Rock-handling techniques at Sishen iron-ore mine

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SYNOPSIS

A description is given of the methods used in management planning, pit-equipment selection and maintenance-operator training, and formal organization of mining personnel.

SAMEVATTING

Die metodes van bestuursbeplanning, die keuring en instandhouding van groeftoerusting, operateursopleiding en die formele organisasiestruktuur van die mynbouafdeling, word bespreek.

Introduction

The production of iron ore at Sishen Mine began in June 1953, the ore being crushed and screened in a dry state. In 1961 a crushing and wet-screening plant was erected, and in 1963 the first heavy-medium beneficiation plant was commissioned.

The production of iron ore for the Sishen–Saldanha Export Project began in 1976 after considerable expansion of the pit equipment and facilities. An additional, improved heavy-medium beneficiation plant was also built. The maximum total output of these two plants, which supply lumpy and fine ore for domestic and export markets, is rated as 27 million tons per year.

Run-of-mine ore and waste rock are at present being mined at a rate of nearly 80 million tons per year.

Management Planning

Long and Medium-term Planning by the MPS[1]

Heavy reliance is now placed on a powerful computerized mine-planning system, MPS, which has been partially installed at Sishen. The ore-body is modelled as follows: drawn geological sections are digitized and link-point sets between sections are indicated; intermediate sections are interpolated linearly by the system; and hence a three-dimensional model of the ore body is constructed. Any section that is perpendicular to the survey co-ordinate system can be viewed on the graphics terminal or plotted on paper to the desired scale. Once these sections are checked by the geologists, pit design can commence.

Long and Medium-term Pit Planning

The most economic pit design is determined by use of the Lerchs–Grossman dynamic programming algorithm[2] constrained by the marginal volumetric instantaneous stripping ratio, the estimated maximum pit-slope angle, and the surface contours of the area.

This layout is typically unpractical, but, by means of the simplified interactiveness of the system, pit profiles are smoothed and haul roads inserted. The tonnages of ore produced from the final and optimum pit designs are then retrieved from the model of the ore-body. Part of the long-term pit plan is shown in Fig. 1.

Outputs of the MPS

Besides pit plans drawn to desired scales, tonnages of ore and waste rock by level and by area are calculated. One of the most useful outputs is the determination of minimum and maximum† stripping curves[3] (Fig. 2). If the minimum curve is followed, the present value of the cost is minimized, but the pit equipment and service facilities must be continuously expanded. If the maximum curve is followed, the present value of the total production facilities is maximized, with a later redundancy of these facilities. An average stripping policy ensures at least stable production facilities over the life of the pit, which is advantageous to management control.

Roads and Declines (Ramps)

The main pit roads, which are 30 m wide, usually have a slope of 1 in 15, with a maximum slope of 1 in 12 in special circumstances. Safety berms are built by the tipping of waste rock on the cliff side of these roads (see Fig. 7).

Access roads are built for the pit electrical-distribution network and the pit dewatering pipelines.

Declines are normally 50 m wide, with a minimum width of 30 m.

Waste Dumps

The first priority is that the waste dumps must be as close as possible to the pit for minimum haulage distances, waste-rock dump and pit-wall stability and drainage having been taken into account. Dumps are built at present in 20 m slices with a maximum height of 60 m.

Medium-term Planning

Forecasts of ore sales are periodically reviewed, and this information is used in the scheduling of ore and waste-rock production according to the objective of minimizing costs, constrained by the present stripping-ratio policy and the ore specifications, which require blending of the ore from several areas. These decisions are carried over to 1 in 5000 scale plans, where priority areas are indicated and ranked.

Short-term Planning

The object of the short-term planning is to translate the medium-term plan into weekly and daily plans so that the production objectives are realized efficiently

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†Maximum curve established by mining the pit level to final pit limits.

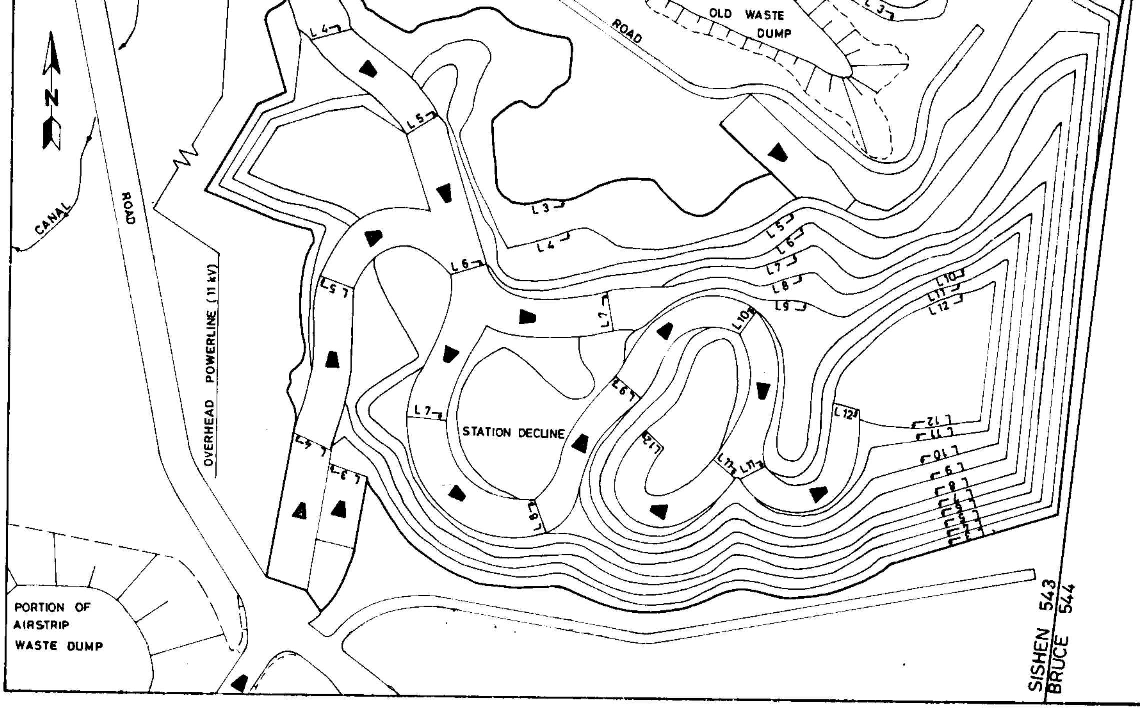

Fig. 1—Portion of the long-term plan for South Pit (scale 1:5000)

