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The use of research in management*

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SYNOPSIS

Research is a business activity, and is as different from other business activities as banking is from mining. In attempting to use research to solve their problems, managers do not always recognize its unique features, and are frequently disillusioned with the outcome. With a view to enabling managers to use research more effectively, an outline is given of the features of research as applied to mining. Types of research are distinguished, and stages in the research-and-development process are identified. The time-scales and resource requirements of the various types and phases of research are explained. Examples of research that have reached implementation in gold mining are given to illustrate the features mentioned. Practical and economic considerations are discussed, and pitfalls and recommendations in the use of research are highlighted.

SAMEVATTING

Navorsing is 'n besigheidsaktiwiteit, maar verskil van ander besigheidsaktiwiteite soos byvoorbeeld bankwese van mynbou. In hulle poging om navorsing te gebruik om probleme op te los erken bestuurders nie altyd navorsing se unieke eienskappe nie en word dan deur die resultate teleurgestel. Met die oogmerk om bestuurders in staat te stel om navorsing meer doelmatig aan te wend, word die eienskappe van navorsing, soos van toepassing op mynbou, weergee. Die tipes navorsing asook die verskillende stadia in die navorsing en ontwikkelingsaksie word onderskei. Die tydskale en die hulpbronbehoeftes van die verskeie tipes en fases van navorsing word verduidelik. Voorbeelde van navorsing wat reeds die implementeringsfase in die goudmynbedryf bereik het, word gebruik om die eienskappe wat behandel word toe te lig. Praktiese asook ekonomiese oorwegings word bespreek, vakstrikke geïdentifiseer en aanbevelings oor die gebruik van navorsing gemaak.

Introduction

The vast scale and extreme conditions under which mining is conducted in South Africa has led to mining operations being conducted at the limits of existing knowledge and technology. In the past it was possible to adopt techniques developed elsewhere in the world and to adapt them to the particular conditions prevailing in South Africa. But, as the scale of mining increases and the conditions become more extreme, managers are confronted with the need to seek new knowledge and new techniques to address the many new problems.

Where a problem can be addressed simply by the application of existing knowledge to a new situation, managers can turn to consultants for advice but, where new knowledge or new techniques are required, research and development (R&D) are the only means which these can be obtained.

In mining, there are many areas where advantages can be gained from the application of the results of R&D. The following are typical areas.

(i) A knowledge of the nature of a mineral deposit can provide a better understanding of the mineralization process and the geological structures. This knowledge can be used to good advantage for the purposes of mine planning and valuation.
(ii) The optimal mining method and equipment can be selected and developed in terms of recovery, cost, safety, and available manpower resources.
(iii) Mining equipment and processes can be developed to improve operating efficiencies.
(iv) A knowledge of strata control and underground environmental problems can facilitate the safe and complete extraction of mineral deposits.
(v) Mineral-processing techniques can be developed to improve plant recovery and to permit the extraction of complex ores.

While R&D are common activities in most businesses, the uniquely different features of mining research and development are frequently not appreciated. This paper highlights the many ramifications, the resource requirements, and the risks and limitations of R&D to assist managers in making decisions on when they should make use of R&D.

Process of Research and Development

Research can be defined as the endeavour to find new facts or to collate old facts by critical study. It is directed towards the advancement of knowledge.

Development is the application of known technical methods to evolve, by trial and error, something that can be used either as an end product or as part of a productive process. It starts with a fairly well-defined concept and objective based on the outcome of the research. It consists of a succession of cyclic stages of design, construction, and evaluation, with attempts during each successive cycle to eliminate the problems identified during the preceding cycle.

It is necessary to distinguish between adaptive and revolutionary development. *Adaptive development* involves the modification of a concept that has already been proved to work in different circumstances, while *revolutionary development* involves making a concept to work

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that has never been made to work before.

Research can be divided into three categories.

Basic research consists of investigations into a broadly defined problem area with the aim of gaining new knowledge. When successful, it leads to concepts from which applied R&D can continue.

Applied research is the conducting of investigations with the purpose of shedding new light on a specific, well-defined problem, usually with commercial application in mind. It is normally conducted as an outcome of basic research, or when a particular problem arises during the course of a development programme.

