THE DESIGN OF COLLIERY INFORMATION AND CONTROL SYSTEMS

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ABSTRACT

The paper is concerned with describing an investigation of information usage in the control of colliery operations. The premise of the work is that to make the most of new information retrieval technology currently being installed in collieries research is needed to provide compatible advances in methods of information usage. The approach adopted was to construct a continuous simulation model using system dynamics capable of providing a laboratory assessment of alternative managerial control policies based on alternative sources and levels of aggregation of information.

The model developed represents a typical colliery situation composed of three working coalfaces and incorporating planning production, development and manpower sectors. The face sectors transform coal reserves to mined coal output, under manpower constraints and geological shocks, and these are all interlinked by means of allocation policies for manpower and shifts.

A range of policies for the exercise of control through these allocations are considered subject to a range of shocks. It is concluded that, although there are difficulties in designing single policies which are universally best, there are clear advantages associated with fully integrated colliery policies based on information inputs from all aspects of the operations.

1. INTRODUCTION

During the mid 1970's, as a consequence of the rise in the price of oil, demand for coal rose and the coal mining industry in the U.K. was revitalised after a long period of decline (1) (2) (3). As a consequence of this a new strategy to increase coal

output was developed. This involved the exploitation of new reserves by large new collieries such as at Selby, major extensions to existing collieries with significant existing reserves, and the increased use of modern technology, both for better and more efficient mining equipment (Advanced Technology), and for improved information retrieval (the computer based system MINOS (4)). This paper concerns research into a need generated by the latter but with the practical potential to have a significant impact on all aspects of the revitalisation.

With the advent of mini and, in the late 1970's, micro computers, the technological advances in the speed of operation and capacity of information retrieval methods has been unprecedented. The true purpose of collecting information is, of course, to enhance the quality of managerial decision making and through this to improve performance. Hence the potential of new information retrieval technology will not be fully attained until comparable advances are made concerning information usage. There is clearly a need therefore to develop methods which are capable of assessing the effects on performance of alternative information inputs to managerial policy making and of alternative policy formulations. The work described in this paper is therefore concerned with methods for designing managerial control. In fact it can be argued then that until usage of information has been examined in such ways it is not possible to make rational decisions concerning information retrieval.

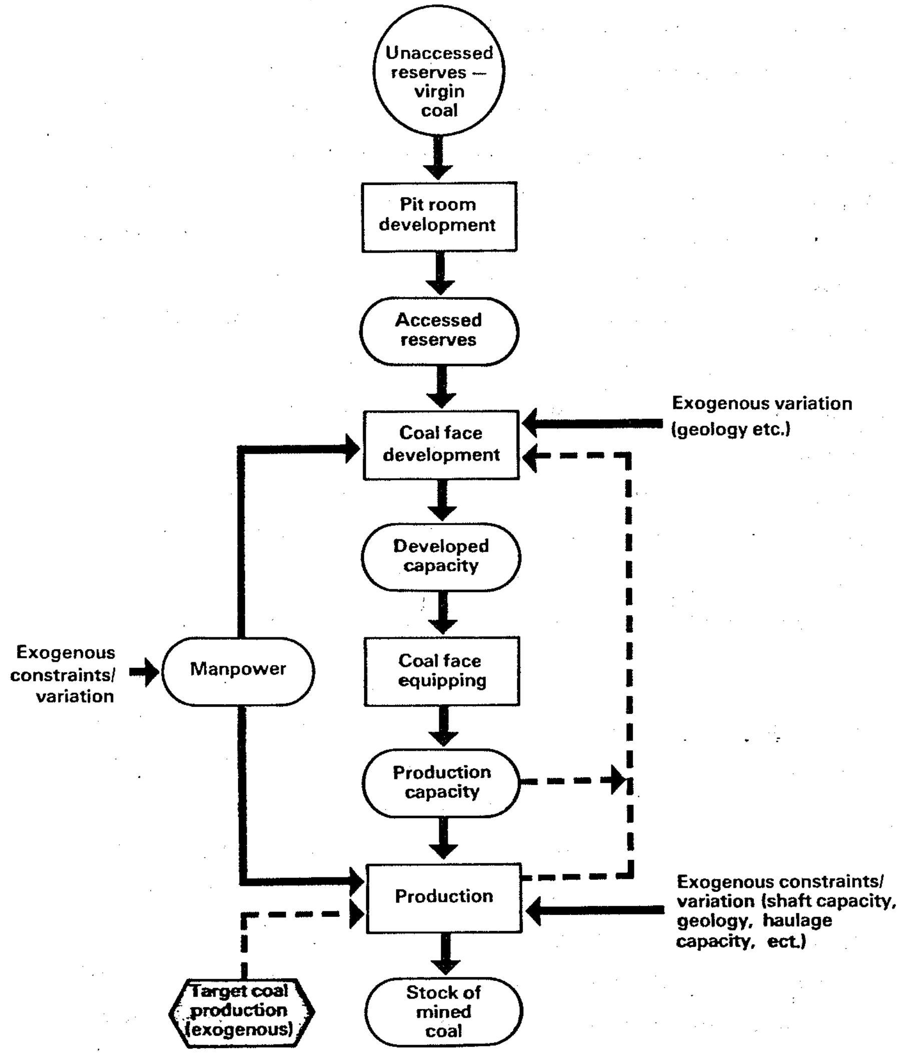
The methodology used in this research to develop a framework for the design of control in collieries was System Dynamics. This was chosen because it implicitly provided a basis for representing a colliery as a complex information feedback system capable of facilitating a simulation analysis of alternative operating policies, and their robustness under a wide set of exogenous effects such as geological risk and manpower availability.

The representation of a colliery as a feedback system will first be outlined and subsequently experiments with and results from the application of the ensueing model will be presented. The model to be described can be considered as a trial development to ascertain the feasibility of the approach for the purpose defined. It represents a typical colliery situation where the three coalfaces and their associated replacement developments are operated with the object of attaining a target output given geological and manpower availability fluctuations.

2. THE COLLIERY AS A SYSTEM

In the most general sense a colliery can be described as a system for converting coal reserves buried underground to mined coal on the surface (which may be used for electricity generation; industrial; and domestic use). This being said, the boundaries of the system are easy to identify and relate to the physical characteristics of the colliery as a unit.

Thus the simplest model of a colliery as a coal conversion system is shown in fig. 1. This identifies the main states in



COLLIERY PRODUCTION PROCESS

FIGURE 1.

which coal exists and the processes which transfer the coal between the states (such as 'coal face development'). The representation of a colliery in this way is the first stage in the development of a system dynamics model. It defines the physical stocks of coal which can be considered as levels or state variables which are an integral part of this modelling philosophy. The diagram also identifies major shocks to the system from exogenous factors and captures the main planning and control elements.