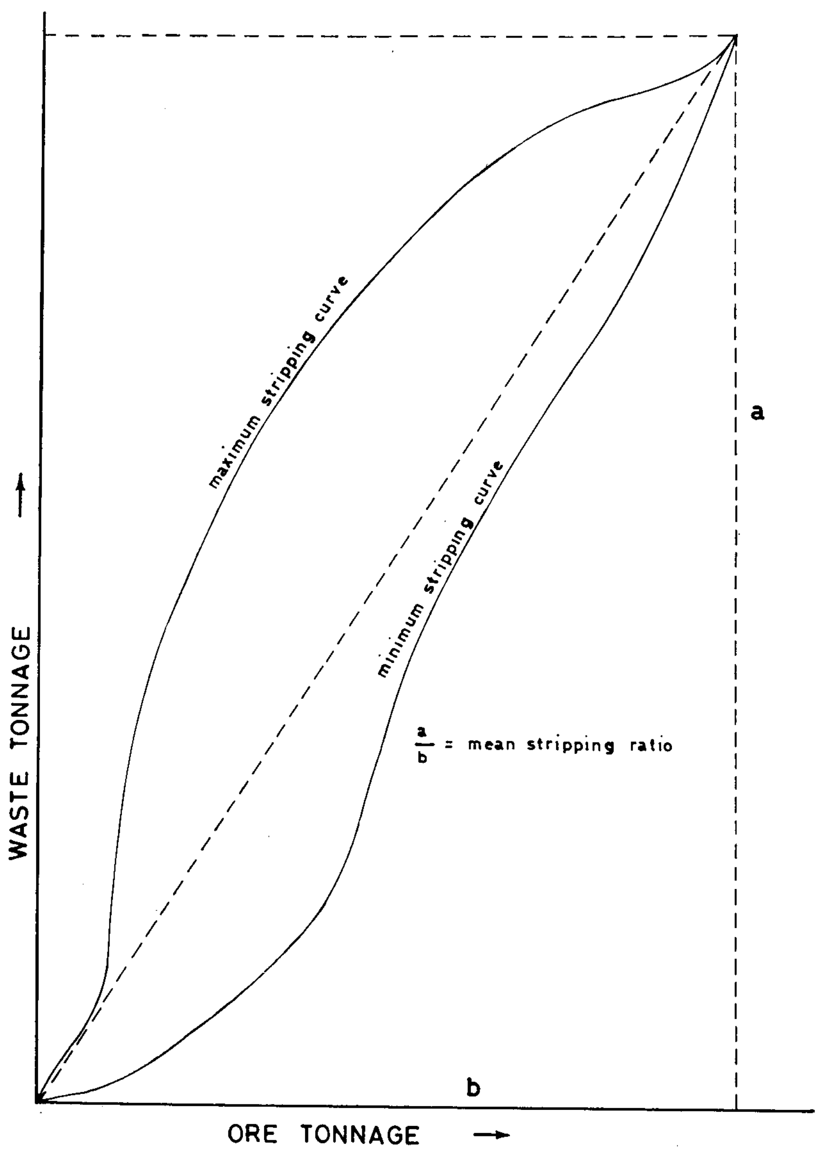

Fig. 2—Example of the stripping curves obtained from the MPS at a marginal volumetric stripping ratio of 4,3 to 1

TABLE I

PERFORMANCE STANDARDS FOR PRIMARY PIT EQUIPMENT AND MACHINES

Description	No. working at present*	Manufacture and type	Present machine-production performance standards†
Rotary drills‡ for 310 mm blastholes	12	8 × Bucyrus Erie 61R 4 × Gardner Denver 120	Penetration rate North Pit: 8 m/h Penetration rate South Pit: 7 m/h Tons per metre = 180 (North and South pits) Tons per week per machine: N. Pit, 133 000 Tons per week per machine: S. Pit, 116 000
11,5 m^3 shovels	9	P&H 2100	1200 t/h or 111 000 t/w
15,3 m^3 shovels	5	P&H 2300	1700 t/h or 157 000 t/w
90 t trucks	15	Unit Rig M-100	250 t/h (mostly used in South Pit)
150 t trucks	40	17 Wabco 150–B&C 8 Wabco 170–C 15 Unit Rig M–36	310 t/h (mostly used in North Pit)

*The machine availability and the utilization of machine availability are each 80 per cent for all the equipment listed.

†The rock handled varies from extremely hard and tough ore with a density of up to 5,0 and a uniaxial compressive strength of 300 MPa, to fairly soft calcrete with a density of 2,4.

‡These drills are shown as 310 mm machines, but 3 machines are at present still 250 mm machines.

TABLE II

PERFORMANCE STANDARDS FOR SECONDARY PIT EQUIPMENT AND MACHINES

Description	No. working at present	Type	Standard
Rubber-tyred dozers	3 9 3	Cat 824 Cat 834 Michigan 280	0,8 to 1 per primary shovel 1 to 2 per waste dump 1 per 6 primary drills 1 per 50 million tons/year for construction
Track dozers	2 5 1 1	Komatsu D355 Cat D9 Cat D8 Cat D6	1 per 8 million pit tons plus 1 for construction
Road graders	3 4	Gallion T600 Cat 160	Must be calculated according to length of pit roads and traffic density (large trucks compact roads severely so that heavy-duty graders are required)
Rubber-tyred dropball machines	3	BE 60T	One per 5 shovels
Front-end loaders	1 4 2	Kimco (2 m^3) Cat 988 (4 m^3) Dart (11,3 m^3) Cat 910 (1 m^3)	Used for the plating of fine material on roads and general construction work; 1 used at bulk ammonium nitrate store; the 2 large loaders help clean up tailings at shovels
Trucks	3 2 3	Terex 15 ton Wabco 30 ton Cat 35 ton	These work in conjunction with the front-end loaders
Water tankers	6 3	Old Euclid 30 tonners converted to water tankers Oshkosh (15 000 litre)	Used for road maintenance and dust suppression, and number depends on length of haul roads and climatic conditions
Anfo explosives trucks	2	10 ton Mercedes Benz type	Sishen uses approximately 10 to 15% Anfo at present; bagged ammonium nitrate is used at present
150 mm and 120 mm drilling machines	2 2 3	Drillboss Crawlmaster G.D. Kommando	One per 30 million tons per year The use of rubber-tyred secondary drill type is being evaluated
Various diesel and electrically driven 600 cfm and 900 cfm compressors	11	Ingersoll Rand and Gardner Denver	One per secondary drill
11/3,3 kV pit transformers mounted on skids	20	South Wales and Vanrow Engineering	1,4 per drill 1,6 per shovel *Rating;* 350 kV.A for drills 1500 kV.A for 11,3 m^3 shovels 2500 kV.A for 15,3 m^3 shovels
Mobile diesel–electric generator set trailer mounted, having an output of 1000 kW	1	Neils Motovator	One needed for a large mine to move shovels and drills rapidly, and is towed by rubber-tyred dozer

and effectively. This is achieved by co-ordinating daily meetings. Plans and documents show the scheduled activities, machine movements, and production goals of all the primary equipment. Blasting must be planned so that there is a minimum disruption of production, and so that satisfactory floor reserves of broken ore and waste rock are maintained.

Facilities and Equipment

The Strategy of Equipment Selection

The primary reason for the choice of large rock-handling mining equipment at Sishen was the economy-of-scale principle. Proportionately less labour is required to operate and maintain larger equipment, which in turn also reduces township costs.

The reason for the choice of a truck–shovel operation was the complex geology of the ore-body, which necessitated the selection of a flexible mining method. The largest and most efficient operational off-highway truck at the time of selection in 1974 was the 150t pay load electric-wheel truck. There were larger trucks on trial and in operation around the world, but the economics of these units had not yet been proved.

