# The development and application of a Computer System to aid in the planning of production in mines

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SYNOPSIS

A computer system to aid in the planning of production in mines and its application to a complex colliery are described. The system consists of three phases, the data base maintenance program, the 'production simulator' and the report generation facility. In the first part of the paper the categories of information kept on the data base and the functions of the simulator are described in general terms. The application of the system to a multi-product colliery operating a variety of mining methods in a number of superimposed seams is described in the second part. In conclusion some comments are made on further applications and intended future developments.

SINOPSIS

'n Beskrywing van die komper sisteem soos aangemeend vir 'n gekompliseerde steenkoolmyn word uiteengesit. Die sisteem bestaan uit drie fases nl., die data basis instandhoudings program, die ,produksie nabootser' en die rapport ontwikkelings fasiliteite. In die eerste gedeelte van die verhandeling word die inligtingskategorië wat op die data basis gehou word asook die funksies van die nabootser in algemene terme beskrywe. Die aanwending van die sisteem tot 'n veelvoudige-produk steenkoolmyn wat verskeie mynmetodes in 'n aantal ooreenliggende steenkool riwwe toepas, word in die tweede gedeelte beskrywe. Ten slotte word sekere gevolgtrekkinge en opmerkings gemaak wat betrekking het op verdere aanpassings en toekomstige ontwikkelings.

## 1. INTRODUCTION

The Collieries Research Laboratory of the Chamber of Mines is developing a coherent system of programs to aid in the full spectrum of activities arising in the planning of new as well as of operating mining enterprises. It is the purpose of this paper to introduce one of the subsystems available at the present time. This program has been termed 'production simulator'. Its development was originally stimulated by a request from the Federale Mynbou/General Mining group to help in the planning of production in one of their more complicated coal mines.

For some time the possibility of setting up an optimisation model was considered. However, it was eventually decided that at the present time such an approach would have severely limited application and appeal, in view of both the size of problem and the types of parameter that can be handled at realistic cost. Instead, the philosophy was adopted of trying to combine the capabilities of the human planner — his insight and experience — and of the machine — its speed in executing repetitive simple decisions and computation — to best advantage.

This concept quite naturally leads to the construction of a *model of the mine* containing background information in the form of relevant geological, technological and financial data on the one hand, and a *production plan* specified in the simplest possible terms on the other. The latter directs the machine to draw on the model and to *simulate* the plan in all aspects. The planner now has a tool for accurate and speedy investigation of those alternatives which his experience tells him are worthwhile.

A general description of the system is given in Section 2 of the paper. In Section 3 the categories of information required to make up a model are discussed. The functioning of the simulator and associated report generator are treated in some detail in Sections 4 and 5, respectively. The application of the system to the Hlobane Colliery is covered in Sections 6 through 9. This example was chosen to illustrate most of the features in the production simulator. The background of this mine is discussed in Section 6. Short descriptions of the computer model and some planning alternatives are given in Sections 7 and 8, respectively. Section 9 reflects an appraisal of this application. The paper concludes with suggestions regarding further applications and some remarks on intended future developments.

## 2. GENERAL DESCRIPTION OF PRODUCTION PLANNING SYSTEM

The general functional layout of the production planning system is shown in Fig. 1.

All relevant mine information is stored on the data base. The latter is maintained by means of a general computerised filing system and kept on magnetic tape or disc.

As indicated in Fig. 1, a distinction is made between *background* data which is applicable to the evaluation of all planning alternatives, and *plan* data that is specific to any one such alternative. The underlying idea is obviously to facilitate investigation of alternatives, but there is nothing absolute in this subdivision. Physically, both categories of information reside on the data base and can be updated easily. Trial changes of back-

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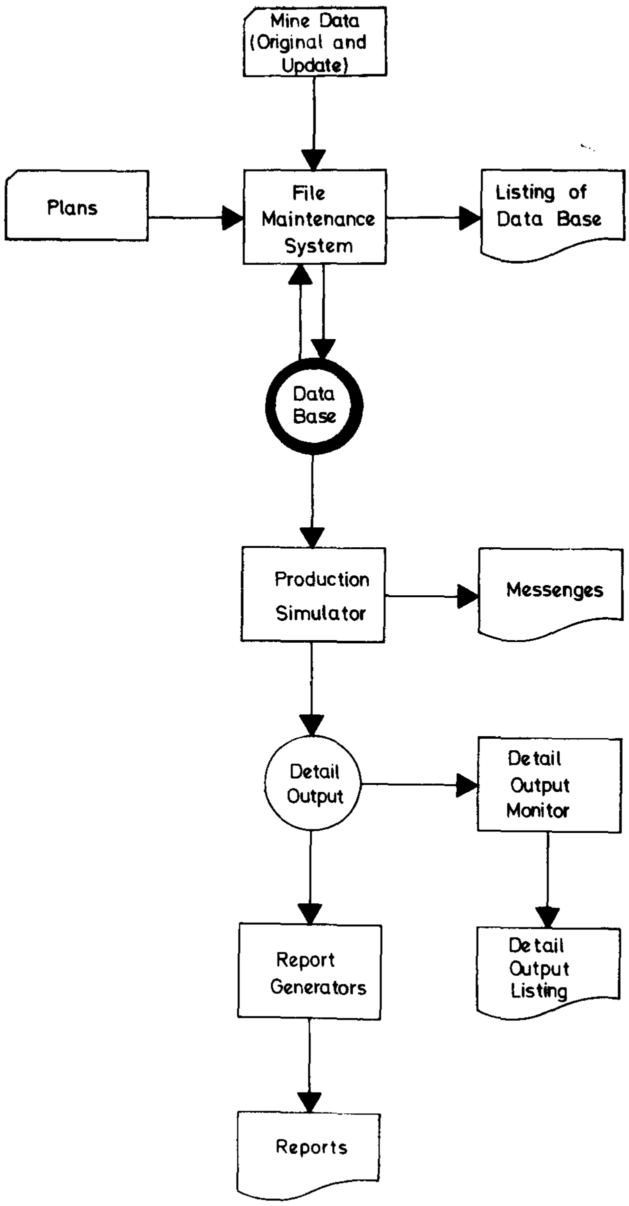


**Fig. 1—Functional layout of production planning system**

ground data for the purpose of sensitivity/risk analyses are very conveniently executed.

Every data base update is accompanied by a change listing for checking purposes. When desired, a complete listing can be requested.

A more detailed discussion of the different categories of data kept on the base will follow in Section 3.

The production simulator draws on the data base when evaluating the various planning alternatives. During the course of a simulation, numerous inconsistency messages may arise as indicated in Fig. 1. The normal output is transmitted to the so called *detail output* file. This file can be monitored. It would, however, be meaningful only to the personnel controlling the data base.

Management reports are produced from this detailed output via a report generation program that allows the user to specify his reports with regard to contents and format by means of control information on the data base.

## 3. INFORMATION REQUIRED BY THE PRODUCTION SIMULATOR

The various categories of data required by the present version of the production simulator are discussed below.

It must be remembered that the program is designed to handle general entities. The level of detail carried in any one mine-model is left entirely to the user. The system will deal with omissions of data by default wherever possible.

### 3.1 *Resources*

While all resources are treated in essentially the same manner by the machine, it is convenient, for purposes of discussion, to break them down into sub-categories.

#### 3.1.1 *Reserve blocks*

The program assumes that the mine has been blocked out in accordance with the intended lay-out. The size of reserve block will be suited to the level of detail required to achieve the objectives of a particular investigation.