Fig. 1, although playing a key role in outlining the main characteristics present in the colliery system is too abstract to help in the detailed delineation of the system dynamics model, which, if it is to be at all valid must be an adequate representation of the real physical system. Indeed, the detailed physical structure of the system is an important determinant of the model structure as will be seen. Thus it is necessary to examine the colliery in more detail to ascertain how it operates.

The central aspect of colliery operations is the development and use of production capacity, and this is illustrated in fig. 2.

The accessing of reserves is carried out initially by driving the major roadways and these open up large areas of the coal seam being worked. This is referred to as pit room development and as it is frequently carried out by outside contractors it is considered external to the model and only the more detailed face room development works as shown in fig. 2, is considered. This consists of driving two parallel face access roadways for

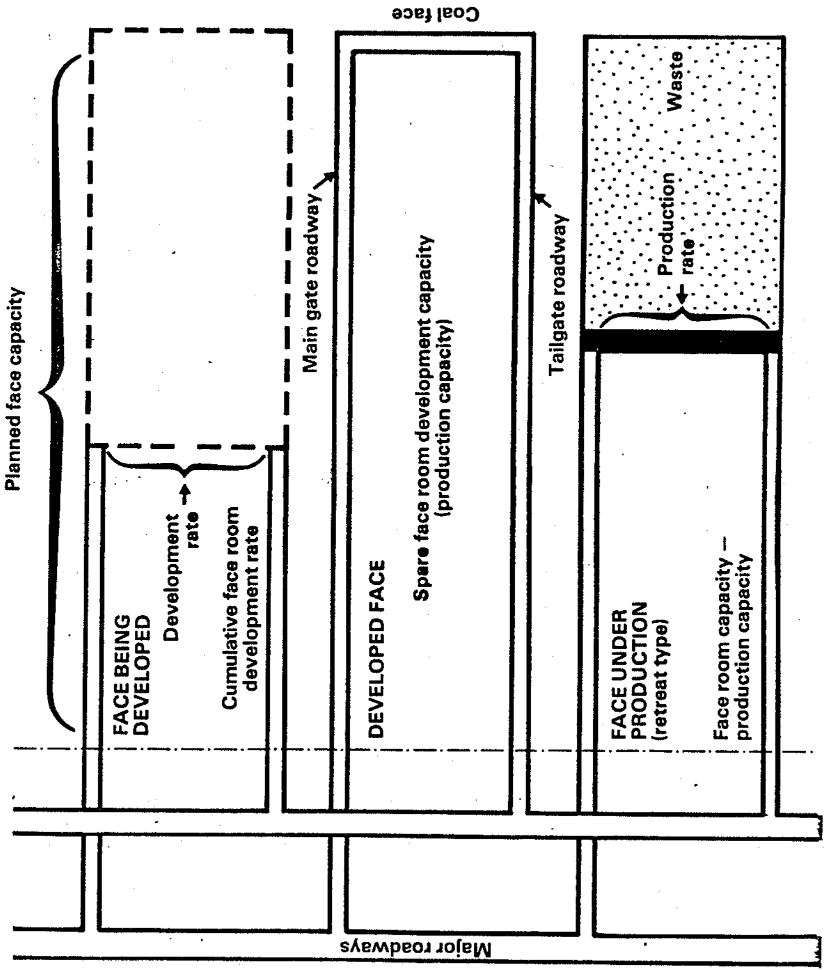


FIGURE 2. COLLIERY PRODUCTION PROCESS *(plan view)*

each coalface and the face line which links them at their extremities, to create an area of coal to be extracted known as the planned face capacity. Such a coalface in mid development is shown at the top of fig. 2.

There are a variety of ways in which this face room development subsystem could be modelled. For the purposes here attention will be restricted to the most commonly used form of development where each operating face has a designated replacement face associated with it; the development of which is started when the stocks on the production face fall to a pre-determined level. Before a developed face can produce coal it must be equipped with the necessary coal extraction machinery and the final act of development is to install this equipment. This creates a fully developed face as shown in the centre of fig. 2.

Once a coalface has been developed production can take place. Production consists of cutting slices of coal from the face and the whole face line moves forward with the roof being allowed to collapse behind it. In fig. 2 this is shown in the bottom coalface with the production face line moving back towards the main roadway. This is technically known as retreat working on a longwall face (5).

It is obvious from figs. 1 and 2 that developed capacity is generated by a development rate, and that this developed capacity is converted to production capacity once the whole face has been developed. The production capacity is then depleted

by the production rate and the cycle repeated. These two rates are, to a certain extent, dependent on the number of men assigned to these functions and this allocation of men must be the major agency for the control of these rates. These rates are influenced by external factors such as changing geology.

In real life a colliery system is complicated by the fact that a number of coal faces may exist at any one time, of both development and production types. The rates of production and development on these faces must be co-ordinated, and this may impose conflicting demands on the available resources (primarily men).

The need to control face development and production implies a plan. That is a desired state of affairs at any point in time, divergence from which will instigate corrective control actions. This is expressed in the colliery situation by the Action Plan which specifies the required present and future state of the colliery in detail up to a period of 18 months in the future. The Action Plan provides that the collieries' operations are integrated within the Area and that long term business objectives are met. The Plan, which is updated theoretically every 3 months, sets targets against which actual performance can be measured for operational control.

Colliery management is held accountable for meeting production targets on an annual basis (with quarterly checks), based on a yearly budget setting procedure. Obviously the overall state of the colliery is considered together with the financial performance, but primary index of performance is the tonnage of coal produced.

Clearly from the above description of basic colliery operations, a colliery can be conceived of as a dynamic feedback system as defined by Coyle (6). There is obvious dynamic behaviour in terms of production and development rates. Although these are subject to some uncontrollable elements they are largely controllable via manpower development policies. Their control is in fact a key element in colliery management. Control is in principle applied by the definition of target states for cumulative production and development. Information is fed back from the system states for the exercise of this control and due to the complexity of the system in terms of multiple production and development faces which will generate conflicting priorities, there may be a variety of control policies which can be investigated to improve overall performance.