The rule of thumb in matching trucks to shovels is that trucks should be filled in three to five passes of the shovel. At Sishen, preliminary simulation studies showed that a 11,5 m^3 shovel matched the 150 t truck very well. When production expanded, it was decided to take further advantage of the economy-of-scale principle by purchasing larger shovels (15,3 m^3), which have thyristors that rectify the electrical power. The size of the primary crusher is an important constraint in the choice of a shovel-and-truck combination. At North Plant, where most of the export ore is crushed and beneficiated, the primary crusher is a 60 by 102 Nordberg extra-heavy duty gyratory, and the largest rock that can be handled is approximately 1400 mm by 1100 mm by 2500 mm. At South Plant, the primary crushers that had been installed were an Allis Chalmers 74 by 54 gyratory and an Allis Chalmers 40 by 48 jaw crusher, which could not accommodate the 150 t trucks. Therefore, 90 t electric-wheel vehicles were chosen. A recently commissioned third primary crusher at the South Plant is a 60 by 89 Allis Chalmers gyratory, which is capable of accommodating 150 t trucks. This crusher replaces the jaw crusher, which cannot handle the plant feed when the 74 by 54 is down for maintenance.

Table I shows the size, type, and performance standards of the primary equipment.

Secondary Pit Equipment

The secondary equipment assists the primary equip-

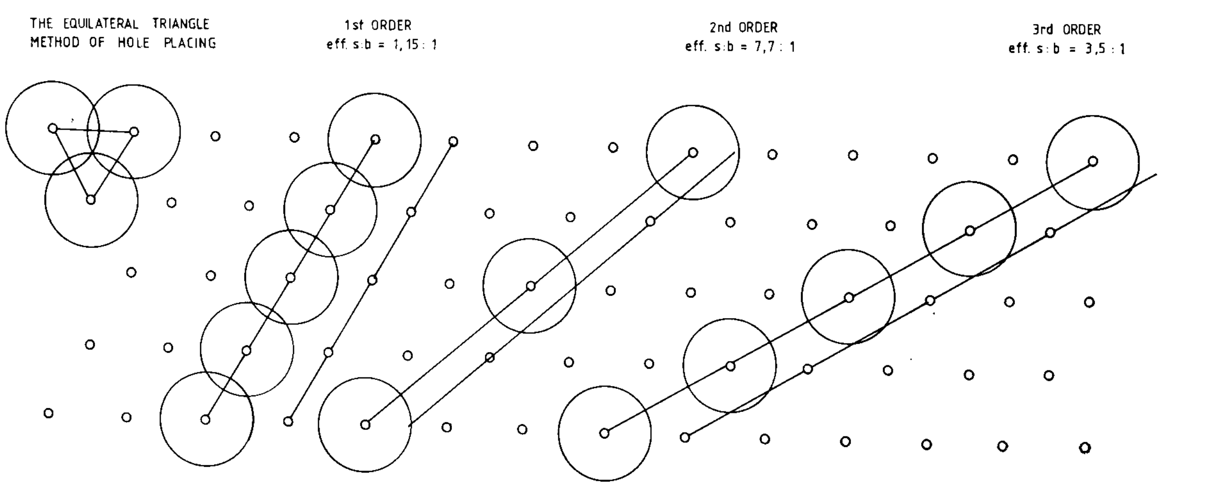

Fig. 3—The three ways in which equilateral-triangular hole placings can be tied in to achieve different effective s:b ratios

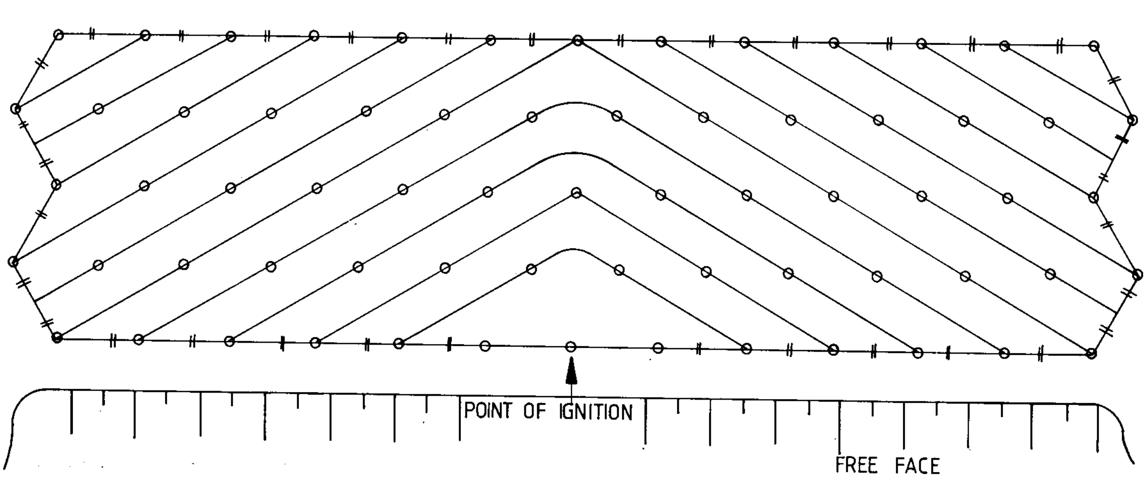

Fig. 4—Present drilling and firing patterns

ment by preparing and maintaining smooth, level working surfaces at the loading and drilling areas, the roads and ramps, and the waste-rock tipping sites.

Thus the optimum economic use of a dispersed fleet of dozers, roadgraders, front-end loaders, and small trucks is an allocation and communication problem, in which a number of activities must be performed; these activities can be executed in different ways, and the resources needed are limited.

Standards for secondary equipment are thus drawn up in a more subjective light than primary equipment and are only approximate. Table II shows the performance standards for the secondary equipment and machines.

Rock-handling Techniques

Drilling and Blasting Practice

The primary objective in open-pit blasting is seen, not only as the fragmentation of rock into the largest possible size range compatible with the type and size of mining equipment available for loading, hauling, and crushing rock[4], but as an economic operation from the systems point of view. The rock bearing the valuable mineral in the bench faces must be blasted to a size that results in the minimum costs in the total system of drilling, blasting, loading, hauling, and crushing[5].

Bench Height

A bench height of 12,5 m was selected because it was found that shovels and drills operate very effectively at that height. The use of higher benches is being investigated.

Blasthole Diameter

The development of large electric rotary drilling machines, the improvements in bit technology, and the widespread use of bulk explosives that are mixed on site have made large-diameter blastholes possible. These have resulted in a downward trend in drilling costs, the cost per unit volume of hole being inversely proportional to the diameter of the drillhole.

Sishen is at present in the last phase of changing from 250 mm to 310 mm blastholes. This change has reduced the drilling costs by 20 to 30 per cent. Fragmentation is affected by increases in drillhole diameter, and, while this was not a problem in the change to 310 mm holes, it could be a factor in a decision to change to 380 mm holes.

