The selection of underground equipment for coal mines*

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SYNOPSIS

The most important criteria in the selection of mining equipment (mining conditions, operational performance, engineering design, manufacturer's involvement, and financial considerations) are discussed in turn. Some mention is made of the equipment population in South African collieries, and it is pointed out that both the manufacturer and the mine operator should take due cognizance of future trends in equipment.

SAMEVATTING

Die belangrikste maatstawwe by die keuse van myntoerusting (mynboutoestande, bedryfswerkverrigting, ingenieursontwerp, betrokkenheid van die vervaardiger en finansiële oorwegings) word om die beurt bespreek. Daar word melding gemaak van die toerustinggetalle in Suid-Afrikaanse steenkoolmyne en daar word op gewys dat sowel die fabrikant as die myneksploitant behoorlik kennis moet neem van toekomstige tendense in toerusting.

Introduction

In recent years, coal mining has undergone dramatic changes throughout the world. A new vitality, unprecedented in the history of this age-old industry, has emerged. With the aid of the most sophisticated technology available, research and new developments on equipment and techniques are the order of the day.

Although the power-generation, metallurgical, and petrochemical industries promised a fairly stable future for coal in South Africa, until some fifteen years ago it was regarded internationally as a fading commodity. Up to that time, natural mineral oil and nuclear power, supplemented by hydroelectric and solar power, were regarded as the prime sources of energy over the medium term, i.e. for the next fifty years. However, the Opec-inspired oil crisis, which came to a head in 1973, the continuing and to date unresolved debate on nuclear power, and the slow progress in the development of solar power have enhanced the future of coal beyond all expectations. Throughout the turmoil of what is best-termed the 'oil-based energy crisis', vast quantities of coal reserves were waiting to be exploited. Today, with all the market indicators prophesying a bullish future for this mineral, it is generally accepted that global development will have to rely heavily on coal if energy demands over the next few decades are to be met.

According to one of the more conservative forecasts of world energy consumption, coal could supply about 75 per cent of the increase in energy demand over the next twenty years. This would mean a threefold increase in the use of coal, directed mainly towards power generation, and an expansion of ten to fifteen times in steam-coal trade. There are indications that the major growth in export will come from the United States of America, Australia, Canada, and the Republic of South Africa.

The prospects for coal, and hence coal mining, appear to extend far into the future, and decisions made now by the investor, the equipment manufacturer, and the coal-mining engineer will influence the industry for a long time to come.

Choice of Mining Method

In deciding on a method of mining, the coal-mining engineer has three avenues open to him: surface mining, underground mining, or a combination of the two. The parameters dictating the choice of mining method depend on economic, geological, and technological considerations, the last of the three imposing the least constraint on the decision.

The choice of whether coal will be mined by surface or underground techniques depends, among other things, on geological information and, more specifically, on the nature and thickness of the overburden. In general, only reserves occurring at shallow depths can be surface-mined, although in multiple-seam deposits the use of strip-mining techniques may permit mining at depths up to 90 m.

In the Republic of South Africa as elsewhere, surface mining has expanded tremendously over the past decade. Although this trend is expected to continue for some time, it must be realized that the majority of the world's coal deposits are accessible only by underground mining. Since the reserves in South Africa that are extractable by underground methods have been calculated to constitute some 80 per cent of the total *in situ* reserves, it is reasonable to assume that the greater part of South Africa's coal production, like that of the rest of the world, will still come from underground mines by the end of the century.

Fig. 1 is a simplified representation of the known reserves in the Republic and the methods available for mining them. The depths and percentages are rough estimates, and are merely intended to give some impression of the options open to the mine designer.

Mining methods vary considerably throughout South Africa, and depend on geological, economic, and tech-

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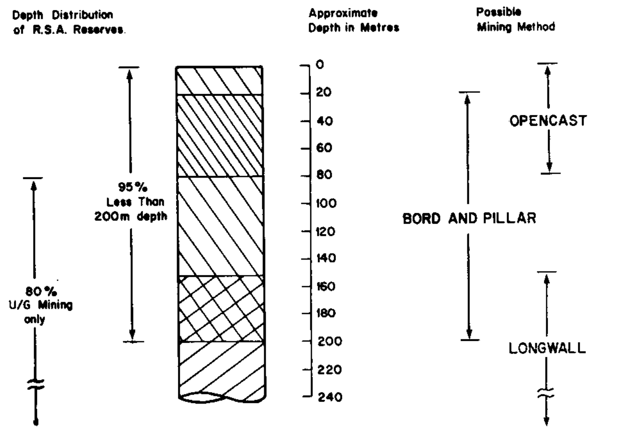