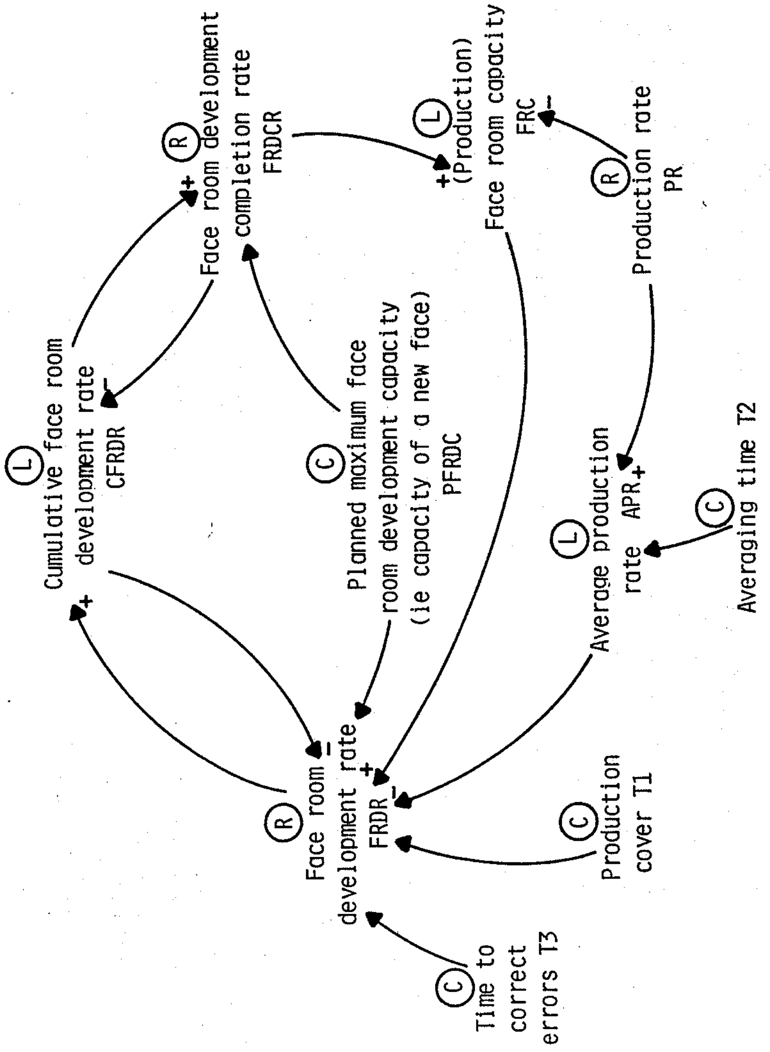
3. A SYSTEM DYNAMICS COLLIERY MODEL

3.1 Model Structure

The first part of the system dynamics modelling process is to conceptualise the system under investigation in terms of level and rate variables, and to express these in diagramatic form to illustrate their interconnectiveness. Such an Influence Diagram is shown in fig. 3. This illustrates the simplest possible feedback interpretation of the colliery system described in the previous

FIGURE 3.

Initial Colliery Planning and Control Model (Version I)



section of the paper. The development rate is accumulated into the development capacity, which when equivalent to a complete face is instantaneously transferred to face room (production) capacity, which is then depleted by the production rate. In this situation the production rate drives the system with the development rate being dependent on the production rate and current state of the achieved development capacity.

In order to account for the complexity of the real world colliery system this basic structure was extended through a number of iterative steps. This evolutionary approach in which each added factor was tested and validated resulted in a validated final model of a hypothetical yet typical colliery.

The use of a hypothetical as opposed to actual colliery situation was chosen so that the results obtained would have sufficient generality to be widely applicable. A specific situation may have such characteristics as to make it unique and so invalidate any generality as to the conclusions drawn from it.

The general structure of the model created is shown in fig. 4 which clearly illustrates the separate sectors. There are three coal face sectors as this situation is not uncommon in reality and gives sufficient complexity to illustrate the merits of different control policies.

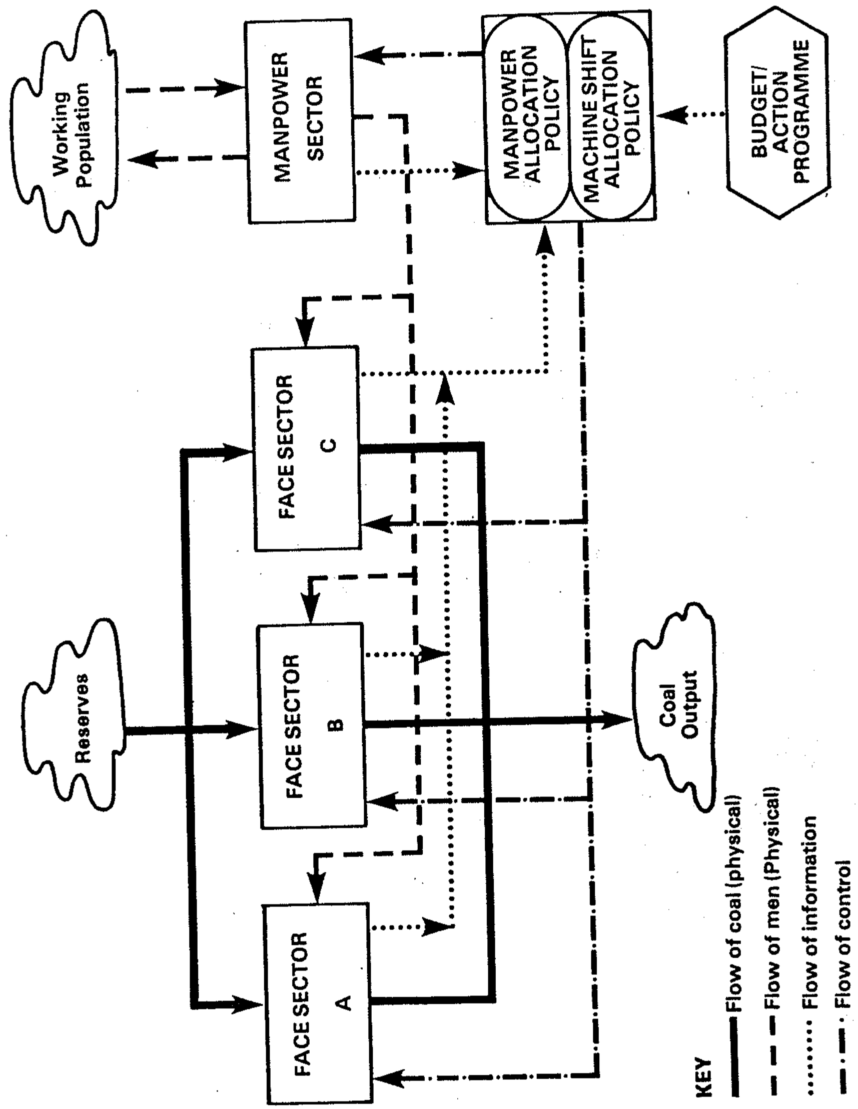


FIGURE 4. COLLIERY SECTORS AND THEIR RELATIONSHIPS

These face sectors translate accessed coal reserves into coal output.

The operation of these face sectors is dependent on the manpower available, the manpower being generated within its own subsector. The allocation of the manpower in terms of men to machine shifts and machine shifts to faces is carried out subject to the policies adopted by the colliery management in order to meet the specified plan. These policies are defined in a further policy sector.

An individual coal face sector is illustrated in fig. 5. This shows the physical flows of coal and men through the actual development and actual production subsectors associated with the coalface and identifies the major variables. The schematic in fig. 5 also shows that two planning subsectors are associated with each coalface. These planning subsectors essentially mirror the 'actual' subsectors and generate the two variables 'planned development capacity' and 'cumulative planned production rate' against which the actual performance is compared. Discrepancies are thus generated which are used as controlling variables in the managerial control policies. Information feedback on these discrepancies occurs with the discrepancies being fed back from each coalface sector to the management control policy sector.

