F4.1,2X,2(2X,F6.1,2X,F4.1))
107   FORMAT(//2X,10HEND OF RUN)
108   FORMAT(2X,4HTIME,4X,10HFIRST FACE,20X,11HSECOND FACE,19X,
     16HWINDER,9X,17HBUNKER AT SURFACE/10X,2(8HPOSITION,2X,4HCOAL,2X,
     25HSTONE,2X,4HHEAT,3X),5HQUEUE,2X,4HLOAD,4X,6HSTOCKS,10X,
     38HOUTFLOWS/85X,4HCOAL,4X,5HSTONE,3X,4HCOAL,2X,5HSTONE)
110   FORMAT(80X,3(F5.1,4X)/)
      STOP
      END
```

```
LENGTH    717, NAME   COALSIM2
```

Zeroing Face Registers

```
      BLOCK DATA
      DIMENSION ACV(5),FLOC(10,5),FLOS(10,5)
      DIMENSION IIA(5),IIB(5),IIC(5),IID(5),AIA(5),AIB(5),AIC(5),AID(5)
      COMMON/ISTAT/IIA,IIB,IIC,IID,AIA,AIB,AIC,AID
      COMMON/FIERCE/FLOC,FLOS,ACV
      DATA IIA,IIB,IIC,IID/20*0/,AIA,AIB,AIC,AID/20*0/,
     1FLOC,FLOS/100*0/,ACV/5*0/
      END
```