Fig. 1—Coal reserves in the Republic of South Africa and available mining methods

nological considerations. For example, the depth of a surface mine depends on the economic stripping ratio, which is a function of the depth and composition of the overburden, the seam thickness, and the price of the product. Bord-and-pillar mining depends on the width of the seam, the depth below surface, market considerations, and percentage extraction. Being extensions of bord-and-pillar mining, pillar and rib-pillar extraction are in addition (like surface and longwall mining) subject to constraints resulting from surface features such as roads, railways, buildings, powerlines, dams, and rivers.

King[1] gives a forecast of the annual coal production in South Africa and shows trends in the different methods of mining for the period 1965 to 1990.

Most South African coal is produced by underground mining, the main methods being longwall mining and bord-and-pillar mining. In recent times, a third distinct mining method, rib-pillar extraction, has emerged. Unlike other pillar extraction methods, which are secondary operations flowing from bord-and-pillar mining, rib-pillar mining differs in both the primary and the secondary extraction phases. Although the mining equipment, such as continuous miners and shuttlecars, are the same as for bord-and-pillar mining, this method is viable at greater depths. Yet, it is not as capital-intensive as longwall mining.

Selection of Equipment

The determination of the most economic mining system is regulated by a host of factors. Although modern techniques such as those involving microprocessors, computerized programmes, and simulations based on sound engineering principles increase the probability of success in the decision-making process, human judgement substantiated by experience remains the single most important input in the selection of production equipment.

The criteria used in the choice of equipment are so intimately related to those applied in the formulation of mining methods that they cannot be separated. Once the mining method has been selected, the choice of equipment is narrowed down substantially; in fact, conceptual selections have already been made during the selection of the mining method.

The selection of the technique to be employed in the exploitation of a mineral deposit depends on geological, geometrical, and ecological factors, as well as market analyses, and the availability of capital, infrastructure, technology, labour, expertise, and a suitable means of financing.

In the choice of the most suitable equipment, the same factors are used in addition to other criteria, although there is a definite change in emphasis: whereas economic considerations such as capital deployment, return on investment, the opportunity cost of money, market demands, and marketing prospects are the main issues in the selection of a mining method, compatibility with mining conditions, reliability, efficiency, and productivity are the prime considerations in the choice of equipment. The initial cost of equipment should not be regarded as very important unless operating costs including labour, maintenance, and replacement costs are also taken into account.

The most important considerations in the selection of mining equipment can be grouped into the following categories: mining conditions, operational performance, engineering design, manufacturer's involvement, and financial considerations. Some of the building blocks used in this decision-making process are depicted in Fig. 2.

Fig. 3 summarizes the elements required in the selection of a specific machine. The diagram relates to a shuttlecar, but the criteria apply to all types of equipment.