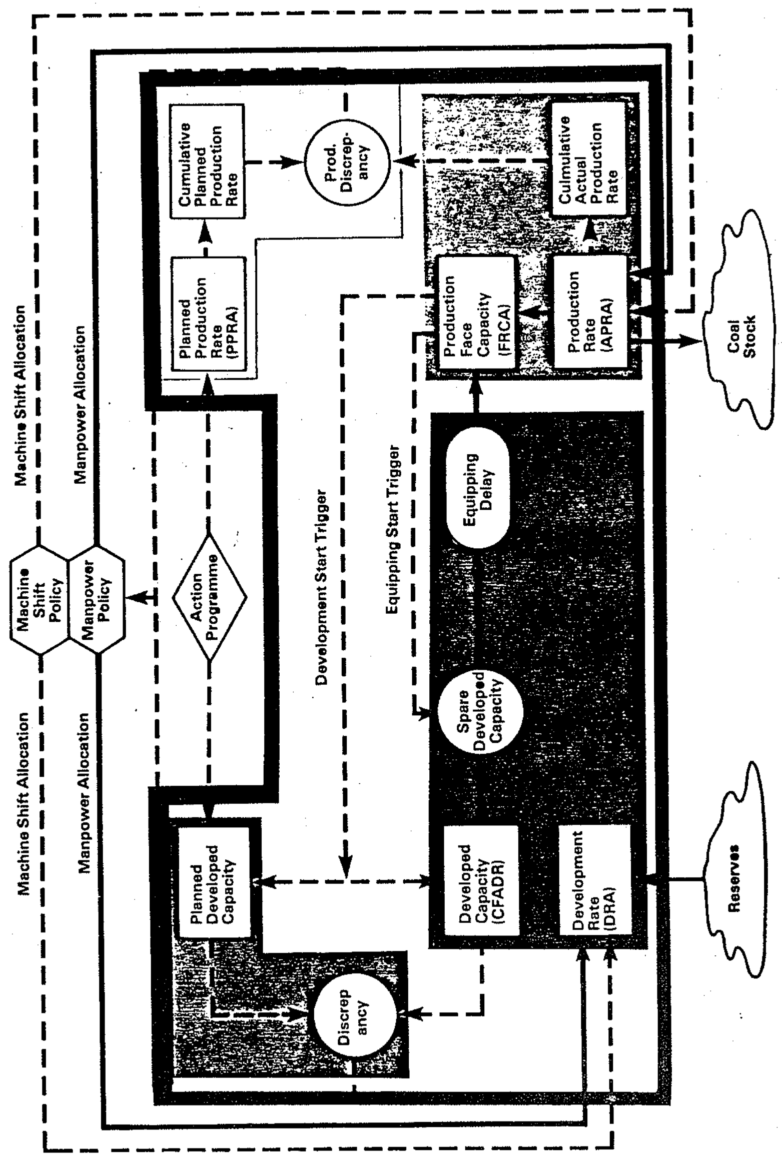


FIGURE 5. A TYPICAL FACE SECTOR.

This very briefly describes the major aspects of the model. The three face sectors are simply replications of the basic face submodel with parameter changes to represent the individuality of each face.

3.2 Managerial Control Policies

It is obvious from the foregoing that the core of the model is the managerial control policy sector. The basic information links into this sector from the face sectors have been described in the previous section, however dependent on the sophistication of the policy to be implemented further information may be required.

In general terms control can be considered in a number of dimensions. Firstly the key variables by which control is implemented must be defined; secondly the frequency of application of the control must be specified; and thirdly the type of control (that is which information is to be used and how) must also be defined.

The key control variables are the number of machine shifts to allocate to each face on each day (0, 1, 2 or 3), and the manpower to allocate to each machine shift.

The frequency of application of control depends very much in colliery management on the level of management at which the control action originates. A colliery manager may take action himself at any time (i.e. carry out continuous control), but is ultimately accountable

and held in check by the planning/budgeting system. Hence higher levels of management in conjunction with the planning department may influence or impose changes on the colliery at discrete points in time (review point control). The control policies which have been tested using the model fall into two general types: the first category concerns what we shall refer to as semi-integrated (SI) policies, which are based on only a subset of the total information available from the total state of the colliery and which are current feasible and commonly applied. The second category concerns what we shall refer to as fully-integrated (FI) policies which should be feasible to apply given the information retrieval methods becoming available. The fully integrated manpower allocation policies are based on the work of Wolstenholme (7) who has developed and applied similar algorithms to the management problems of controlling bunker discharge rates in conveyor belt systems. This is not to imply that these algorithmic policies are programmable in the sense of automating managerial decision making. They can, however, form a logical basis for such decision making and obviously the manager must also take into account a whole variety of other factors when making such an allocation decision.

Fig.6 illustrates the control policies tested and it will be noted that consideration of review point control will be restricted, as in practice to overall guidance on machine shift allocations and only through semi-integrated control methods. Each policy will be briefly described below:

a) Manpower Allocation Policies

In an ideal situation there will always be sufficient men available to give full manning on all shifs on all

FIGURE 6.

CONTROL POLICY DELINEATION

Key variable used for policy implement-ation	Review point control	Continuous Control	
Machine shifts (per face per day)	Semi-integrated	Semi-integrated	Fully-integrated
Manpower per machine shift		Semi-integrated	Fully-integrated

faces at all times. However, when there are insufficient men they must be deployed on some sort of rational basis. Manpower deployment is a common problem (see for example Teal (8) and can only be done when the men actually turn up for work (approximately continuously).

The continuous semi-integrated policy defined in Fig. 6 assumes that no information is available or required on the state of the coal faces as men are allocated to production in preference to development. This is done such that development at least continues with minimum manning if possible and in the extreme case of the faces not being capable of minimal manning then a development shift is dropped.

In contrast the fully integrated policy uses the face discrepancy as the basis for manpower allocation, and compares discrepancies between faces such that the face which is furthest behind receives most men (whether it be a production or a development face).

b) Machine Shift Allocation Policies

In the foregoing policies for allocation of men to machine shifts it was assumed that the allocation of machine shifts was fixed. In reality, shift patterns are maintained for as long as possible as changes can cause a great deal of disruption (not least in industrial relations). However, if necessary, machine shift allocations can change and these policies delineate several rational bases for such changes.

Changes at discrete points in time will be considered first. This is analogous to the situation where the machine shift pattern is reviewed when the Action Programme is updated. This occurs every three months and on the basis of the actual status of the system at this review point the planned allocation pattern for machine shifts may be revised. It is assumed that the manager will then work to this pattern in the actual allocation of machine shifts.