Information recorded with a block will include extractable reserve figures for each alternative mining method considered feasible, quality parameters and various types of inter-resource connectors. For example, the latter would be used to ensure that a certain mining method will not be scheduled into a particular block unless the overlying reserve block is fully extracted. Also, the fact that a reserve block is served by a certain section of the haulage network, for instance, would be indicated using an inter-resource connector.

Finally a block in which a particular mining method is expected to deviate from standard performance (to be discussed below) on account of bad roof conditions, for example, would carry modifying information pertaining to production rates, other resource requirements or costs incurred. By default, all modifying factors are taken as unity.

#### 3.1.2 *Service networks*

An arbitrary number of service networks including haulage, ventilation, electric power, etc., may be defined. The amount of detail in any one model would again depend on the user's objectives. These network definitions have essentially the form of a string of resource blocks tied together by a set of connectors. If applicable, for the purpose of installation, the length of each section is recorded. The alternative types of haulage, for example, that may be considered for installation in a section, must be entered.

#### 3.1.3 *Labour, equipment and stores*

Labour, equipment and consumable stores items also take the form of resource blocks. An arbitrarily detailed breakdown into various categories, in order, for instance, to facilitate the planning of cost centre expenditure, is feasible.

### 3.2 *Operation definitions*

In this second major category of information, all types of activity that can be scheduled or exist in the mine must be defined. Their performance and resource requirements under standard conditions are required.

Each operation is considered to have a preparation period for which a preparation time must be stated. This is followed by the productive period described in

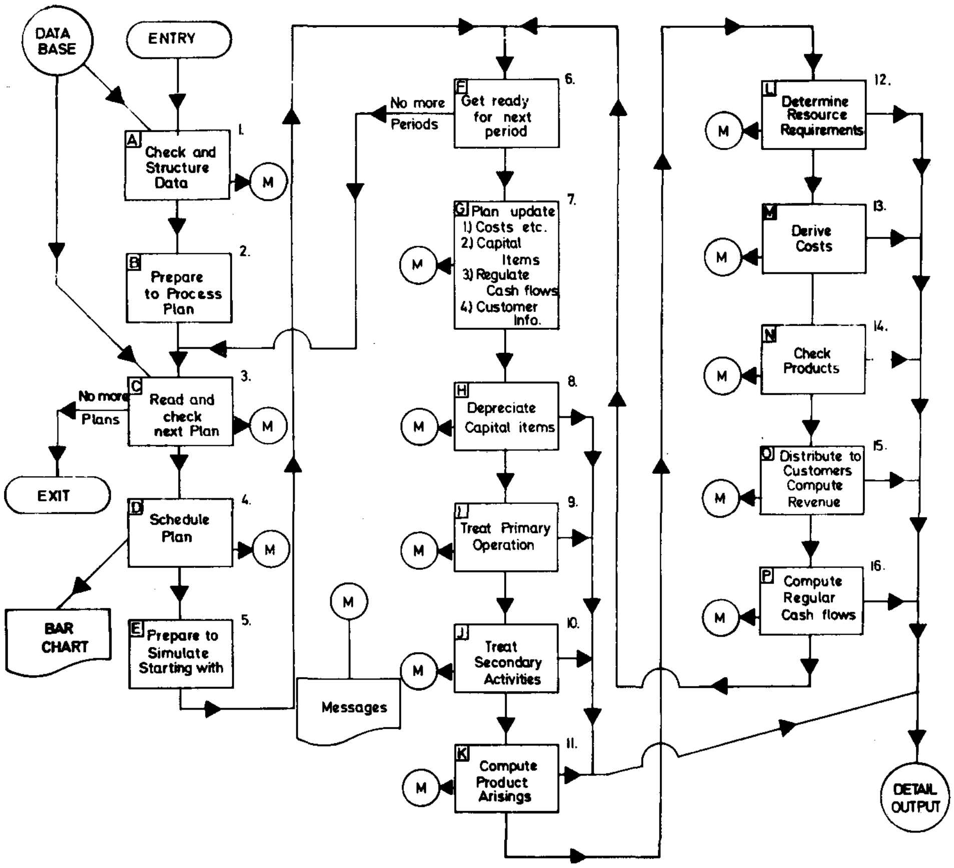


**Fig. 2—Functional flowchart of production simulator**

terms of its production rate which, depending on the type of operation, may be a mining rate in tons/month, a rate of tunnel advance in metres/month or a haulage installation rate in metres/month, for example.

These figures are supplemented by standard labour, equipment and stores requirements expressed in terms of the resource categories defined earlier. Requirements may be stated per unit time or per unit production quantity, whichever is applicable.

It must be remembered that when a particular mining method is scheduled into a reserve block, the operation standards are changed by possible modifying factors pertaining only to that particular block, as discussed earlier.

Each operation definition may contain a set of conditions that must be satisfied by the receiving resource block before the operation can be scheduled into the block. Similarly, the state of this and neighbouring blocks after having been subjected to the operation, may be defined.

3.3 *Unit costs*

Operations may draw on cost items either directly or via their specific resource requirements which then in turn are associated with certain costs per unit of resource.

Any cost breakdown is feasible. The amount of detail will again depend on the purpose of the model.

Costs can be inflated automatically and discontinuous adjustments of selected cost categories at specified instants in time may also be made.

3.4 *Capital items*

Capital items may be included if it is desired to carry the complete financial aspects of a model. The system keeps track of values and depreciations for an arbitrary number of items. They may be activated at specific points in time when modelling, for example, the effects of equipment acquisition in the course of a simulation run.

3.5 *Regular cashflows*

This category of information has again been included to enable the user to round off the financial aspects of his model. Regular cashflows could be used to account for periodic or single repayments on equipment, for instance. In general, any kind of expenditure that cannot be related to individual operations, may be treated in this way. The facility exists for making these flows dependent on global quantities like total tonnage mined or sold, for instance.

Cashflows, like costs and capital items, may be activated and deactivated as required in the course of a simulation run.

3.6 *Product descriptions*

This section becomes significant for a multi-product mine. Each product must be defined and its acceptable quality parameter ranges must be stated.

3.7 *Customer-descriptions*

Customers are defined in terms of their requirements by type and quantity range of product. Revenues may take the form of a fixed amount plus contributions proportional to various quality parameters. The customer composition may be subjected to arbitrary changes during the course of a planning exercise.

## 4. FUNCTIONS OF THE PRODUCTION SIMULATOR

This section should be read with reference to the functional flow chart in Fig. 2.

### 4.1 *Checking and structuring of background data*

When starting up a simulation, the system draws on the data base and structures the necessary background information in its memory for convenient accessibility during the run. This is conveyed by box 'A' in the flow chart. In the course of reading in the various data categories described in section 3, extensive checks are carried out by the machine.

Inconsistencies are pointed out to the user by means of messages where appropriate. This is indicated by the circle marked 'M' on the flow chart. In case of an inconsistency the system will attempt to carry on by making some default assumption if this is at all possible. This philosophy has been followed throughout.

### 4.2 *Reading and checking of plans*

Next, each plan in turn (any number of alternative plans may reside on the data base) is read in, checked and prepared for simulation as indicated by boxes 'B' and 'C'.

### 4.3 *Scheduling of plans*

In order to facilitate specification of plans, the user need not be concerned with time scheduling his activities. The system computes durations by looking up block reserves and production rates. It is assumed of course, if a certain operation is scheduled into a resource, that the latter must be exhausted. If this is not so, the machine computed durations may be overridden. Relationships between operations may be expressed in terms of precedence conditions. For example, it may be said that this mining operation must not start before a certain stretch of haulage has been installed or that a particular preparation activity must be scheduled to finish before a certain production operation starts.