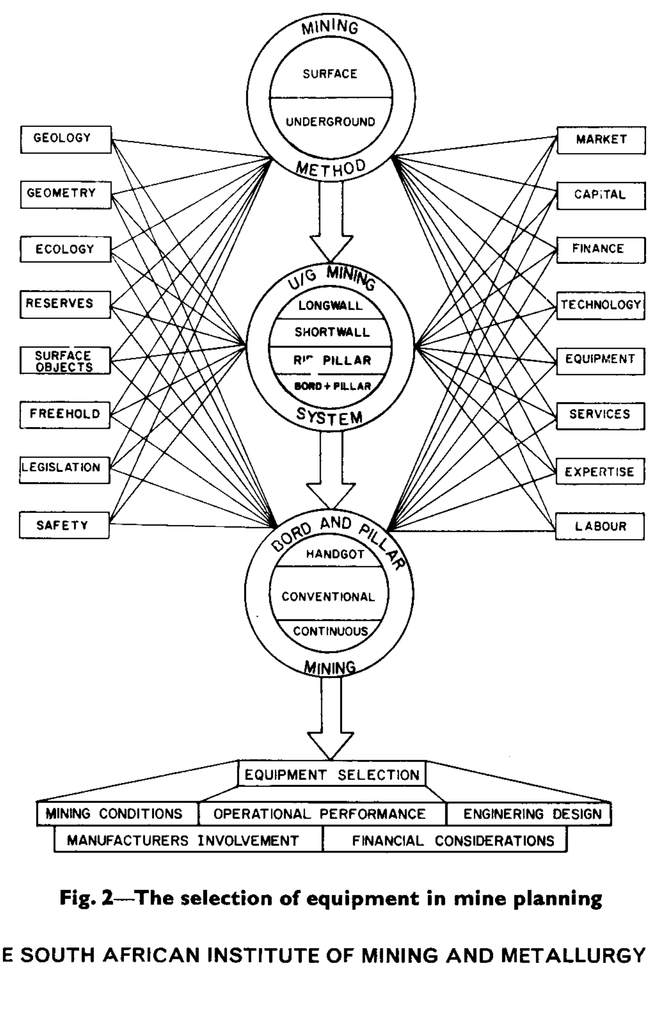

Fig. 2—The selection of equipment in mine planning

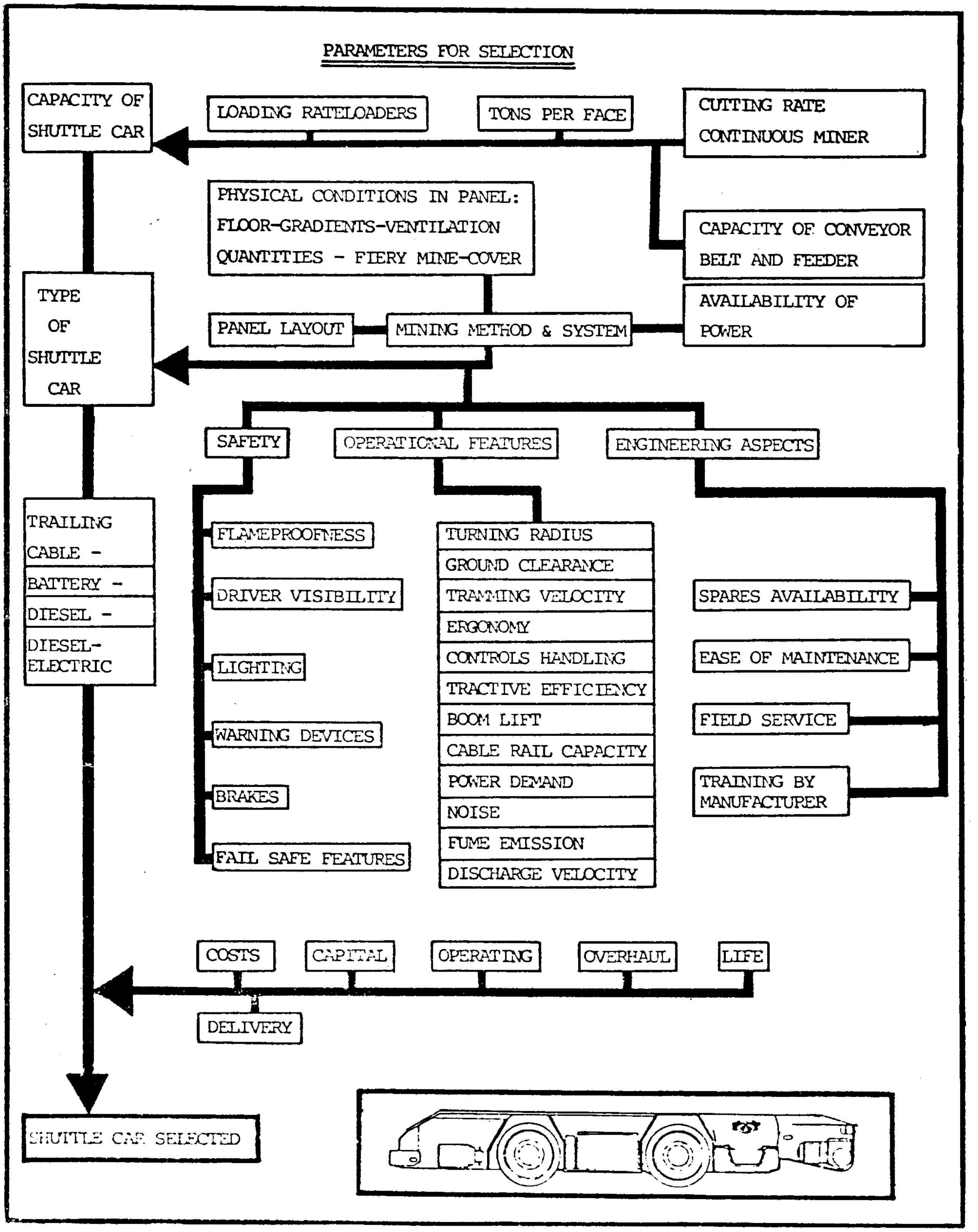

Fig. 3—Criteria for the selection of a shuttlecar

Mining Conditions

Mining conditions are probably the largest variable in the selection of equipment. Not only do conditions differ considerably from mine to mine or from seam to seam, but substantial variations may occur within the same seam on a particular mine. It is therefore extremely difficult to give hard and fast rules to satisfy all conditions. The changing of even one element in the total structure of a venture can create another permutation, resulting in a completely different approach.

Condition-related factors in the selection of equipment include the following.

Working Height

The working height not only determines the profile of the equipment but also has a strong influence on the type of equipment to be employed. In narrow seams, for example, preference may be given to continuous miners with continuous haulage arrangements or tram scoops with ejector buckets, instead of shuttlecars and load–haul–dumpers.

Floor and Roof Conditions

A poor roof may necessitate the use of continuous miners, whereas a severely undulating floor could prohibit this type of equipment. A soft, decomposed floor could swing the decision away from wheel- or track-driven machines to equipment such as continuous-haulage and trackless continuous miners.

Ventilation

The quantity and quality of ventilation available determine whether the air in a bord-and-pillar section will be split or coursed. In turn, the decision could favour either conventional mechanized equipment or continuous miners. Diesel and diesel–electric equipment, as opposed to electrically driven and battery-operated machines, will also be influenced by this factor. According to the South African Mines and Works Act and Regulations (1956), the quantity of ventilation available limits the output of a mine. In an operating mine it is thus senseless to select equipment with capacities in excess of that determined by the ventilation unless the ventilating air can also be increased.

Mineral Hardness

The use of conventional mechanized or continuous miners, or of hand-held electric drills or hydraulic jumbo drills, depends on the hardness of the minerals present. In general, the harder the coal seam, the more are explosives are used for breaking.