Bulk Explosives

Anfo is preferred in dry, relatively easy breaking

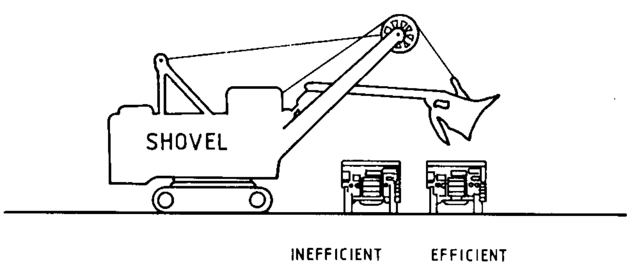

Fig. 5—Truck-loading technique

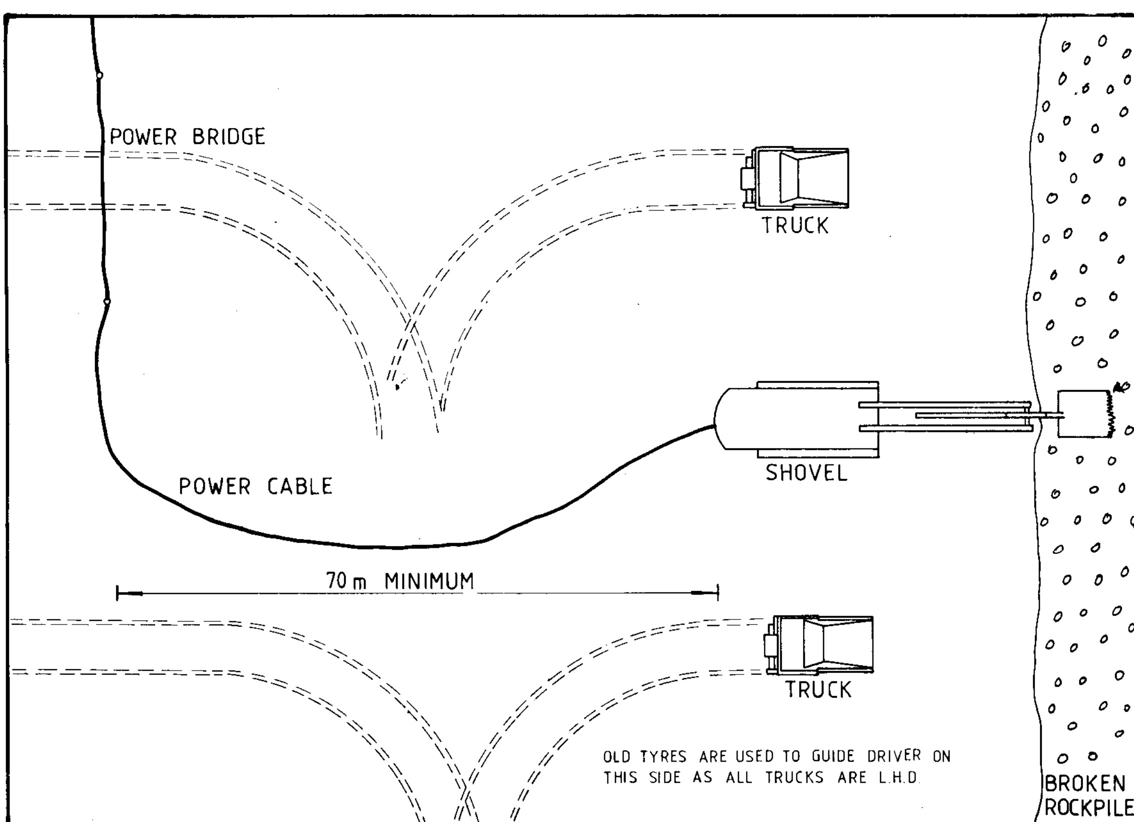

Fig. 6—Double-sided loading technique (It should be noted that no 'spotters' are used; instead, the trucks are reversed so that the driver's cabin is on the inside radius and the driver can see one of the rear wheels)

TABLE III

PATTERN AND SUB-DRILL (ALL MEASUREMENTS IN METRES)

Type of rock	250 mm blastholes		310 mm blastholes	
	Pattern b×s	Sub-drill	Pattern b×s	Sub-drill
Hard ore	5,4×6,2	2,4	6,5×7,5	3,0
Medium ore (quartzite)	5,9×6,8	2,6	7,2×8,3	3,2
Soft ore and banded ironstone	6,4×7,4	2,4	7,9×9,2	3,0
Calcrete	7,0×8,1	2,6	8,6×9,9	3,2

conditions because of its lower cost. In wet, dense material, slurry explosives are used.

Sinex series F600 slurry is supplied by AECI in 12 t payload trucks on a down-the-hole service contract. The energy can be varied by the addition of 4 to 14 per cent aluminium.

Sub-drill (Table III)

Sub-drill is necessary for efficient digging to grade, and the optimum sub-drill depths for various rocktypes, structural conditions, and drilling patterns are at present still under review. Crater cones usually break out at approximately 25 degrees to the horizontal, and these cones should be of sufficient depth to break the face to the required floor level. As the number of rows blasted increases, there appears to be a decrease in the depth to which the cones break.

Pattern (Table III)

All the holes, except those in the ramps, are drilled on an equilateral-triangular pattern since it gives complete coverage of an area for the least amount of overlap and produces 30 per cent more broken ground per hole than the square pattern[6]. Crack patterns develop best when the holes are fired far apart, as shown in the second- and third-order diagonals in Fig. 3[6]. The chevron method of firing the patterns is shown in Fig. 4.

Stemming Height

Excessive burdens in the front rows are avoided by the use of an inclinometer, which measures face dips for the correct determination of front-row positions. When faces have irregularities, easer holes are used.

At Sishen, the stemming standard is 5 m in the front and middle rows, and 7 m in the rear row. A small variation (up to 1 m) is allowed.

Optimum Charge

The standard, which is still under evaluation, is 3,0 to 3,2 t of 10 per cent aluminium slurry per kilogram, or its equivalent. The mass of explosives charged is calculated for each hole on this basis. Where Anfo is charged, a 4 m rise of 10 per cent aluminium slurry is used as a toe load.

The chevron method is preferred (Fig. 4) because it helps hold the muckpile together[7].

Delay Intervals

The aim of multi-row blasting is to maximize shovel production and minimize production delays due to blasting. Blasting can cause up to three hours of lost production in the section of the pit where the blasting is done. Thus, in new pits, where face lengths are restricted, 'deep' multi-row blasts are desirable for maximum production. The delay interval between rows in the firing pattern is the key to this problem.

Delay intervals between rows are at present 40 ms. High-speed photography of the blasts has indicated that longer delays should be used. There has been a high incidence of cut-offs when longer delay intervals are used. However, experiments with long down-the-hole delays, which are immune to cut-offs, are planned.