The complete schedule is produced in box 'D' and forwarded to the simulation proper.

### 4.4 *Control of simulation timing*

In the course of a simulation run the performance of the model is re-evaluated at regular time intervals. The length of the basic period is chosen by the user and will depend on the details contained in the model. As indicated by boxes 'E' and 'F', each time period is considered in turn until a plan has been exhausted. After that the system returns to box 'C' and picks up the next planning alternative and so on until all plans have been simulated.

### 4.5 *Plan updating of background information*

The first function performed in every period is the execution of so-called *plan update commands* as indicated by box 'G'. They form part of the user's plan and allow him to add, delete, replace or change temporarily certain categories of background information. These changes are effective only for the present plan and are not propagated into the data base. At present it is possible to 'plan update' cost items, capital items, regular cashflows and the customer structure. For example, the user might want to specify that he expects a discontinuous change in salary structure three years hence over and above the automatic percentage increase allowed for by the system. Similarly, he may want to convey that a certain customer contract becomes effective at the end of year two of the present plan.

### 4.6 *Treatment of capital items*

Box 'H' handles the depreciation of capital items to be allowed for in the model. At this stage the system starts writing onto the detail output for later analysis by the report generator, as indicated on the flowchart.

### 4.7 *Handling of primary operations*

User specified operations are referred to as *'primary'*. These comprise all activities initiated through definite decisions on the part of the mine planning team. Normally the various production operations would fall into this category. However, depending on the amount of detail to be simulated, preparation operations such as various types of development as well as installation of all kinds of services, particularly haulage, may be included.

As a first step, in box 'I', the machine accesses both reserve block and operation definition information for each scheduled primary activity in turn. The state of the block is checked to ensure that the intended operation can, in fact, take place in it. If not, an appropriate message is written, but then the correct state is assumed in order to be able to carry on.

Next, the quantity produced during the period under consideration is computed. It must be remembered that while this would normally represent a tonnage of broken material, it could, for instance, also refer to a length of tunnel driven or haulage installed.

At the finish of a primary operation, the affected reserve block state indicator is switched according to information in the relevant operation definition. In the case of a haulage installation, for example, data defining the type of haulage installed would be transferred to the haulage block.

### 4.8 *Treatment of secondary activities*

Service activities that are uniquely implied by the scheduled primary operations are referred to as *'secondary'*. For example, material being transported from a certain reserve block to the surface would normally take a unique path along the haulage network; hence all sections of haulage along this path can be activated to carry the required tonnage without involving any decision making by the planning team. The system is designed to switch the required segments into operation automatically as 'secondary' activities by means of the program section denoted by box 'J'. The contribution of the various primary operations to the total load carried by the secondary activities are recorded individually on the detail output file.

If a service network cannot be activated uniquely by a primary operation, for example, in the event of outbye forks, decisions on the *'route'* have to be taken by the user and must be provided via the plan.

In tracing the appropriate path, the system checks whether the service blocks encountered are in fact in the appropriate state. Messages indicate the existence of blockages, but continuity will be assumed in order to continue the simulation.

4.9 *Treatment of products*

Each reserve block has associated with it one or more '*product distributions*'. These determine the products in terms of quantity and quality that will be obtained from unit quantity of reserve after the latter has been processed in the beneficiation plant. The simplifying assumption made here is that materials from different sources will not influence each other significantly when passing through the beneficiation process.

In box 'K' the reserve blocks being mined in the present period are looked at in turn, and detail output is written. All products identified by originating reserve block, are stored in '*bunkers*' for later testing and distribution to customers.

4.10 *Resource requirements*

Next, in box 'L', the resource requirements of all primary and secondary activities busy during the present period, are determined. As already pointed out in Section 2, the amount of detail in this area is completely controlled by the user. The machine picks up the information from the relevant operation definitions, modifies it if necessary by data in the reserve blocks and relates it to time or quantity as the case may be.

4.11 *Derivation of costs*

After appropriate inflation, in box 'M', the costs of all activated resources are determined and recorded. Alternatively, operations may be defined directly in terms of cost rather than resource requirements. Again the user has to decide which mechanism he prefers in a particular set of circumstances. An arbitrary mixture is permissible within each operation defined in the model. For example, one might decide to work in terms of physical labour categories. At the same time, however, the consumption of certain stores may be available only as lumped cost figures, there being no point in attempting a more detailed breakdown when viewing these in relation to the overall accuracy of the model.

4.12 *Product checking*

Box 'N' serves to check all products with regard to the various defined parameters. In practice, one often has to deal with empirical relationships of the form whereby a particular area of a mine must contribute only a certain fraction of the total output in order to achieve a satisfactory product. This type of test is available. Messages are written where necessary. The products are left in the bunkers in compounded form for distribution.

4.13 *Treatment of customers*

Box 'O', in handling the product-to-customer distribution, forms an exception to the general rule in that here the system does make decisions. However, this being a typical linear programming problem, the decisions are simple and are best handled by machine. The user can still have full control over the distribution by manipulating customer priorities. The machine works on stated priorities, rather than actual prices.

4.14 *Computation of regular cashflows*

Finally, in box 'P', the regular cashflows generated in the present period are picked up and put on the detail output file. As mentioned in Section 2, they may depend on other quantities in the system that have arisen in the course of this period.

Next the system advances into the succeeding time interval.

## 5. REPORT GENERATION

The facility for generating a wide variety of reports is of utmost importance in this type of computer application.

Reports — while recognising the level of detail in the basic model — must be suited to the level of management for whom they are intended. Since it is quite impossible to foresee all requirements in this regard, considerable effort has been spent in providing facilities for the user to define his own reports both with regard to contents and format. This is achieved by carrying '*report definitions*' on the data base along with all the other information. The report generator draws on these definitions when condensing the detail output into meaningful tables.

## 6. BACKGROUND TO HLOBANE COLLIERY

6.1 *Mining*

The colliery is some 60 years old, has limited reserves and consists of two separate outcropping mines about six kilometres apart. Three flat seams with different wash-