Geological Disturbances

Dykes, faults, sills etc., if in abundance, could favour the use of load–haul–dumpers instead of gathering arm loaders and shuttlecars. The load–haul–dumpers can negotiate severe undulations in the floor, as well as handle the loading of heavy and hard rock materials.

Seam Gradients

Gradients that are consistently more than about 1:12 could prohibit the use of battery-operated vehicles owing to a drastic reduction in battery life. The use of diesel or electrically driven equipment would then be favoured.

Pillar Centres and Bord Widths

Being a function of depth and safety factors, the physical dimensions of equipment and their turning radii depend to a lesser degree on pillar centres and bord widths.

Percentage Extraction

The maximizing of extraction by pillar and rib-pillar extraction has largely become the speciality of the continuous miner–shuttlecar combination. However, top-coaling remains the exclusive area of mechanized mining using either gathering arm loaders with shuttlecars or load–haul–dumpers. It seems unlikely that continuous haulages will find application in top-coaling.

Operational Performance

The operational performance of a piece of equipment means different things to different people: to the operator it may mean power, speed, manoeuverability, controls handling, and comfort; to the supervisor, it may mean capacity, rate, health, and safety; and to the maintenance crew it may mean availability and reliability. In the spheres of middle and higher management, factors such as operating costs, efficiencies, and productivity tend to be the prime considerations.

Whatever the bases of appraisal, each has its own advantages and shortcomings, and sheds light in a particular area. Like pieces in a jigsaw puzzle, they must be used in combination to build up a composite picture of the issue in question.

Operating Costs

The means of defining and measuring operating costs are influenced by the type of equipment employed and the policies governing their operation. In some instances, machine overhauls and labour are included to produce an overall figure, while in others the calculation includes only breakdown and maintenance spares, lubrication, and power or fuel consumption. (Operating costs are expressed in rands or cents per ton, per hole, per cut, per hour or, seldom in the case of underground equipment, per unit distance.)