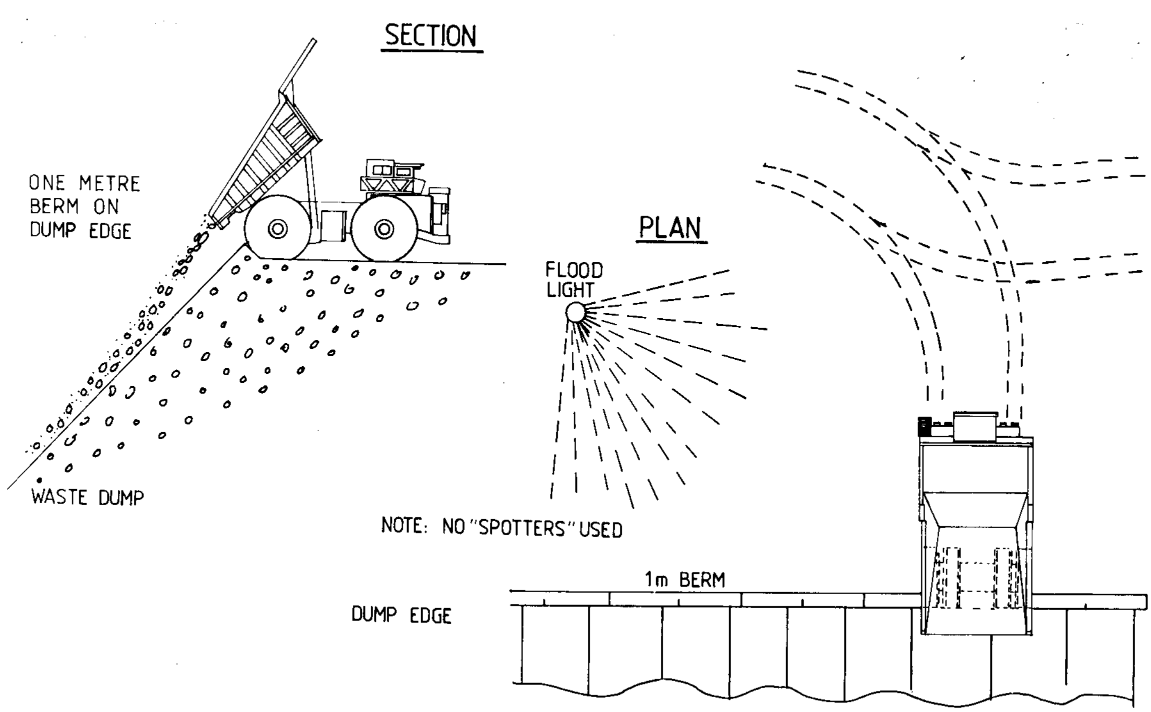

Fig. 7—Waste-dumping techniques

Blast Preparation

Each hole is charged with two lines of Premium Cordtex attached to two 400 g Pentolite boosters, one of which is placed slightly above floor elevation and the other 2 m above the first. The explosives are pumped down the hole, and the mass is carefully controlled according to a blasting plan, which shows the calculated amount of explosives for each hole. Holes are then tied in with Standard Cordtex and fired at blasting time by means of a 2 m safety fuse and detonator.

Practical Methods of Evaluating a Blast

Experience has shown that, when a block has been blasted well,

— 'throw' should be limited;
— the main muckpile should be compact with few big rocks;
— the rear face should be fairly straight;
— there should be a drop in the rear face;
— the corners should be cleared;
— few tension cracks should be seen at the rear;

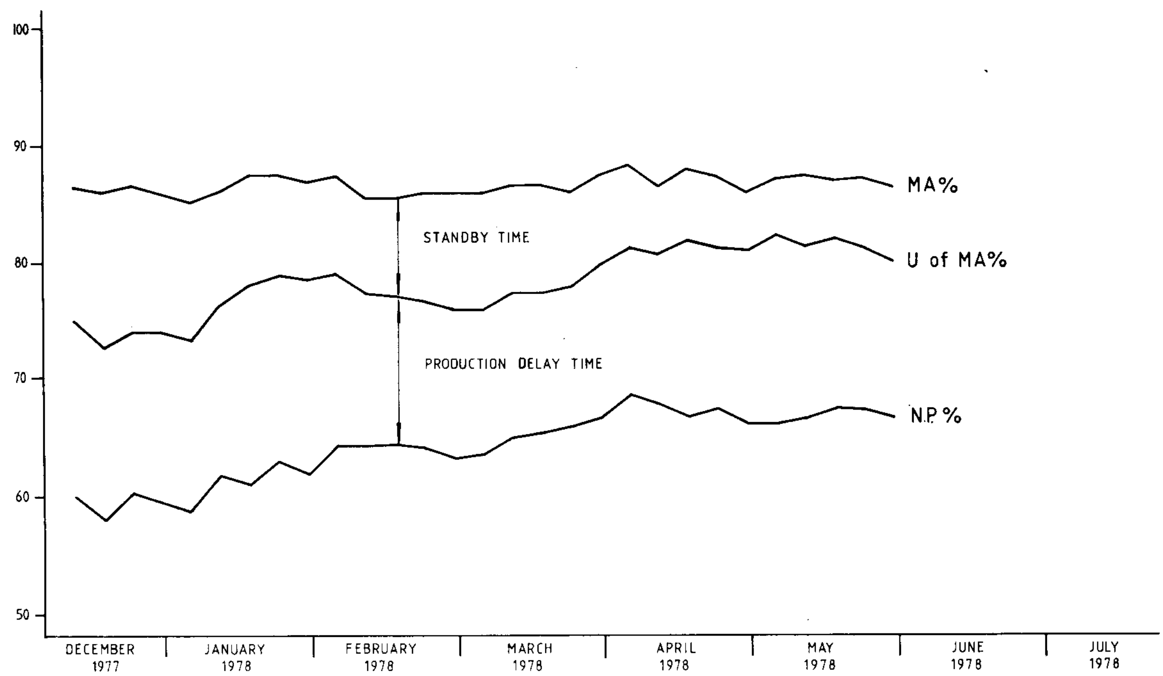

Fig. 8—Exponentially weighted moving averages of the availabilities of the 310 mm Gardner Denver rotary drills

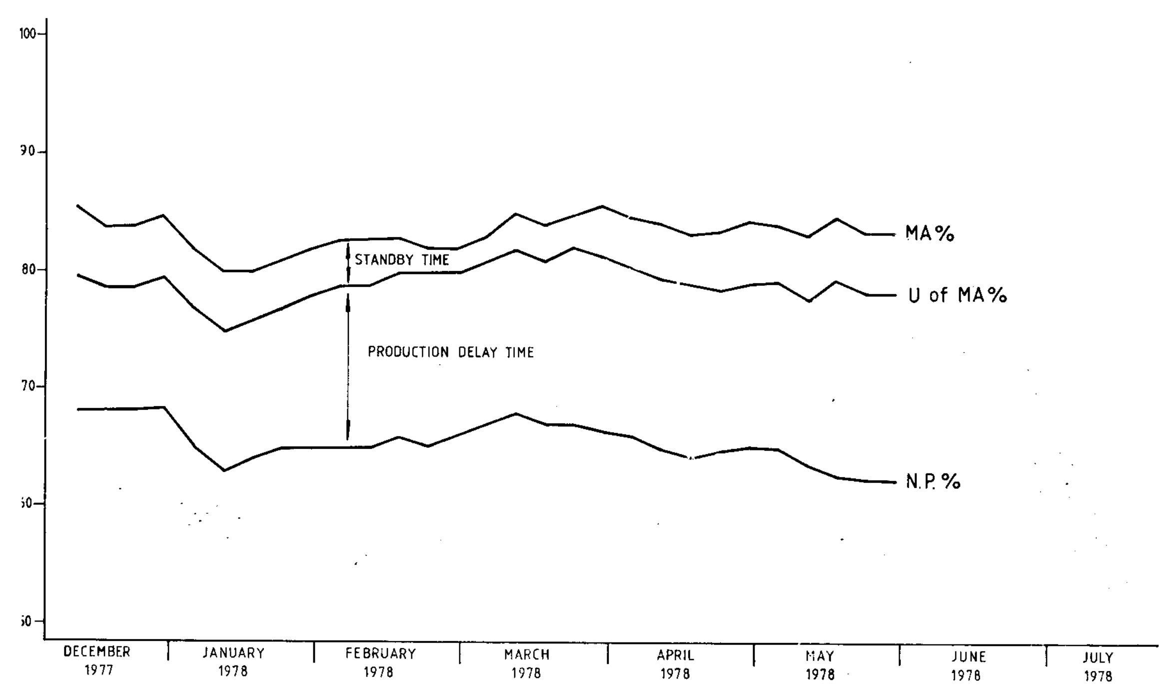

Fig. 9—Exponentially weighted moving averages of the availabilities of the P&H 2300 15,3 m shovels

— the muckpile height should be the same as the bench floor level above;
— longer delays and/or a shallower chevron pattern should be used if the area at the cut is too high;
— excess height and backspill also means that the rear layers 'queue' behind the earlier layers and are 'choke' blasted;
— there should be no cratering anywhere;
— when loading out, there should be no uneven floors or toes;
— subsequent shovel-loading rates should be high, and floors should easily be dozed to grade.