The basis for changing the planned machine shifts is defined here to be on the basis of discrepancies. The production faces are considered in isolation and if they are behind schedule to such an extent that they are 'critical' then their shift allocation is increased. This increase may be catered for in two ways: simply by absorbing a built in productive capacity (i.e. spare men); or by sacrificing a development shift for each extra production shift allocated. The first of these recognises that spare capacity may be built in to cater for anticipated future geological effects. The second is where an unanticipated exogenous shock may occur.

Given that the planned number of shifts may be set at a review point the manager may wish to change the actual allocation between these points to cater for unpredictable changes in the situation and this

is the basis for continuous control.

In continuous control a semi-integrated policy such as was described for review point control may be applied. However, it is also possible to consider the application of a policy which takes into account the situation on all faces in determining the changes to be applied on one face (that is the status of both production and development faces). In essence when a discrepancy on <u>any</u> face becomes critical the shifts allocated are increased and this increase is compensated by a reduction in other allocations proportional to the shifts previously allocated. This allocative algorithm also has the capability of allocating 'spare' shifts (that is shift capacity released when a development is completed, for example). This means that any 'spare' men are fully utilised.

The basis on which the consequent shift changes are made here is relatively simplistic being simply in proportion to the prior allocation, however the principle could be extended to other bases such as the magnitude of the discrepancy between planned and actual performance (relative to the total discrepancy across the colliery).

The above range of policies demonstrates the ability of the model to cater for the evaluation of widely differing managerial control policies.

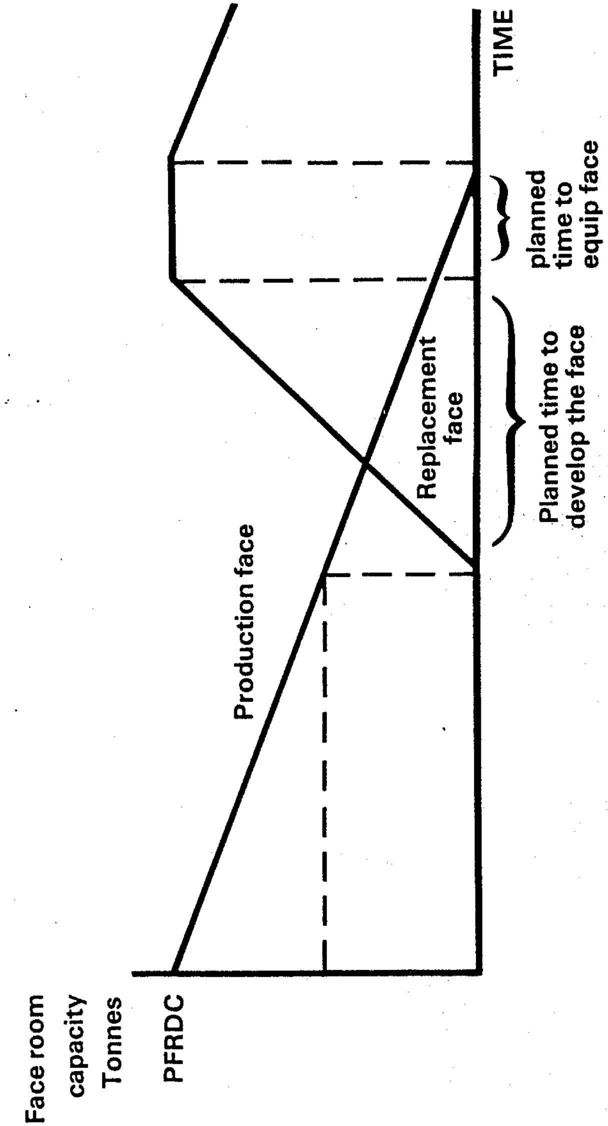
4. CONTROL POLICY EXPERIMENTS AND RESULTS

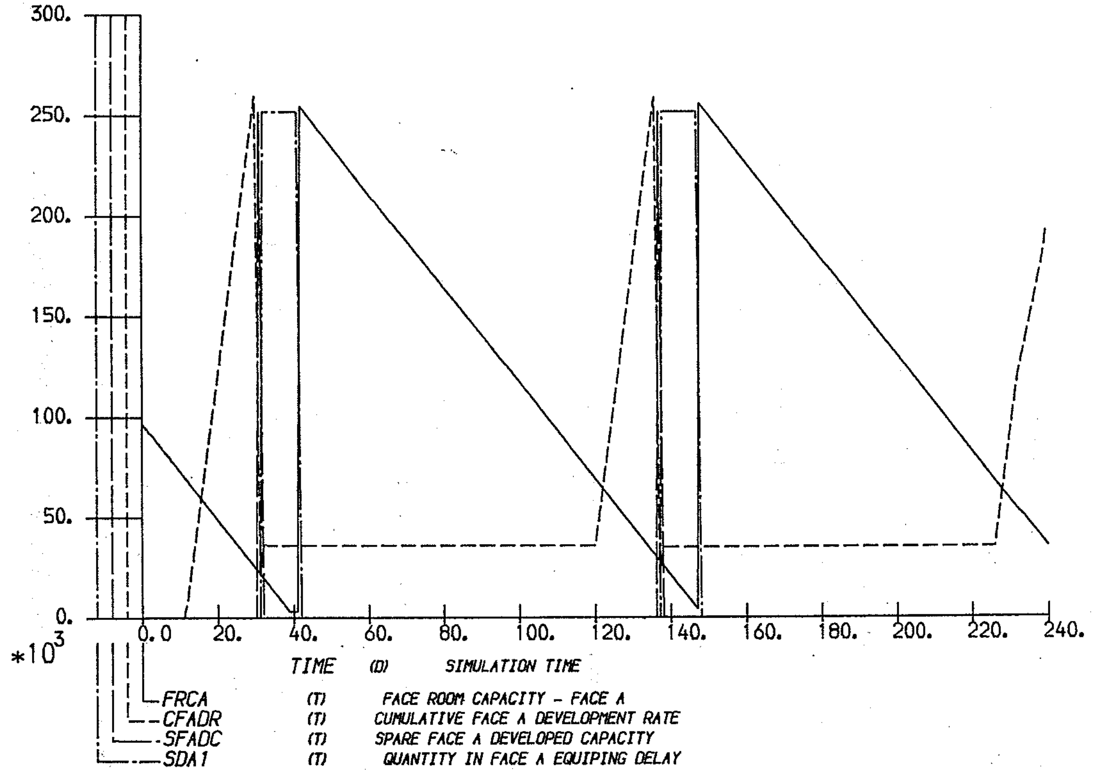
In order to test the effectiveness of managerial control policies of the type described in the previous section a series of experiments was designed and carried out. The experiments catered for varying situations which tested policy robustness by imposing several exogenous shocks. These shocks represented firstly a deteriorating geological situation causing a reduction in face output, and secondly a deteriorating manpower availability. The shocks were replicated in each series of tests and each policy so as to obtain comparability of results.