The importance of labour as a part of operating costs should not be under-estimated. Labour-intensive equip-

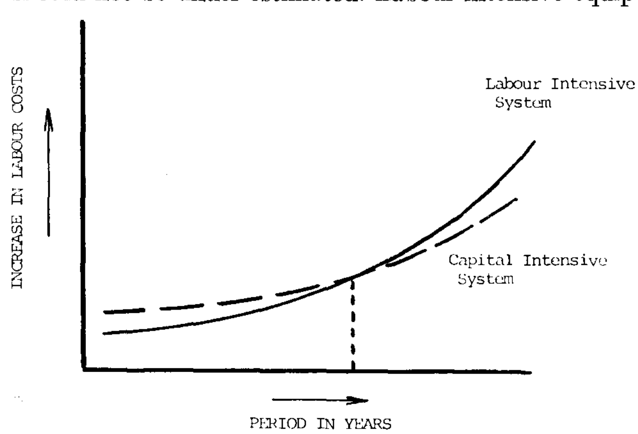

Fig. 4—A comparison of labour costs in labour-intensive and capital-intensive mining systems (after Cloete and Halgreen[2])

ment may appear attractive when its capital cost and operating expenses are considered, but a projection on future wage increases may favour the more capital-intensive system. Cloete and Halgreen[2] have demonstrated this graphically (Fig. 4.)

Efficiency

The efficiency of a machine is commonly confused with its productivity. Many people relate efficiency incorrectly to tons per man, or something similar. It must always be borne in mind that efficiency is measured against a standard, whether a standard specified by the manufacturer or one based on the results of similar equipment or activities. The evaluation of efficiency is influenced by factors such as mining conditions and operating procedures. Unlike engineering efficiency, which is a measure of output against input, operating efficiency is the ratio, expressed as a percentage, between actual results and rated, standard, or potential capacities.

A useful measure of the efficiency of a machine or operation involves comparison with a standard that has been set on the basis of time studies.

Productivity. Productivity is normally expressed in terms of the output per man, the output per time unit, or the duration of an activity or operation. Productivity in itself is meaningless unless it can be compared with something similar or related to a financial value.

Reliability. The reliability of equipment cannot be readily quantified. It is subject to a number of factors such as engineering design, mining conditions, operating procedures, maintenance schedules, and overhaul programmes, and is only one of the factors influencing availability.

Availability. Equipment availability is subject to various elements such as breakdowns, maintenance, and standby schedules, as well as to external factors (for example, an underground conveyor belt being on stop owing to a breakdown on the surface plant). When availability is used in the evaluation of equipment performance, it is essential that all the factors influencing the availability are correctly identified.

Ergonomics. The study of human efficiency in a working environment is a subject that, until recent years, was grossly neglected in the mining industry. It is fully realized that the performance of machines and equipment depends to a large extent on the operator's degree of contentment. Factors to be considered in this regard are lighting, noise, operator's visibility, handling of controls, safety, comfort, physical force exerted, and degree of skill required.

Compatibility. For optimum performance, equipment must be so selected that its capacity, rate, and design match those of the other equipment in the production line. There is no sense in installing a 2 m wide conveyor belt if the same job can be done by a 1 m belt, and all the shuttlecars in the world will not increase the output if the belt conveyor cannot handle the tonnage. The same sort of analogies can be drawn for continuous miner–shuttlecar and loader–shuttlecar combinations. Over-design is as bad as under-design. In either instance, the maximum return on investment and the shortest pay-back period will not be achieved.

Safety and Health. These aspects are of great importance in the selection of equipment. Although the technology for the manufacture of extremely safe equipment does exist, it is regulated by economic considerations. A fair balance between degree of safety and cost has thus to be sought at all times.

The evaluation of operational performances in the selection process is to a large extent based on historical fact and experience. Only by the conscientious and accurate accumulation and recording of results, together with their sensible analysis, computation, and presentation, do these facts become meaningful. However, such statistical data may not always be readily available when new equipment is to be introduced to a specific mining venture.

In the case of novel ideas, principles, or designs, the mine should arrange with the manufacturer or agent to use the equipment for a trial period prior to purchase. Most manufacturers are quite agreeable to this, and may charge a nominal fee for the trials based on some lease formula.

When operational peformance is used as a criterion in equipment selection, it should be remembered that no two mines are the same. Results obtained in one environment may be completely different from those which can be expected elsewhere. Factors such as mining conditions and geometry, management policies, training, and discipline all have an influence on the results obtainable from equipment and machines.

Engineering Design

The design of equipment and machines from a purely engineering point of view has been the subject of numerous papers and discussions. This is a topic of vast proportions, which is outside the scope of this paper.