Loading and Hauling

Essentially, the two prerequisites for efficient loading and hauling are level, clean roads and floors, and the practice of double-sided loading of the shovel.

Uneven floors and roads cause truck mainframe failures, power-cable damage, and reduced shovel-production rates.

Floors are controlled by sighting on a surveyed plane, 1,4 m above floor level, given by string attached to a three-legged pipe frame. The shovels are marked with a line 1,4 m high. High and low points can be established by the use of a staff.

Efficient and effective organization at the shovel means, firstly, that power-cable bridges must be used so that trucks can be loaded on both sides, and, secondly, that a rubber-tyred dozer must be available to clean the spillages and tails. Loading and dumping techniques are shown in Figs. 5 to 7.

Maintenance of Pit Equipment

This section is responsible for the efficient and effective management of the following:
— Pit electrical-distribution and installation systems
— pit-dewatering system
— maintenance of primary and secondary pit equipment
— maintenance of diesel–electric and diesel–hydraulic loading and shunting locomotives
— running-shed type maintenance for main-line diesel–electric locomotives.

This section also takes part in the decision-making for the selection and specification of pit and maintenance equipment.

Methodology

The object is to help achieve minimum total mining costs by maximizing the economic life of machines, materials, and components.

The basis of this system is an extensive and sophisticated planning system, which includes records of every part. Predicted part lives serve as guidlines for selective scheduled inspections in which parts are evaluated for replacement. Thus, the optimum work on a machine can be planned and scheduled.

Most maintenance work is performed on day shift, and a skeleton staff copes with breakdowns on night shift.

Facilities

A central workshop building, 153 m long with two main sections, 25 m and 15 m wide, and equipped with overhead cranes, is used to repair the pit equipment and the shunting locomotives. Scheduled services on the pit equipment are carried out in the 25 m wide section, while the re-conditioning of engines, wheel motors, and hydraulic components is carried out in the 15 m wide bay.

The spares store, storeyard, and offices are adjacent to the shop. Tyres are stored in a separate 66 m by 20 m building, where there are facilities for the control, matching, vulcanizing, handling, and fitting of tyres.

A very large service station, nearer the pit, caters for the high-pressure water cleaning of pit equipment and the

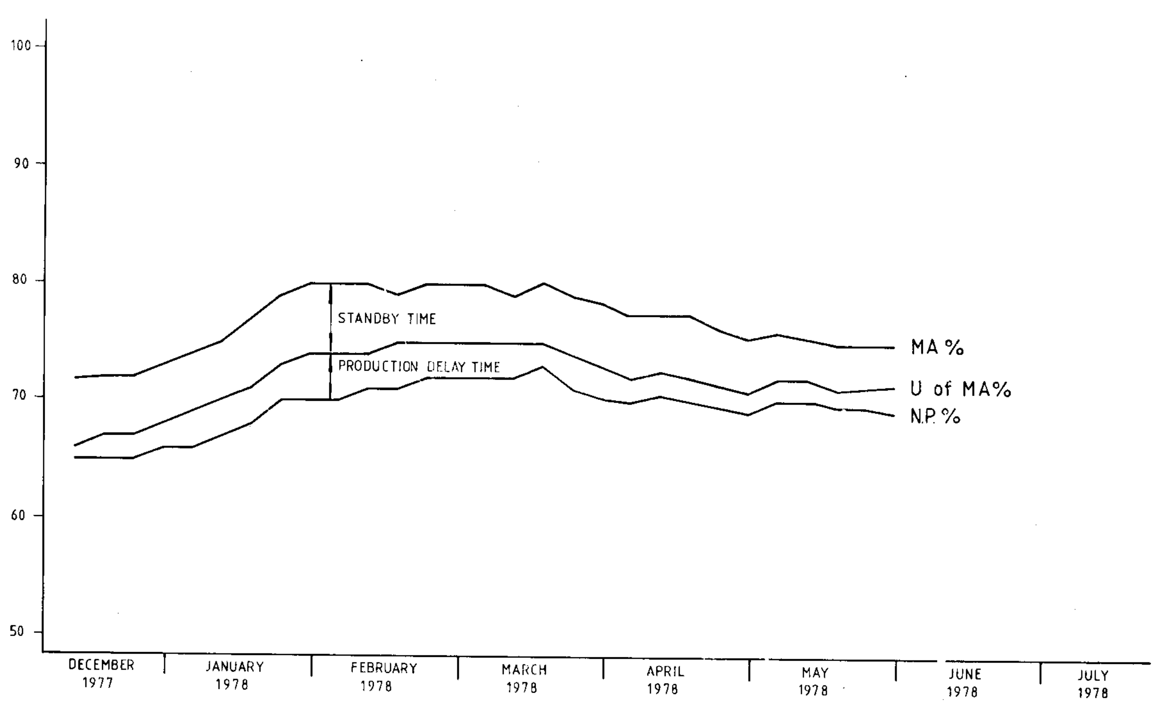

Fig. 10—Exponentially weighted moving averages of the availabilities of the 150t Wabco trucks

provision of fuel, grease, oils, water, and air. The daily maintenance inspections are also undertaken at the service station.

Lubricants are delivered in 7000 litre bulk containers, and are pumped to user points to eliminate re-handling and contamination. Quick couplings ensure quick and efficient lubrication of machines.

Attention has been given to the standardization of lubricants; for example, only one type of engine oil is now used. This meets the low-ash 'Caterpillar Series 3' specification, and has a viscosity range that covers the specifications of both SAE 30 and 40 grades.

Samples of oil, taken regularly from each engine, are analysed by atomic-absorption spectrographic methods to obtain trends of the main elements, thus aiding diagnosis and part life prediction. Oil-change frequencies are changed continuously.

Availability of Equipment

Figs. 8 to 10 show exponentially smoothed availability graphs for the 310 mm Gardner Denver rotary drills, the P & H 2300 shovels, and the Wabco 150 t trucks. The formulae used are as follows:

$$\text{Mechanical availability, } \% = \frac{T-H}{T} \times 100,$$

$$\text{Utilization of mech. avail., } \% = \frac{T-H-B}{T} \times 100,$$

$$\text{Net production, } \% = \frac{T-H-B-Pv}{T} \times 100,$$

where T = total production time
H = maintenance time
B = standby time
Pv = production delay time.