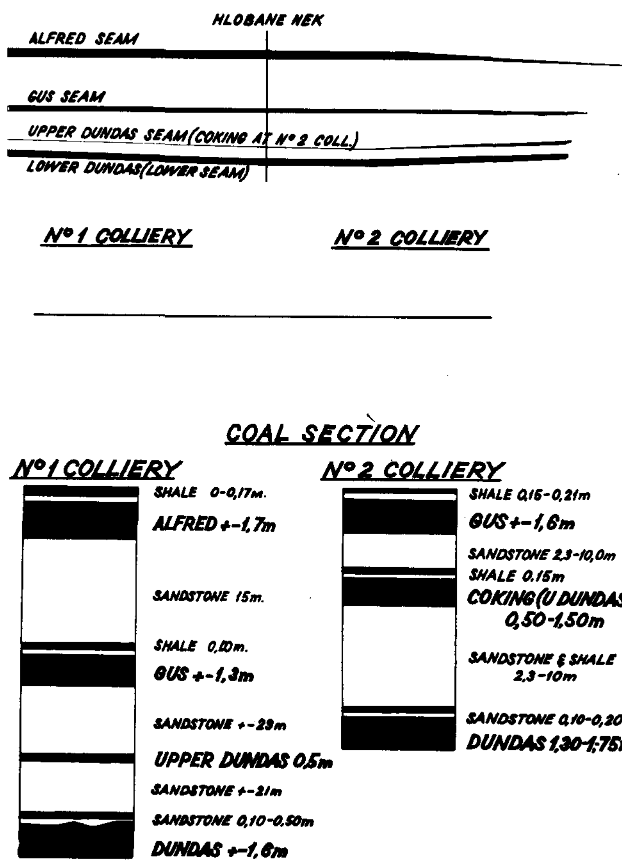


**Fig. 3—Hlobane Colliery**

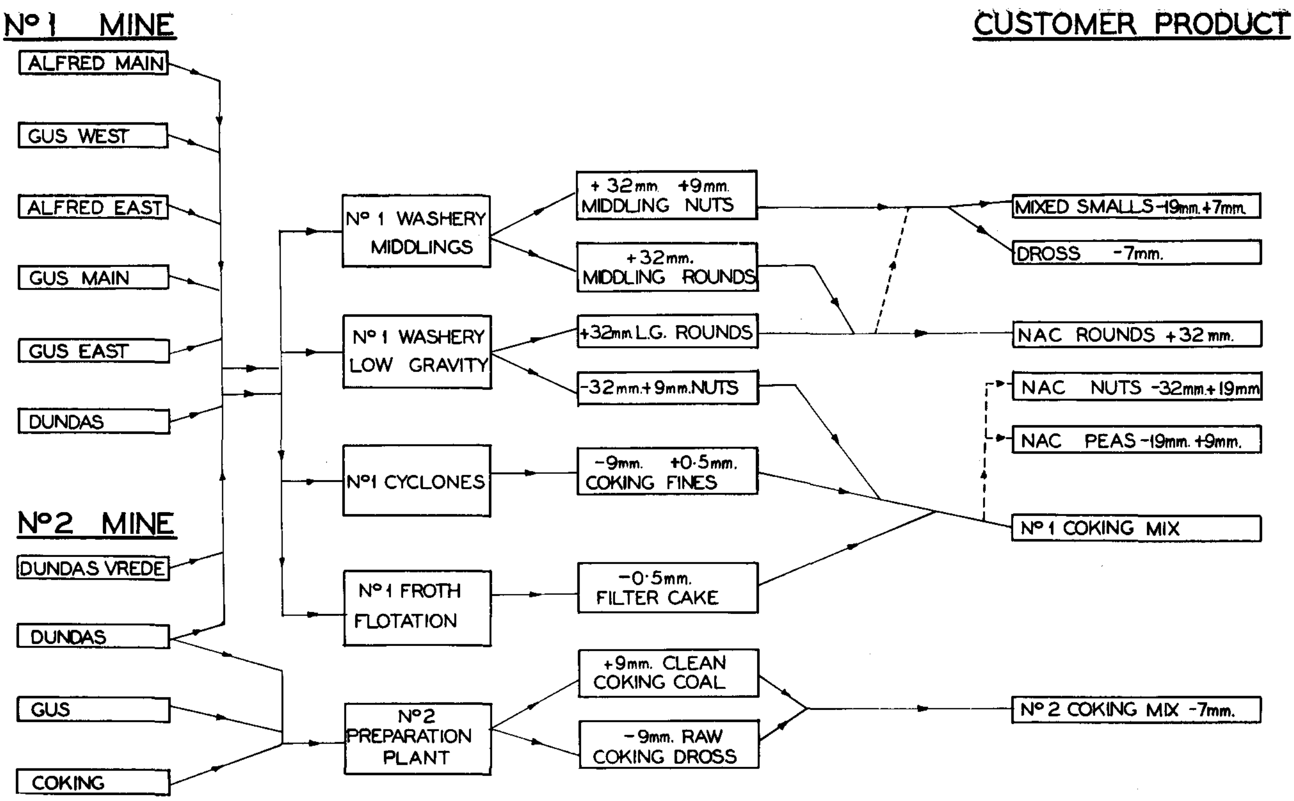


**Fig. 4—Schematic drawing of processes and product arisings**

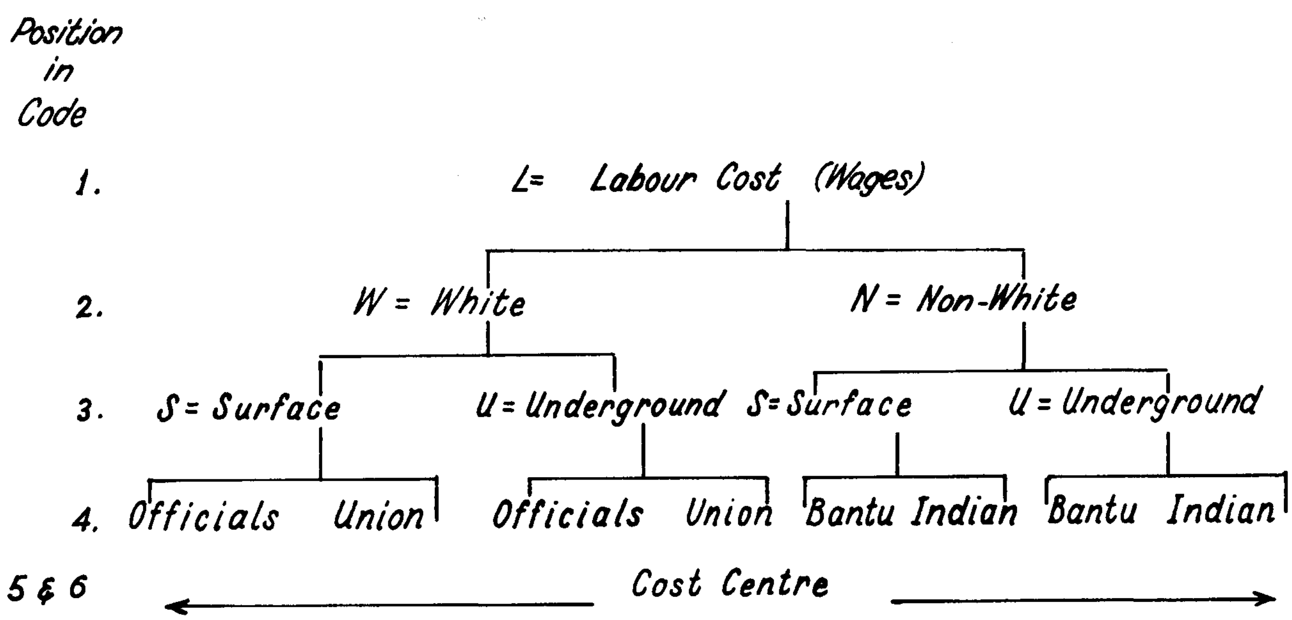


**Fig. 5—Breakdown of labour cost**

ability characteristics in both yield and quality are mined at each. Thickness, quality and composition differ from seam to seam; in addition, they vary significantly from region to region in any one seam.

Fig. 3 shows typical sections through the mountain and the relationship of the seams to one another. Partings between the mineable seams vary from some 20 metres of massive sandstone to less than 2 metres of laminated sedimentary beds. Mining conditions vary between very good and poor. To date, mining has been conducted by handloading into tubs (which are then moved to surface by endless rope haulages) on bord and pillar advance and pillar extraction retreat. This method has limited extraction to seams thicker than 1,1 m.

With the exception of those areas required for access, the remaining reserves are largely:

widely dispersed remnants;
of lower seam thickness (0,6-1,1 m);
contaminated by a higher proportion of waste;
of lower quality.