The evaluation and choice of underground mining equipment are strongly influenced by the advice received from mechanical and electrical engineers in matters such as transmission, power demands, sizes and ratings of gearboxes and motors, standardization and interchangeability of components, materials, and manufacturing techniques. However, certain aspects of engineering design border on operating considerations. These are as follows.

Simplicity of Design

Simple design not only has an impact on the reliability of equipment, but also strongly influences the training of both operating and technical staff.

Ease of Maintenance

All parts requiring maintenance must be designed to ensure that the necessary maintenance can be carried out quickly and easily, and items that wear or need to be replaced must be capable of being readily detached, replaced, and aligned. If a sub-assembly requiring maintenance is difficult to reach, and/or involves the removal of other equipment during routine maintenance, human nature being what it is, the necessary maintenance will not take place and breakdowns will result.

Level of Technology

Although developments and innovations in mechanization and automation are highly desirable, the level of competence of the technical personnel must always be borne in mind. The degree of sophistication must not be so remote from the skills of the artisans that repairs cannot be done. The availability, cost, and duration of additional training may well prove not to be worth while. The working environment and practices may also favour robustness and simplicity rather than sensitivity.

Manufacturer's Involvement

In mining as in all other industries, the involvement of the manufacturer does not end with the sale of equipment. As McElhattan[3] has remarked,

> . . . it is extremely important that equipment designers and operating mining personnel have good liaison and regularly discuss the needs of the industry . . . . Also, the relationship between mine management and equipment manufacturers has become an exceedingly important factor in the analysis and selection of a mining system. Each needs the other in an even higher management relationship than that of buyer versus salesman. The degree of success of any new mining venture or profitable continuation of an existing operation may well be decided by the relationship between the mine operators and equipment manufacturers.

The relationship can be manifested in various ways. The manufacturer's contribution can consist in after-sales services, availability of spares and expertise, service exchange components, consignment stocks of spares, customer training, and continued research and development. From the operator's side, information on experience and operating data, as well as new ideas and suggestions, could contribute to better equipment and machines.

This exchange has become very important, and in many instances decisive, in the selection of equipment. A manufacturer losing all interest in his older equipment every time he introduces a new model has very little hope of remaining in the market.

Financial Considerations

The financial considerations in selecting equipment, whether a single machine or a whole mining system, are very often grossly neglected. To some people, after a quick glance at the cashflow status, the capital outlay is the major, if not the only, financial criterion in the selection of equipment.

Quantitative methods, such as the calculation of net present values (NPV) and discounted cash flows (DCF), are important tools in an assessment of the financial implications of acquiring equipment. With such methods, it is possible for the outright purchase of the equipment to be compared with lease or loan contracts. Factors such as tax concessions on a capital investment, the finance charges on a lease, and the interest rates on a loan all have an influence on the final answer.

The payback period is another aspect that requires close scrutiny. This is defined as the time required for the recovery of the initial capital expenditure from operating profits (all on an after-tax basis). A quick payback period is considered by some to be particularly important if a company has a liquidity problem, or if there is a considerable chance that cash flows will suddenly cease

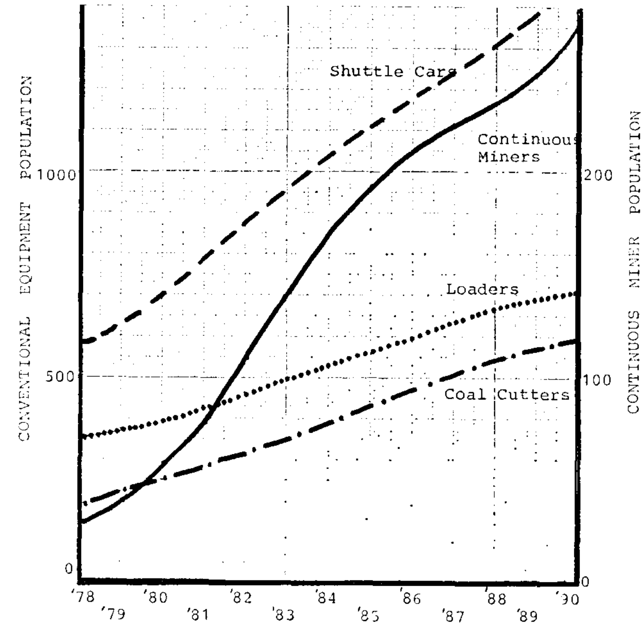

Fig. 5—Conventional machines and continuous miners in South African collieries (actual and forecast)

altogether at some stage. Where the payback period on a capital expenditure occurs in the space of a few months and the life of such equipment is several years, this could be a green light to go ahead with the purchase.