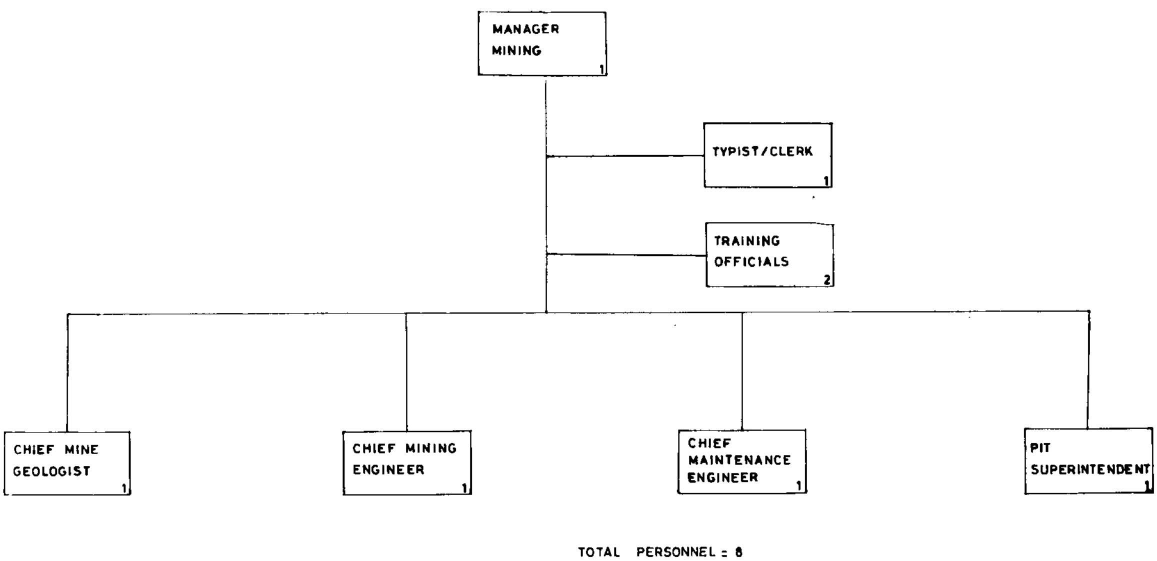

Fig. 11—The mining management

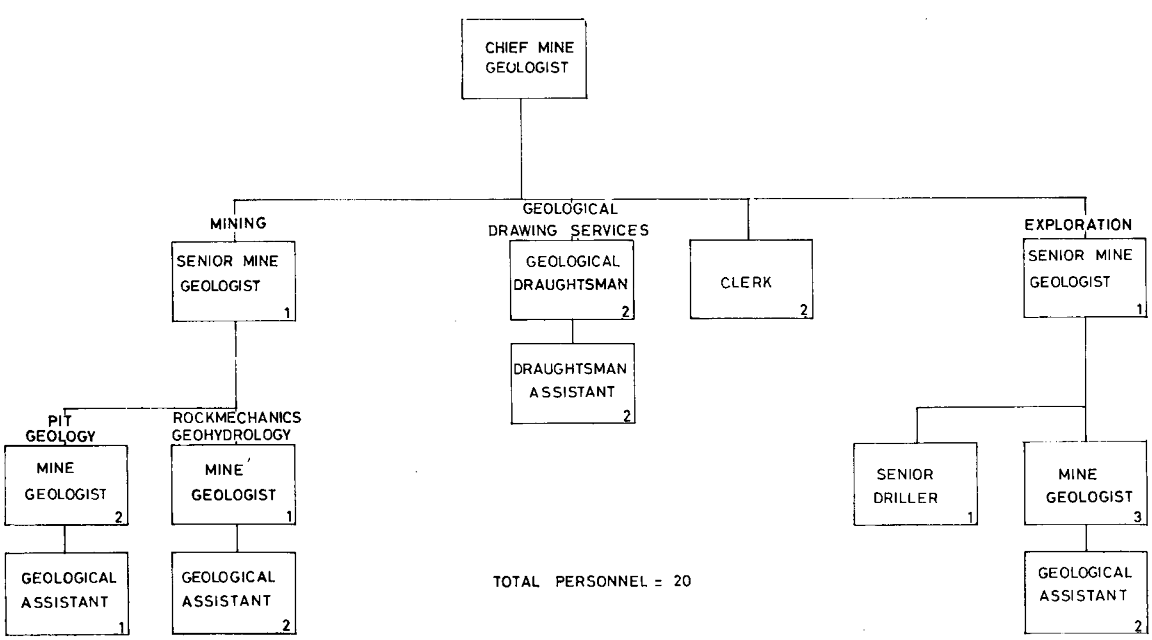

Fig. 12—The geological section

The exponential smoothing is done according to the following formula[8]:

Smoothed factor, $F = AS_t + (1 - A)S_{t-1}$,

where A = weighting factor (in this case 0,15)

S_t = actual factor for period

S_{t-1} = smoothed factor in period $t-1$.

Training

Training of operators is essential for the economic use of mining equipment.

Operators are selected firstly by means of physical-fitness tests and then by means of co-ordination and aptitude tests.

TABLE IV

NUMBER OF PERSONNEL IN THE MINING SECTION

Group	Qualified staff	Unskilled staff
Mining Management group	8	—
Geology	20	17
Mining Engineering	43	44
Maintenance	252	315
Operations	138	654
	461	1 030