In addition, mining layout is complicated by the presence of numerous faults and dykes.

6.2 *Products*

The principal product of the colliery is prime coking coal. However, certain fractions which lack coking qualities and cannot be absorbed in the coking coal product are disposed of in a number of size and quality categories for steam-raising. In order to ensure that all specifications in the coking coal fraction are met, coal from the various seams has to be blended in certain ratios.

A schematic drawing of the sources, processes and products is given in Fig. 4.

It will be noted that there are two coal preparation plants.

*No. 1 Plant* consists of:

(i) a double stage Wemco dense medium washer,
(ii) a cyclone section,
(iii) a froth flotation section.

The +9 mm fraction is treated in the Wemco washer at specific gravities of about 1,55 and 1,74. The cyclone unit operates at a specific gravity of approximately 1,5 and handles the 0,5 to 9 mm fraction. The froth flotation section deals with the −0,5 mm fraction.

*No. 2 Plant* consists of:

a single stage Wemco dense medium washer which treats the +9 mm fraction. The −9 mm fraction is absorbed untreated into the coking mixture.

A shift to a wholly coking coal market is being investigated at present and forms part of the plans considered.

6.3 *Blending of seams*

From the above it becomes apparent that apart from cost considerations, operations at this mine must be so scheduled that *the existing reserves in the various seams are extracted in such proportions as to generate products of acceptable quality at maximum yield over the remaining life of the mine.*

## 7. THE MODEL

7.1 *Form of input and output data*

In setting up the model a balance had to be struck between the form of data in the existing recording and accounting system and the form in which it would be processed by the simulator.

At the same time, results from the simulator had to be such that they could be verified against actual results and presented to operational personnel without complicated transformation procedures.

7.2 *Codes*

For identification purposes codes consisting of not more than eight alpha-numeric characters have been used throughout. They have been selected to facilitate grouping for reporting and summarising purposes. Costs, for example, are divided into three main groups; Labour, Stores and Other (or Sundries). They are identified in the first position by letters L, S and O, respectively. A more detailed breakdown of labour costs is given in Fig. 5

The same philosophy has been applied in other cost and resource categories.

7.3 *Product distributions*

The quantities of the various products which result from the treatment of one unit of reserve together with their respective qualities (calorific value, ash, swelling index), form one *product distribution* identified by a unique code. These product distributions have been determined on a regional basis for each seam and relevant preparation process from the respective washability curves.

Preparation processes are determined from the washability characteristics of the coal to be treated and the products with their quality specifications called for by the market. Market changes relating to product and/or quality necessitate the creation of new product distributions for the areas affected in order to reflect the associated change in preparation process.

From the assigned codes, the mine, seam, region, preparation process and mining operation can be identified.

7.4 *Reserve blocks*

Reserve blocks are bounded mainly by geological features. They have common boundaries and common identification codes on all superimposed seams for easy inter-seam reference. The first three characters in the code indicate mine and seam, thus uniquely identifying each block.

In respect of each coal reserve block the following data have been entered:

(i) possible mining operations,
(ii) quantity to be mined by each operation,
(iii) preparation operations necessary,
(iv) modifying factors, if any, relating to preparation time, production rate, waste packed underground, resource requirements or costs.
(v) influence on surrounding or superimposed blocks.
(vi) connection to transport network,
(vii) relevant product distributions,
(viii) state indicators to test a total of 10 conditions (e.g., availability of transport).

7.5 *Transport networks*

Transport networks have been set up to permit the flow of coal from the face to the respective preparation plants. (Fig. 6).

7.6 *Operation definitions*

Apart from specifying standard production rate, preparation time, resource requirements and costs, an operation definition handles the change in state of the block on completion of the operation and the influence of this on surrounding or superimposed blocks. To illustrate, let us take the operation '*pillar extraction*' as an example. Before commencement the state indicator must show that:

(i) primary development has been done,
(ii) the area is not flooded,
(iii) haulage is installed,
(iv) the seam above has been completely mined out.

After completion of the operation the state indicators of adjacent blocks are changed as follows:

(i) haulage removed,
(ii) superposition restriction removed from block below.

The various mining and preparation operations have been so defined that the transport network is automatically installed by preparation or development operations and removed by pillar extraction.

7.7 *Level of detail*

The model described above has been set up to test the program and to evaluate short-term (annual budget) as well as medium- and long-term plans (five years and life of mine).

By necessity, it contains a fine level of detail as the following numbers indicate:

| | |
|---|---|
| reserve blocks | 600 approx. |
| transport network legs | 280 approx. |
| labour pools | 105 |
| cost codes and cashflows | 200 |
| operation definitions: | |
| production | 18 |
| preparation | 9 |
| transport network | 21 |
| product distributions | 55 |

The cost codes and cashflows consist of approximately 50 per cent stores and 25 per cent each of labour and sundries. A number of specific definitions for certain surface installations as well as installation and removal of haulage are included in the transport operation definitions. The product definitions arise from 17 regions. The balance is made up of alternative beneficiation processes and variations resulting from mining methods.

In both the product and customer sections a certain amount of consolidation was done for simplicity resulting in a small loss of detail. While the model does not reflect the same detail as, for example, monthly operating returns, it contains not less than the existing annual plans.

## 8. BASIC PLAN AND ALTERNATIVES

8.1 *Setting up operation sequences*

Since the *system* determines the duration of an operation in a block by utilising the relevant reserve and production rate figures, it is not necessary to keep track of time when scheduling mining operations.

A sequential list of *commands*, each comprising operation and block, establishes the movements of a producing unit in time. In practice the first command relating to a producing unit will usually have a specified starting date. Where operation sequences must be interlocked, this may be expressed by means of conditions such as *start A after B is finished or finish C before D starts.*

A time-sequenced plan showing command identification, operation, block, starting date and duration forms part of the output. Using this information, selected bar-charts can be constructed. Changes in costs, capital expenditure and customer set-up are readily handled by special 'plan update' commands previously mentioned.

8.2 *Test run*

The colliery's current five-year plan was the basis for the first simulation to test both program and model data. On successful completion of this test, the data base was extended to its present size to include all reserve blocks and ancillary data in order to run complete life of mine planning exercises.

8.3 *Processing life of mine plan and alternatives*

Establishing the mining sequence accounted for the major part of the preparatory work. The basis of this sequence was to retain a constant number of producing units — 20 at No. 1 mine, 12 at No. 2 mine — for as long as possible.

In order to produce a practical plan, mine production personnel with their intimate knowledge of the mine drew up the general layout and extraction sequence, taking into account the following:

(i) seam mix,
(ii) pit room and accessibility,
(iii) sequential extraction of seams from the top downwards.

The proposed plan resulted in approximately 1 000 commands for the simulator.

Corrections and refinements, e.g. concentration of working faces, were introduced through a series of successive runs guided by the time-sequenced plan, diagnostic messages and a comprehensive set of reports.

Tables I and II are examples of reports produced by the report generator program.

In this investigation, the main emphasis was on production levels, labour, costs, product quantities and qualities.

Capital and customer information was hypothetical with revenue at fixed price levels for two years and cost-plus after that.

Wage rates and stores costs were escalated at five and four per cent p.a., respectively.