The results fell into two types: qualitative graphical output; and quantitative output using a variety of performance indices. The simulation model being written using the DYSMAP (9) language.

The qualitative displays illustrate face capacity fluctuations and manpower resource utilisation. The reference mode for face behaviour is illustrated in Fig. 7, and Fig. 8 illustrates this equilibrium behaviour generated by the model. By simplifying the number of variables displayed and combining the faces, the positions of the face states relative to each other may be displayed as shown in Fig. 9. Aggregated variables of interest may also be displayed as shown in Fig. 10 which displays overall production discrepancies, and manpower availability and allocation.

FIGURE 7. **DYNAMIC REPRESENTATION OF FACE PERFORMANCE**





EXPT-2B. 1. 1

FILE CPC9E2B

FIGURE 8. MODEL GENERATED FACE DYNAMICS

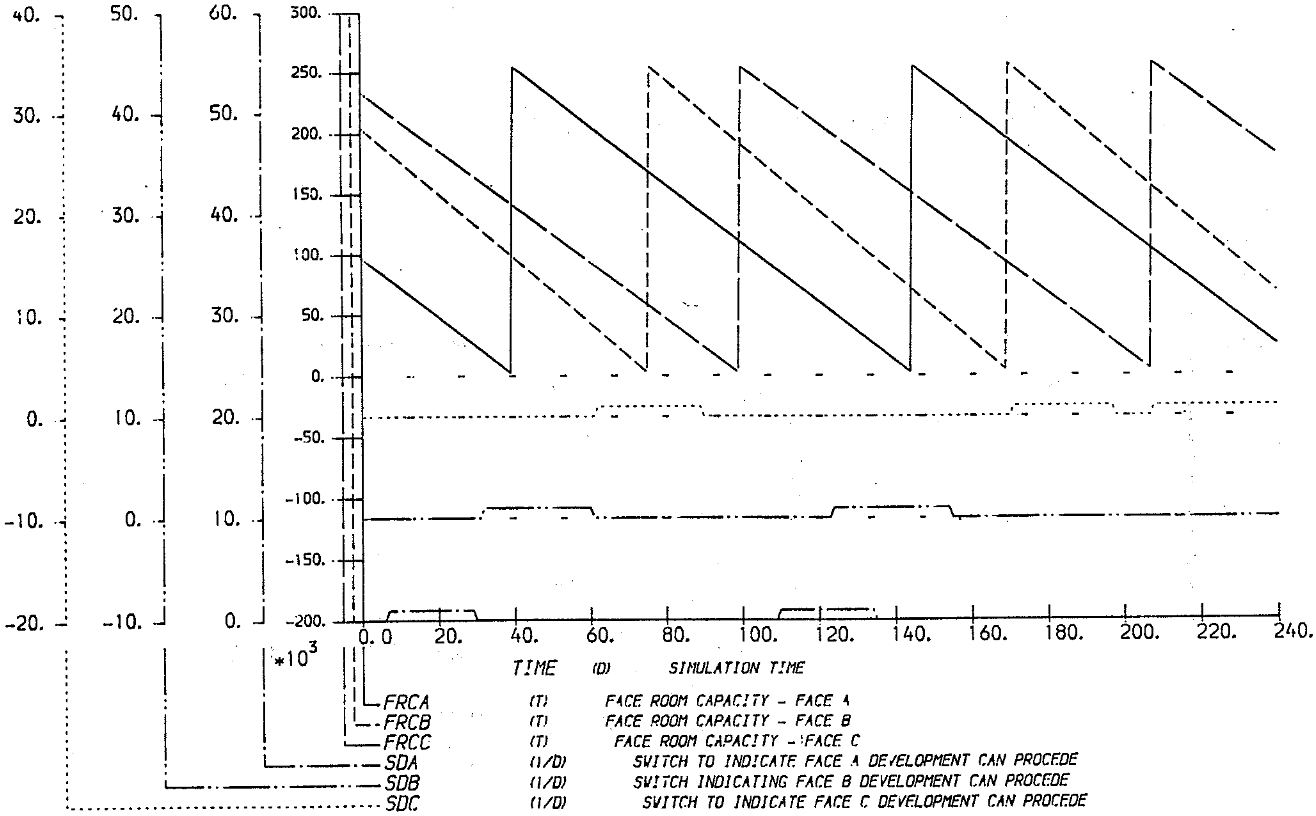


FIGURE 9.

COAL FACE STATES

RUN NO. 1. 1. 1. 1, NO SHOCK

MANPOWER POLICY EXPTS. - SUBSET 1 (A)