As mentioned earlier, the initial cost of equipment should not be regarded as very important unless the operating costs including labour, maintenance, and replacement costs, are also taken into account. However, in a highly competitive manufacturing market and depending on the application of the machine, the purchase price will of necessity be evaluated.

Equipment Population

Fig. 5 shows the number of shuttlecars, loaders, coalcutters, and continuous miners in production in the South African coal-mining industry from 1978 to 1982, together with the trend forecast to 1990. Population figures for some other equipment are given in Table I for the years 1980 and 1981.

In the selection of equipment, it is important that both the manufacturer and the mine operator should take due cognizance of future trends. Nobody wants to have machines or equipment that will be outdated within a few years. This may mean that the manufacturer has spares he cannot sell, or that the operator has difficulty in obtaining spares or service from the manufacturer.

TABLE I

EQUIPMENT POPULATION IN 1980 AND 1981

Equipment	1980	1981
Load-haul-dumpers	212	220
Drill rigs	54	82
Coal drills	984	936
Rock drills	382	346
Face shearers	6	7
Other battery units	65	100
Other electric mobile units	375	474

Conclusion

The selection of underground equipment is a task on which mine managements are engaged virtually on a daily basis, and no two managers approach the subject in the same way. The purpose of this paper was not to introduce novel ideas to the industry, but to indicate, and possibly highlight, the various factors that have an influence on the selection of underground equipment.

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Reference materials

Since 1974, the Council for Mineral Technology (Mintek), under the auspices of the South African Committee for Certified Reference Materials (SACCRM), has been involved in the production of certified reference materials (CRMs). The materials certified so far include a range of rocks, ores, and minerals of South African origin, and a number of intermediate and end products of their processing.

These CRMs are prepared at Mintek in reasonably large batches (usually about 300 kg), and are analysed by a number of carefully selected laboratories in many countries. The statistical evaluation of the analytical data received from these laboratories and the assignment of certified values for constituents are carried out in the Analytical Chemistry Division at Mintek. The majority of the CRMs have certified values for major, minor, and trace constituents.

These CRMs have gained international acceptance, both as reference materials in the analysis of South African ore and mineral exports, and for more general laboratory use in the calibration of instruments and the development of new analytical techniques.

In addition to this collaborative work with SACCRM, Mintek produces a large number of 'in-house' reference materials. Small amounts of a wide range of materials are prepared and analysed by the Analytical Chemistry Division, primarily for use as controls in the analysis of of samples submitted by the various other divisons of Mintek. Where stocks are sufficient, these materials are available outside Mintek. Increasing sales of these 'in-house' materials, both in South Africa and overseas, have indicated that there is a need to extend Mintek's activities in the reference material field.

It has been decided that Mintek will, in addition, produce small batches of 'secondary' reference materials at the request of interested organizations. The analyses required for the assignment of values will be carried out by Mintek, possibly by several analytical techniques. Mintek will also evaluate the data and assign recommended values for the constituents.

For more information, write to The Director, Analytical Chemistry Division, Council for Mineral Technology, Private Bag X3015, Randburg, 2125, South Africa.

Uranium reference material

The Council for Mineral Technology (Mintek), in collaboration with the Nuclear Development Corporation and the Nuclear Fuels Corporation of South Africa, announces the availability of a reference material of low-grade uranium ore (UREM 11 – SARM 31).

The material is a Witwatersrand ore, and has been certified for total uranium content. In addition, a comprehensive investigation has established that the material is in radioactive equilibrium and is therefore suitable for the calibration of radiometric sorting equipment.

A Mintek report (No. M84), 'The preparation and certification of a uranium reference material', describes the preparation of the material, its homogeneity testing, the investigation into its state of radioactive equilibrium, and its analysis for uranium by eleven South African laboratories. The certification procedure is also described.

The report is obtainable free of charge, and the reference material is available in 200 g units at R100 per unit. Purchase orders for this reference material and requests for the report should be sent to the following address: Council for Mineral Technology, Private Bag X3015, Randburg, 2125, South Africa.
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