At the time of writing this paper a number of alternatives to the basic life of mine plan have been prepared and run as exercises. Bearing in mind the remarks made earlier, these alternatives were intended to illustrate the effect of:

(1) *coking coal being sold at predetermined price levels*

In contrast to the cost-plus situation of the basic

TABLE I

HLOBANE COLLIERY — LIFE OF MINE FROM JULY 1971 BASIC PLAN

Summary table monthly profit, costs, tonnages, labour

| Yearmonth | | Working profit | Capital expenditure | Revenue | Working cost expenditure | KILOTONS | | | CENTS PER TON SOLD | | | LABOUR IN SERVICE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sold | Hauled | Mined | Profit | Revenue | Costs | White | Non White |
| 1972 | 6,0 | 158,0 | 200,0 | 559,9 | 401,9 | 110,7 | 159,1 | 166,3 | 142,7 | 505,6 | 362,9 | 210 | 4 714 |
| 1973 | 6,0 | 135,6 | 400,0 | 568,8 | 433,2 | 112,5 | 163,9 | 177,2 | 120,5 | 505,6 | 385,1 | 214 | 4 863 |
| 1974 | 6,0 | 282,9 | 0,0 | 720,4 | 437,5 | 99,4 | 153,1 | 166,5 | 284,6 | 724,8 | 440,2 | 212 | 4 788 |
| 1975 | 6,0 | 271,1 | 0,0 | 719,4 | 448,3 | 95,2 | 144,0 | 160,8 | 284,6 | 755,3 | 470,7 | 214 | 4 795 |
| 1976 | 6,0 | 273,1 | 0,0 | 746,1 | 473,0 | 95,8 | 146,6 | 164,9 | 285,0 | 778,7 | 493,7 | 217 | 4 798 |
| 1977 | 6,0 | 268,4 | 0,0 | 755,5 | 487,1 | 94,2 | 144,8 | 166,4 | 285,0 | 802,3 | 517,3 | 220 | 4 837 |
| 1978 | 6,0 | 267,3 | 0,0 | 782,9 | 515,6 | 93,8 | 141,7 | 164,3 | 285,0 | 834,7 | 549,7 | 222 | 4 867 |
| 1979 | 6,0 | 265,2 | 0,0 | 794,4 | 529,2 | 93,1 | 140,7 | 165,1 | 285,0 | 853,6 | 568,6 | 220 | 4 806 |
| 1980 | 6,0 | 257,3 | 0,0 | 832,2 | 574,8 | 90,3 | 140,0 | 161,9 | 285,0 | 921,7 | 636,7 | 225 | 4 840 |
| 1981 | 6,0 | 250,1 | 0,0 | 857,3 | 607,2 | 87,8 | 149,3 | 177,2 | 285,0 | 976,9 | 691,9 | 231 | 4 871 |
| 1982 | 6,0 | 251,1 | 0,0 | 879,0 | 627,9 | 88,1 | 155,6 | 182,5 | 285,0 | 997,8 | 712,8 | 231 | 4 900 |
| 1983 | 6,0 | 268,2 | 0,0 | 934,4 | 666,2 | 94,1 | 164,6 | 192,6 | 285,0 | 993,0 | 708,0 | 232 | 4 852 |
| 1984 | 6,0 | 269,8 | 0,0 | 962,3 | 692,5 | 94,7 | 168,8 | 196,8 | 285,0 | 1 016,6 | 731,6 | 235 | 4 819 |
| 1985 | 6,0 | 267,8 | 0,0 | 999,5 | 731,6 | 94,0 | 163,0 | 189,2 | 285,0 | 1 063,6 | 778,6 | 237 | 4 720 |
| 1986 | 6,0 | 275,3 | 0,0 | 996,4 | 721,1 | 96,6 | 145,4 | 168,5 | 285,0 | 1 031,6 | 746,6 | 238 | 4 639 |

TABLE II

HLOBANE COLLIERY — LIFE OF MINE FROM JULY 1971 BASIC PLAN

Products table average saleable products with qualities

| Yearmonth | | POTENTIAL COKING COAL | | | | | | | | | | | OTHER COAL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Comix 1 | | | Comix 2 | | | Low gravity rounds | | | | Weighted average | Midnuts | | High gravity rounds | |
| | | Ktons | Ash | SW | Ktons | Ash | SW | Ktons | Ash | SW | CV | Ash | Ktons | CV | Ktons | CV |
| 1972 | 6,0 | 53,0 | 12,4 | 3,5 | 22,6 | 12,8 | 4,8 | 29,6 | 14,6 | 2,0 | 29,9 | 13,1 | 3,7 | 21,5 | 5,3 | 21,5 |
| 1973 | 6,0 | 56,5 | 12,6 | 3,5 | 19,9 | 12,9 | 4,8 | 30,4 | 14,9 | 2,0 | 29,7 | 13,3 | 4,1 | 21,5 | 5,5 | 21,5 |
| 1974 | 6,0 | 53,1 | 12,6 | 3,5 | 17,4 | 13,7 | 4,7 | 28,7 | 14,8 | 1,9 | 29,7 | 13,5 | 4,0 | 21,5 | 5,4 | 21,5 |
| 1975 | 6,0 | 50,4 | 12,5 | 3,5 | 16,8 | 13,9 | 4,8 | 27,8 | 14,5 | 1,9 | 29,9 | 13,3 | 3,7 | 21,5 | 5,4 | 21,5 |
| 1976 | 6,0 | 53,3 | 12,4 | 3,6 | 13,7 | 13,3 | 5,0 | 29,2 | 14,4 | 2,0 | 30,0 | 13,2 | 3,9 | 21,5 | 5,7 | 21,5 |
| 1977 | 6,0 | 54,6 | 12,3 | 3,7 | 10,5 | 15,0 | 5,1 | 29,5 | 14,3 | 2,0 | 30,1 | 13,2 | 3,7 | 21,5 | 5,8 | 21,5 |
| 1978 | 6,0 | 52,4 | 12,1 | 3,7 | 13,0 | 14,9 | 5,2 | 28,8 | 14,1 | 2,0 | 30,2 | 13,1 | 3,4 | 21,5 | 5,5 | 21,5 |
| 1979 | 6,0 | 52,1 | 12,1 | 3,7 | 13,5 | 14,9 | 5.2 | 27,8 | 14,1 | 2,1 | 30,1 | 13,1 | 3,4 | 21,5 | 5,3 | 21,5 |
| 1980 | 6,0 | 50,3 | 12,1 | 3,7 | 13,5 | 14,3 | 5,2 | 26,9 | 14,0 | 2,1 | 30,2 | 13,0 | 3,3 | 21,4 | 5,2 | 21,5 |
| 1981 | 6,0 | 49,3 | 12,2 | 3,8 | 14,0 | 15,3 | 5,1 | 24,8 | 14,1 | 2,1 | 30,1 | 13,2 | 3,5 | 21,3 | 5,0 | 21,5 |
| 1982 | 6,0 | 49,3 | 12,3 | 3,8 | 14,5 | 15,6 | 5,1 | 24,8 | 14,2 | 2,1 | 30,1 | 13,3 | 3,5 | 21,4 | 5,0 | 21,5 |
| 1983 | 6,0 | 51,0 | 12,2 | 3,8 | 19,0 | 12,5 | 5,0 | 24,5 | 14,2 | 2,1 | 30,1 | 12,8 | 3,7 | 21,3 | 5,0 | 21,5 |
| 1984 | 6,0 | 52,9 | 12,3 | 3,8 | 16,6 | 12,0 | 5,1 | 25,5 | 14,2 | 2,1 | 30,1 | 12,8 | 3,9 | 21,3 | 5,2 | 21,5 |
| 1985 | 6,0 | 52,5 | 11,7 | 3,7 | 12,4 | 14,3 | 5,2 | 29,4 | 13,4 | 2,0 | 30,4 | 12,6 | 3,6 | 21,2 | 5,9 | 21,4 |
| 1986 | 6,0 | 52,4 | 11,4 | 3,6 | 12,8 | 15,0 | 5,2 | 31,8 | 13,2 | 2,0 | 30,6 | 12,5 | 3,4 | 21,2 | 6,3 | 21,4 |