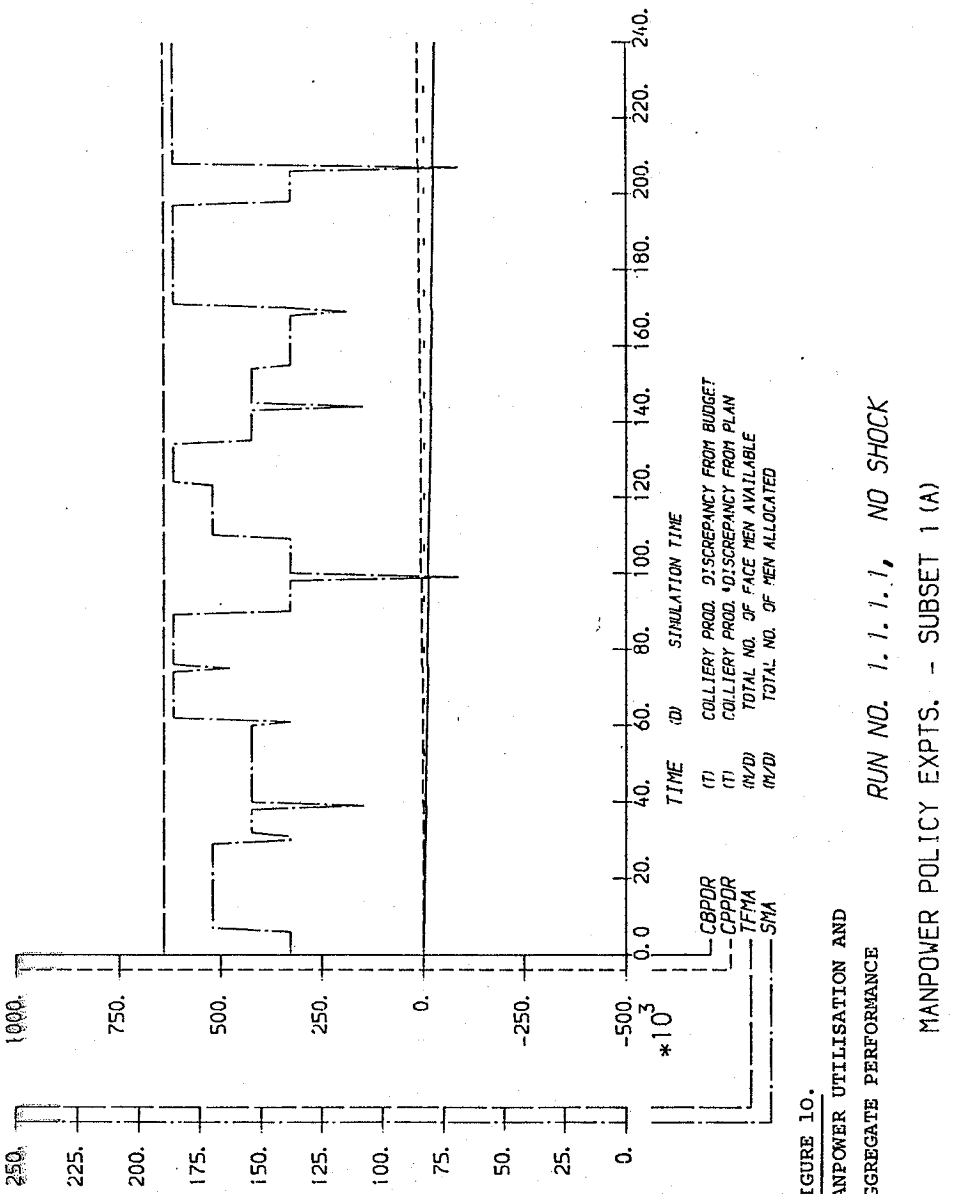


FIGURE 10.
MANPOWER UTILISATION AND AGGREGATE PERFORMANCE

With regard to quantitative output this must of course be indicative of the performance of the system as represented by the model. To this end a number of performance indices were defined to represent various aspects of colliery operations such as cumulative production, developed faces awaiting production starts (spare capacity), downtime due to late completion of a development, and downtime due to insufficient men to run a face.

A set of four experimental runs were then designed in terms of the magnitude of geological and manpower shocks to the system and the previously defined managerial control policies tested against these.

It is not proposed to present the results in detail as they are available elsewhere (10) but Figs. 11 and 12 give an indication of the dynamics of continuous machine shift and manpower allocation policies under the geological shock compared with the base case of no feedback control.

In a manpower shortage situation, the continuous allocation of manpower is an ideal mechanism by which relatively small discrepancies between the actual and desired states of coalfaces may be corrected. Given this need for an allocative mechanism the policy which most effectively achieves this objective is of the fully integrated type taking account of information from all production and development face states.

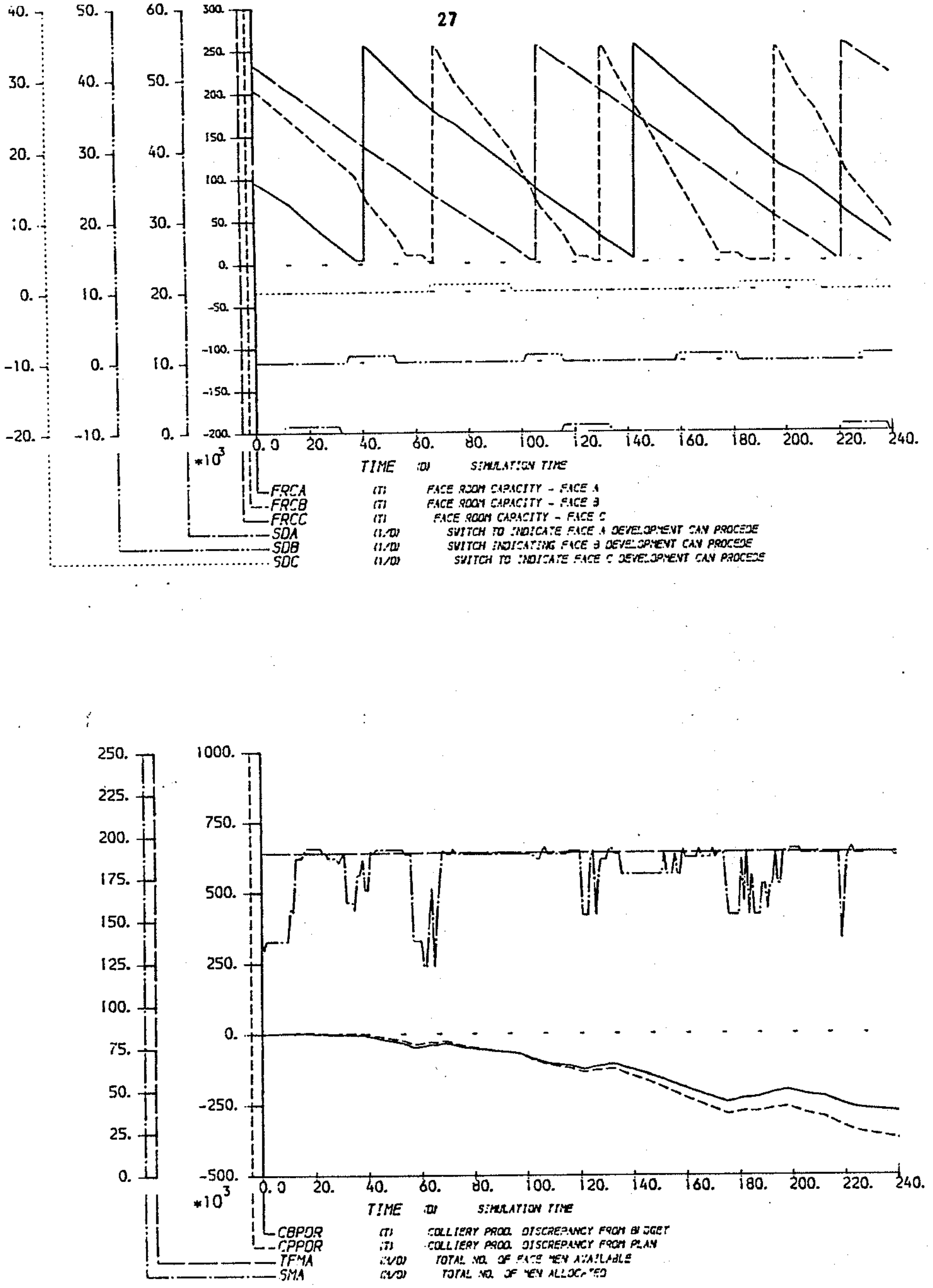


FIGURE 11. RUN 38. 2. 1, GEOLOGY SHOCK

MACHINE SHIFT POLICY EXPTS. SUBSET 3 [illegible]