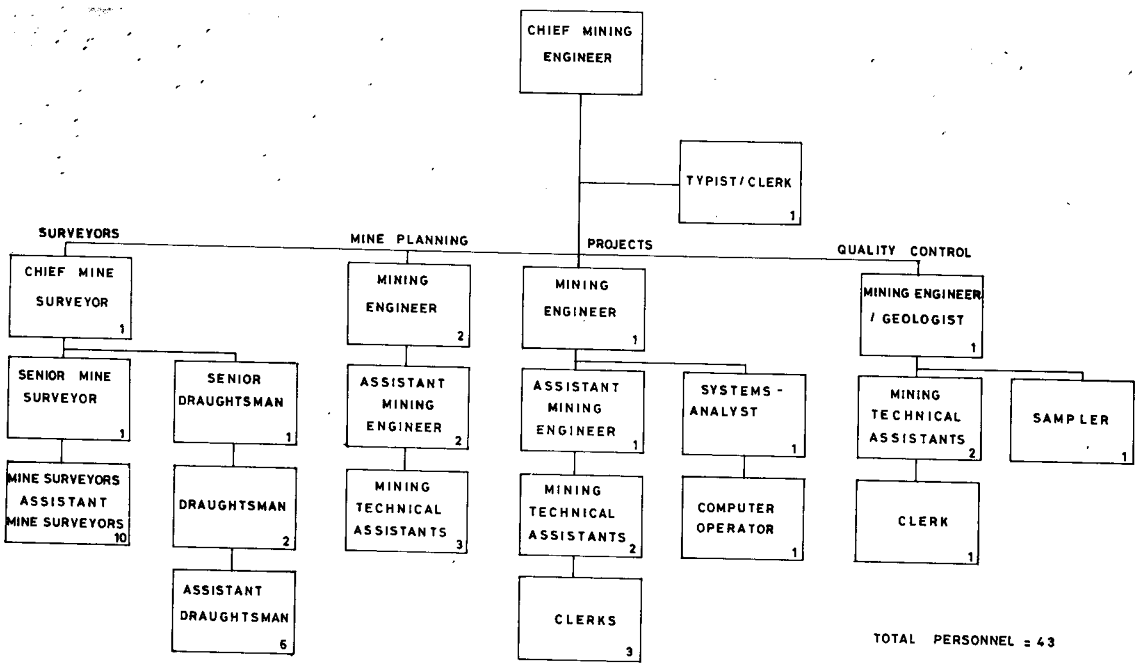

Fig. 13—The mining-engineering section

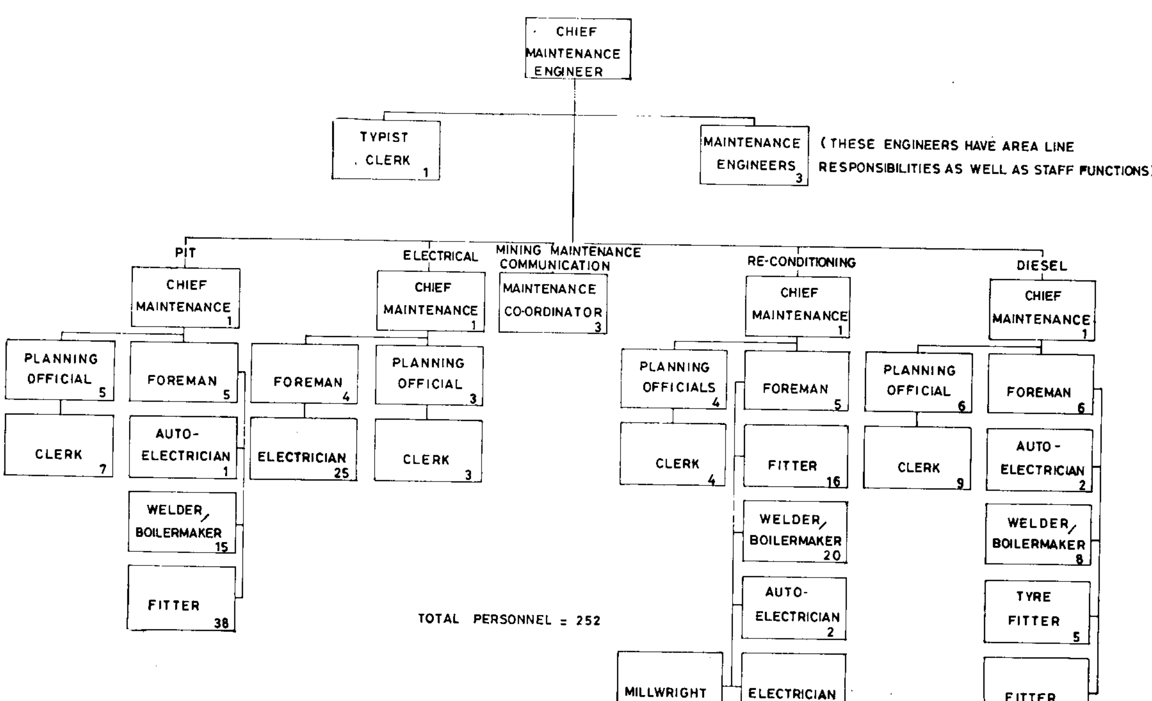

Fig. 14—The maintenance section

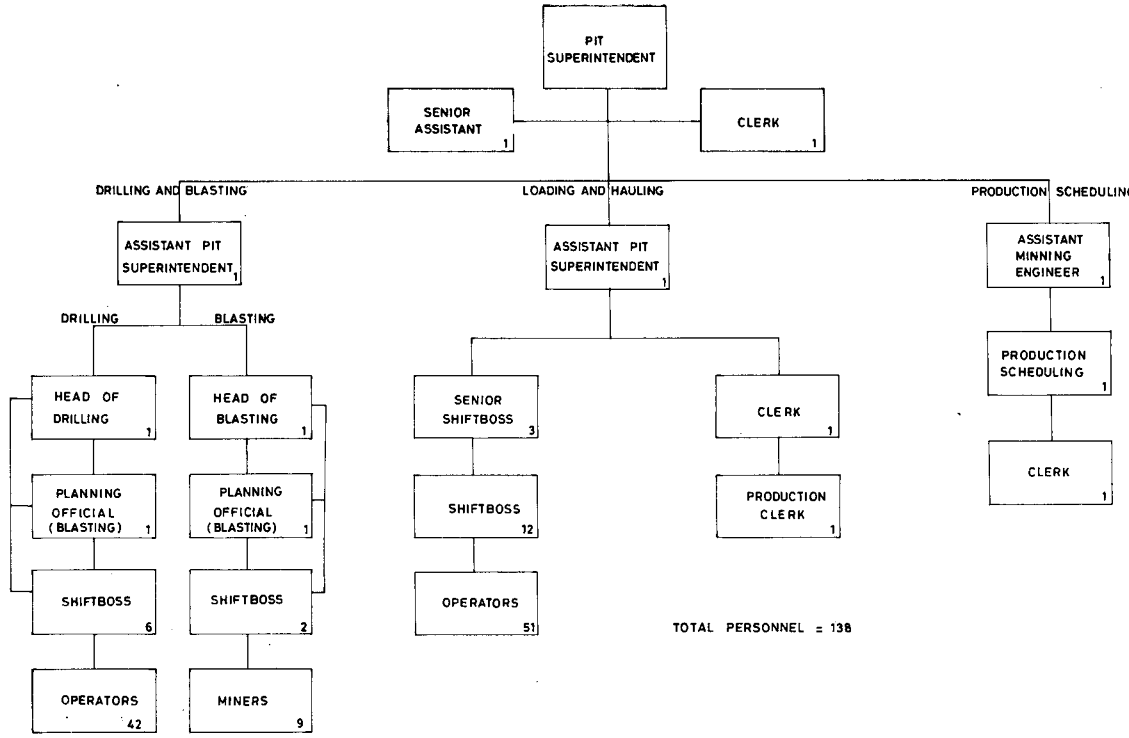

Fig. 15—The operations section

Extensive use is made of the audio-visual method of training. Comprehensive training manuals, written in simple language, provide useful aids to the instructors.

In the case of dump trucks, a driving simulator linked to a film projector is used to familiarize the trainee with driving the truck on pit roads.

Training on a special test ground precedes a spell of instruction in normal pit-production conditions.

Organization

Formal organization charts for the mining section are shown in Figs. 11 to 15. These charts are not static, but are periodically revised and adapted.

A summary of the mining personnel shown in these diagrams is given in Table IV.

The productivity of the mining personnel in May 1978, which comprised 415 qualified staff and 1013 unskilled staff, was 185 tons per man shift.

Changes

An advanced truck-dispatching system, based on the Palabora system[9], came into operation in December 1978. Preliminary simulation studies indicated that this could reduce hauling costs by 6 per cent.

Bulk handling and placing of aluminized Anfo is planned in the medium term. The MPS will be expanded as many planning and pit design decisions are programmable.

Since it is the aim of the Sishen management control to meet production and cost objectives by means of efficient and effective rock-handling techniques, any changes that are seen to promote these techniques economically will be implemented as they become available.

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