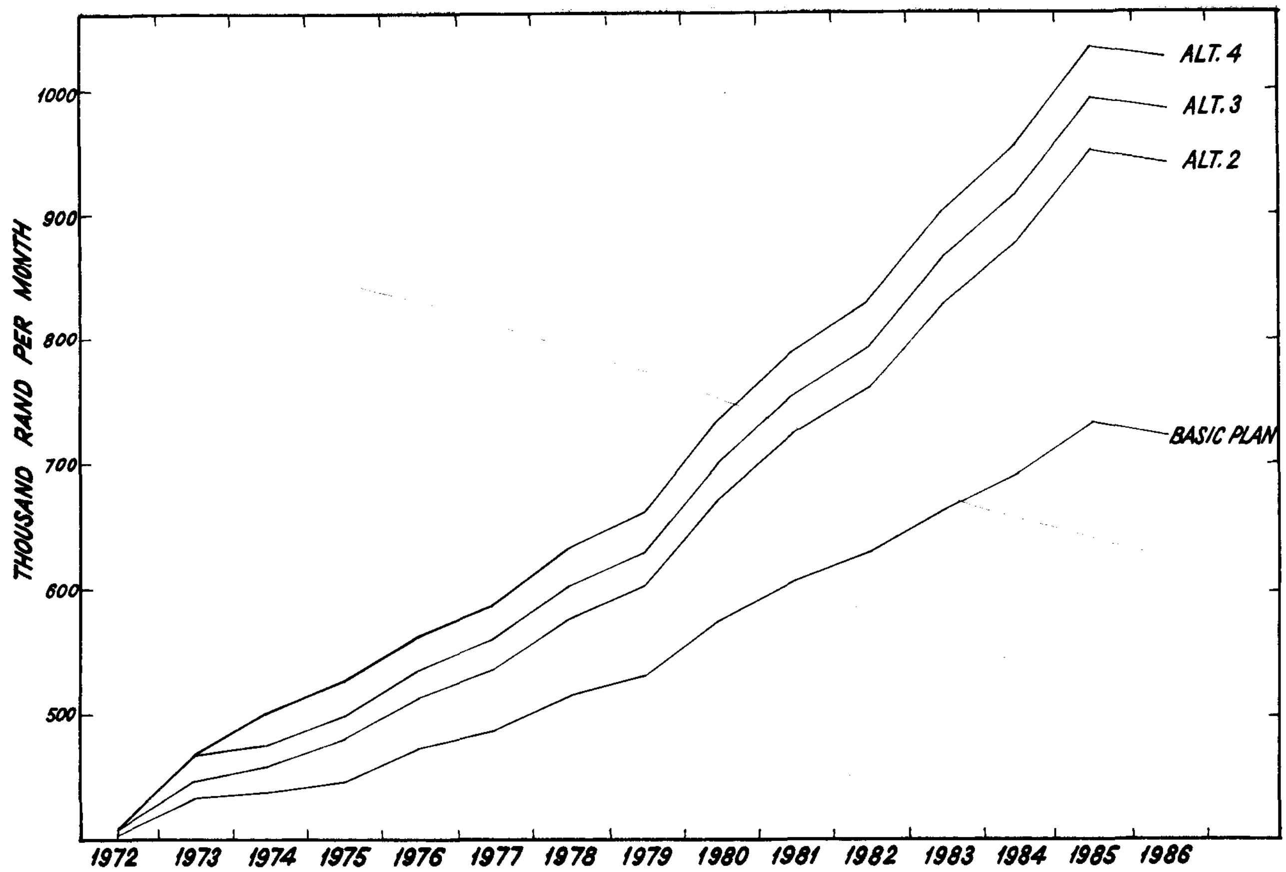


**Fig. 6—Monthly working cost expenditure (R000)**

plan, the price was increased by 25 per cent in 1973 when the change from mixed to a wholly coking coal market was simulated to occur. Thereafter, further increases of 25 per cent were assumed to occur every five years.

(2) *stores cost escalation at eight per cent per annum*

The rate of escalation in the basic plan was four per cent.

(3) *a 30 per cent increase in the wages of trade union members from mid-1972*

This measure is thought to give a coarse indication of the possible effects of a five day week. It was assumed that production would be maintained by means of overtime work. A more accurate simulation of this problem could be made if required.

(4) *a 33 per cent increase in the wages of underground Bantu from mid-1973*

Both White and Bantu wage rates were subject to a five per cent annual escalation in the basic plan. This escalation rate is maintained before and after the adjustments embodied in (3) and (4) above.

(5) *less optimistic product distributions*

In certain areas of the mine, particularly in the thinner seams, only limited sampling information is available. The initial product distributions for these areas were modified to make allowance for less favourable yields and associated qualities.

The preparation time for alternatives (1) through (4) amounted to three man-hours. Alternative (5) necessitated preparatory calculations before the data base could be updated. Approximately nine man-hours were required. Computer processing of all alternatives was completed in one shift.

Fig. 6 illustrates the cumulative effect of alternatives (2), (3) and (4) on the working costs of the basic plan. It will be noted that the changes in stores escalation rate from four to eight per cent (compounded) has a very significant effect particularly in the long term.

The drop in working cost after mid-1985 is associated with a decrease in output. The general movement into thinner and dirtier seams becomes apparent from the trends in the various tonnages depicted in Fig. 7. While mined and hauled tonnages increase, the sales output is maintained at a fairly constant level in accordance with the primary objective of the basic plan. It will be noted that on the sales side the target was exceeded in the basic plan, while alternative (5) fell short. A similar picture emerged as regards qualities.

Messages from the simulator indicated that certain transport networks were being overloaded in the later stages thus highlighting the necessity for careful planning in this area.

## 9. APPRAISAL OF APPLICATION

As an outcome of these investigations further planning exercises are contemplated. Some of these are intended to compare the present hand loading oriented systems with mechanised extraction of the thinner seams. Another application under consideration is the planning