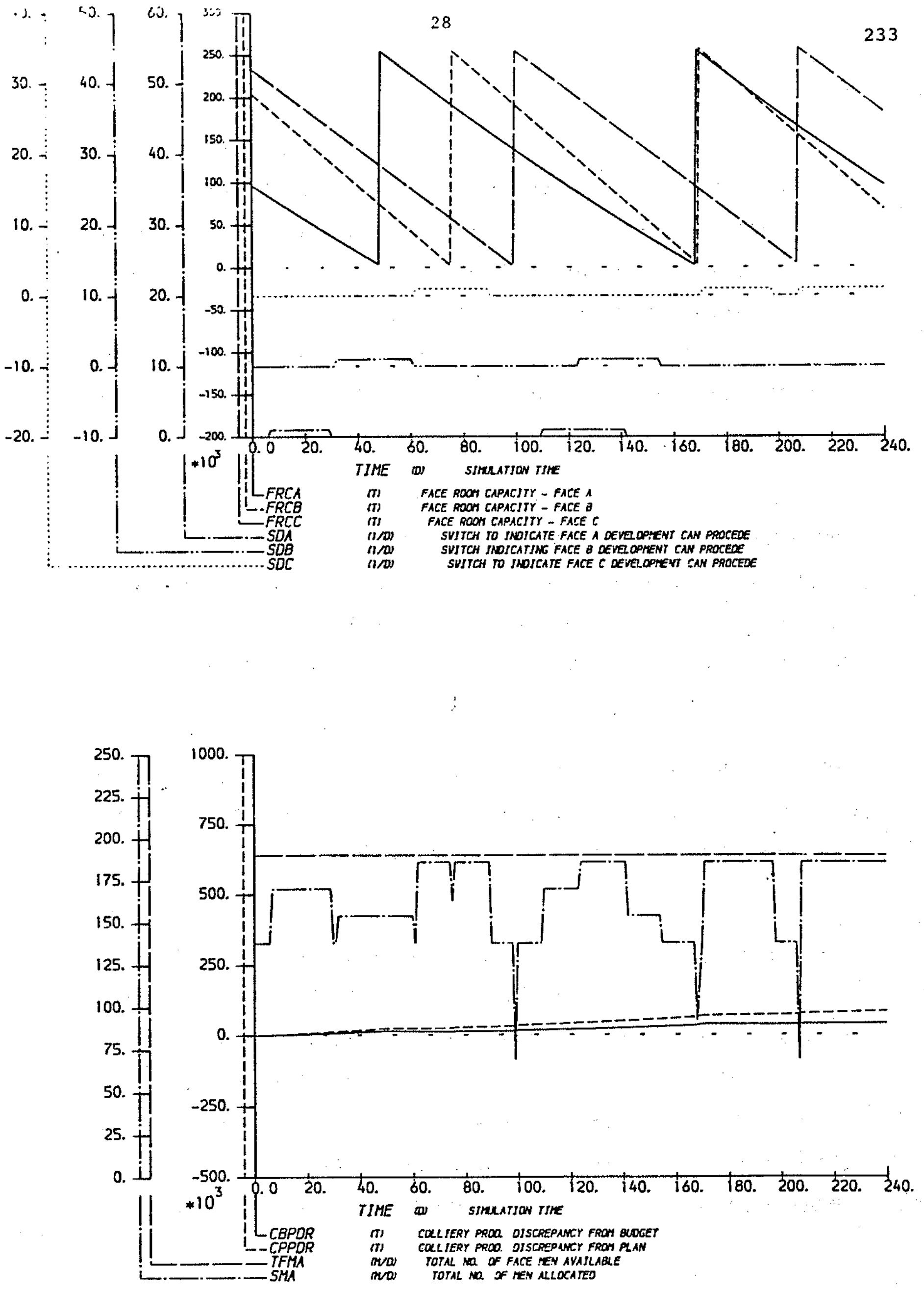


FIGURE 12. RUN NO. 1. 2. 1. 1, GEOLOGY SHOCK

MANPOWER POLICY EXPTS. - SUBSET 1 (A)

The experiments also emphasised the need for a structural link between development and production so as to synchronise the development and production phases on a face. The link tested was relatively crude in so far as the production face state only triggered the development start. The planned development rate through which this control trigger was exercised depended in part on the historical production performance only. The production face state after the trigger point was not fed back to aid development control and thus major changes in the production rate could not be recognised and compensated for in the development, causing on occasion time delays between exhaustion and replacement of the production face. This was of greater importance when continuous machine shift control was exercised. It is not unreasonable to conclude that the continuous feedback of information on production face states so as to redefine continuously the planned development rate would improve this situation, particularly where integrated control over men and machine shift allocation is exercised.

The imposition of periodic review point control whilst necessary as an accountability measure can be seen as causing a certain amount of disruption if the extra manpower requirements are not catered for in the initial design of the number of faces and shifts to be worked. However, even with this greater sensitivity to manpower review point control can ensure slightly better performance if it is carried out by temporarily borrowing development shifts for production purposes.

When continuous reallocation of machine shifts is considered this can pre-empt review point control making it unnecessary. However, considering the continuous machine shift allocation policies it is apparent that integrative policies are superior by providing for the better utilisation of the available men and greatly increasing the total colliery production. The policy does suffer from the drawback of greater sensitivity to manpower availability and the problem of phasing developments into production faces. This latter drawback can be overcome by the provision of an improved production development link as mentioned previously. The results from the machine shift allocation experiments also raise the possibility of using different policies under different types of exogenous shocks and constraints. For example, given a restricted manpower establishment it may prove more beneficial to use the continuous machine shift allocation policies under geological shock conditions and either review point control or no machine shift allocation policies at all under certain unstable manpower conditions.

5. CONCLUSIONS

The research described in this paper has conclusively demonstrated a number of valuable points. The most basic of these, and which now may be seen to be self evident, is that a colliery can be described as a dynamic system within which feedback control is exercised. Having demonstrated this fact through a description of a typical buthypothetical colliery using the system dynamics methodology, the simulation model produced as a result of this description has proved to have the capability of elucidating and testing managerial control policies.

The validated model was used to evaluate a variety of managerial control policies, these policies operating through a resource allocation mechanism of machine shifts and men to these shifts. The control policies included simplistic, though realistic, policies which treated the faces on an individual basis, and integrated policies which considered the interactions between faces.

The identification of 'good' or 'better' policies through this analysis naturally has implications in terms of the feedback of information. The policies require certain types of information at defined times (for example face states expressed in capacity (tonnage) terms). Although this is by no means the only operational information required by colliery management it does define a minimum needed and is based on a rational analysis. Ad hoc or potentially all embracing information retrieval systems may include it, but the analysis previously described not only defines what information is required, but also how it is to be used.

The model developed may be extended and used in a variety of ways. It may be used for further control policy analysis in a theoretical context or, equally importantly, the principles embodied in the model construction can be used to generate

simulation models of actual collieries for use as managerial decision aids. It is additionally felt that the concept of establishing actual and desired states for each coalface essentially formalises a subconscious principle employed by good managers. The exploration of this concept through the medium of a feedback model could contribute significantly to management training by establishing the merits of the principle in all managers and providing a basis for assessing alternative ways by which discrepancies can be corrected.

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