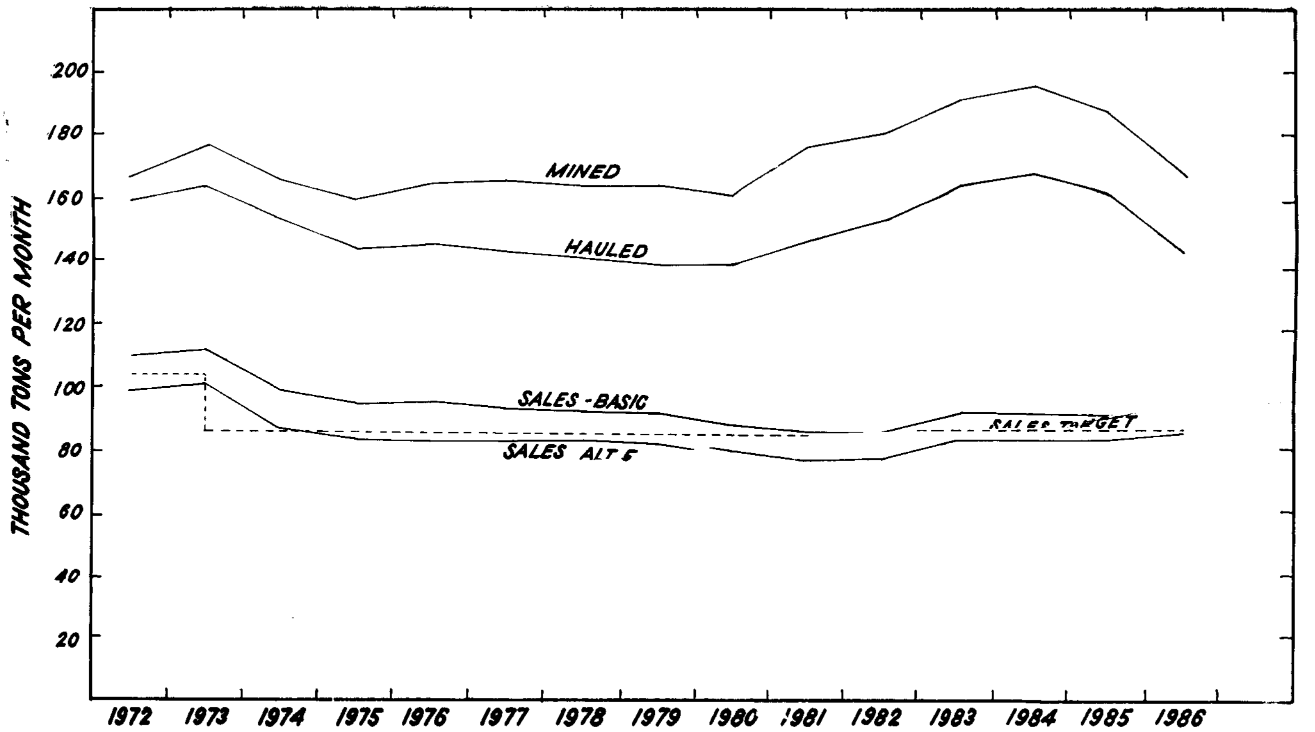


**Fig. 7—Monthly production tonnages in thousands**

on a coarser level of this mine in conjunction with another colliery in the group having a complementary product composition.

From the application described it is evident that the system has sufficient flexibility for handling situations involving:

(i) a number of superimposed seams,
(ii) a variety of mining methods,
(iii) complex transport networks including any number of mine entrances,
(iv) a multi-product composition arising from one or more benefication plants.

## 10. GENERAL CONCLUSIONS

### 10.1 *Remarks on further applications*

The system is not restricted as regards the type of mining operation to be simulated nor does it prescribe the planning horizon and level of detail in the model. Short term budgets, medium term and life of mine plans can be handled with equal ease. In fact, the program is flexible enough to cope with interactions between mines at a mining group level.

Further applications to date have included the evaluation of the influence of geographic expansion in an existing colliery, the effect of different sizes of production machinery on the performance of a newly planned colliery as well as the significance of alternative stoping sequences in portion of a gold mine.

It should be evident that the value of the output from this type of program is crucially dependent on the initial data provided. The data base must be created with a clear view of the objectives in mind. While unnecessary details will complicate subsequent manipulations, a model that is too coarse will have limited scope. However, sensitivity analyses to investigate the effect of changes or inaccuracies in key parameters are conveniently performed by the system and should be employed in building up a suitable data base.

The success of any application will ultimately depend on the personnel controlling the data base. People who are familiar with the planning procedures of a mine or a group will generally be most suitable for the job. No previous experience with computers is required, since the program has been designed with the view that the user should understand its functions and be able to manipulate it in terms of mining concepts.

Finally it should be appreciated that since the basic model information need be provided only once and later be updated occasionally, the value of the system will become most apparent if used on a continuous basis, particularly in situations necessitating the evaluation of a number of alternatives.

### 10.2 *Remarks on future developments*

The present simulator is considered to be a prototype. It was clear from the start that this is a typical 'on-line' application. It will be much easier to develop planning alternatives in direct interaction with the computer through use of a terminal. However, it was thought undesirable to load the first version with the necessarily greater programming effort required for a 'conversational' system. This approach will be adopted in the next version.

Further, it is intended to add facilities for feeding back actual performance figures into the data base. By comparing these against a previously established plan, the machine can now produce exception reports and other aids for the control of operations.

In summary, the next version of the program is visualised as providing a tool for the planning as well as the control of mining enterprises.

## 11. ACKNOWLEDGEMENTS

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# Pert, and how Pert techniques can be used in modern mine management

**By E. J. Boome*, A. C. Schmidt C.A. (S.A.)****

SYNOPSIS

This paper covers the stages of planning required to be performed and the implementation of the plan from grass roots to the partial completion of the sinking of a mine shaft system. The various steps involved in the planning are also examined in some detail. The experience gained in this project and the conclusions reached convince the authors that Pert Planning is a valuable aid to top management.

SINOPSIS

Hierdie verhandeling dek die stadiums van beplanning wat noodsaaklik is vir die uitvoering en aanwending vanaf die begin-stadium tot gedeeltelike voltooiing, van die sinking van 'n mynskag sisteem. Die verskillende stappe wat betrokke is by die beplanning word ook noukeuriger ondersoek. Die ondervinding wat in hierdie projek opgedoen is en die gevolgtrekkinge bereik, het die skrywers oortuig dat ,Vrypostige Beplanning' waardevolle hulp aan die hoogste bestuur verleen.

## INTRODUCTION

PERT, as is well known, is a planning technique which originated in America and was commissioned by the American Navy for the purpose of controlling and co-ordinating the POLARIS MISSILE PROJECT. PERT, which stands for "Program Evaluation and Review Technique", is a computerised system of planning, initially used only for project time analysis, which makes use of three time estimates for each task. These time estimates are *optimistic*, *pessimistic* and *realistic*. The reason for the use of three time estimates is to establish a weighted average time for each activity during processing on the computer. The computer program allows for the geometric mean of the three time estimates to be established by adding the *optimistic* and *pessimistic* time estimates to four times the *realistic* time estimate, then dividing the result by six.

One difficulty with the system has been to get three time estimates for a given task. For example, tenderers generally quote two time estimates for a job, basing these time estimates on their capacity for doing the job, and their own experience of the probability of obtaining materials, raw or manufactured, and their current work load. Thus the delivery time for a specific piece of equipment could appear on their quotation in the form "Delivery can be effected from 18 to 24 weeks from the receipt of firm instructions to proceed". These estimates can reasonably be assumed to be *optimistic* and *pessimistic*. In other instances, based on their best knowledge of capacity and their known workload, they are far more explicit, and the delivery time appearing on their quotation could read: "Delivery can be made within 8 weeks of receipt of order". Again, this type of estimate can be assumed to be either *realistic* or a misleading *optimistic*.

An instance of misleading time estimates can be gained from the analysis of a supplier's past delivery promises and their actual delivery times, because some estimates tend to be over optimistic. A useful feature to be considered is the inclusion of a period over and above that quoted by the supplier, referred to in the various planning departments as "liar's time".

Arising from the inability, or reluctance, of contractors to provide three time estimates for a task, other techniques such as "Critical Path Scheduling", "Critical Path Method", etc. were evolved for use with single task durations. These latter techniques were designed initially for project time analysis, although in recent years the techniques have been sophisticated to include, in addition to project time analysis, such features as

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