Collative research is the gathering of information to answer a specific question. Market research is an aspect of collative research; it is usually conducted before a start is made on a development programme.

Development can likewise be divided into three phases.

Technical trial is the phase of development that encompasses a series of cycles from the start of a development programme until results are obtained suggesting that all the technical objectives of the programme can be achieved within the next cycle.

Performance trial is the phase during which a full-scale trial is carried out under typical working conditions with the purpose of achieving the technical objectives. It is a stage at which objectives are examined critically and defined more precisely.

Production trial is the phase that follows the successful outcome of a performance trial, where commercial considerations can be examined more precisely; for example, whether the designs are cost-effective and amenable to manufacture, and the more accurate determination of operating costs.

The final, and most important, stage in the R&D process is *implementation*. In this stage, the outcome of the R&D programme is applied in practice; the new becomes routine, and experience is gradually accumulated. Where the outcome of the research is a concept, experience enhances the concept. Where the outcome is a product or process, further development takes place, but it is largely concerned with technical refinement and the reduction of costs.

Inherent Factors Influencing R&D

Managers are often faced with decisions as to whether to enter and support R&D programmes. To assist them in making these decisions, it is appropriate to discuss some of the specific features of the various categories of research and phases of development.

Basic research tends to produce minor facts within a short time, and usually, as a series of minor facts, can add up to a significant result over a much longer time. Occasionally a major fact is produced that has revolutionary consequences, but its significance is often not appreciated for some time. Thus, there is a high probability that basic research will not produce useful information, and a small probability that something revolutionary will be discovered.

Basic research requires few resources, a small number of dedicated scientists, some specialized equipment, and little space, with the result that its cost is comparatively low. Since it requires few resources, it tends to be ongoing with the hope that revolutionary information will be produced. Typically, basic research accounts for less than 3 per cent of the costs of engineering R&D programmes[1].

Applied research carries a high element of risk since it is usually concerned with the limits of technology. Therefore, success cannot be guaranteed. Sometimes it produces results of revolutionary consequences to another development programme but of little consequence to the immediate programme. It tends to be multidisciplinary in nature, and is frequently concerned with methods and materials of construction. Consequently, it requires a diversity of specialists and sophisticated research equipment. The duration is most variable on account of the uncertainty, and can extend over many years. Applied research accounts for about 15 per cent of the total costs of engineering R&D[1].

Collative research usually yields a definite answer, does not necessarily require specialist personnel or equipment, and is of short duration. The costs are minimal in terms of overall R&D programmes.

In analysing the inherent factors that influence development, it is necessary to distinguish between developments taking place in the different branches of engineering. It is also necessary to consider the physical size of the device under development.

For instance, in electronic engineering, design is amenable to precise calculation; it can be done rapidly within a matter of days or weeks, and the drawings for construction purposes are simple, mainly using symbols. Construction is rapid, and uses mostly commercially available components, many of which are held in stock. Also, the evaluation is rapid and amenable to precise measurements, and problems can be identified accurately. A full cycle of development can be completed within a few weeks or months.

In mechanical engineering, the design is laborious and not as amenable to precise calculation, and detailed drawings have to be produced for a large proportion of the components; consequently, the design is time-consuming. The construction is slow because many components have to be specially made, often involving many processes. The size of a component has an important bearing on the construction period: the larger the component, the longer the construction period, which may extend over many months or years. The evaluation depends greatly on the conditions under which the device is to be tested, but usually takes many months. Thus, a single cycle of development may take many months or a few years.

In mining engineering, the mine design tends to be empirical and does not take long to carry out; however, the mine construction is slow and may take years. Where mechanical equipment is being developed for use in mining, the evaluation can be very slow and inconclusive because precise measurements cannot be made, and because there are many uncontrollable variables. The slow design and construction stages, together with the slow and imprecise evaluation, can lead to a particularly long cycle of development, which may take many years. A typical example is the development of longwall-mining technology in European collieries, which started before World War II and was completed only in the 1960s.

The resources necessary for any development programme depend also on the branch of engineering. Facilities for electronics require little space and can be established anywhere and at comparatively low cost. Mechanical-engineering development requires more extensive facilities and the support of an advanced manufacturing industry to provide all the different construction processes that may be needed. In development for mining, test facilities under representative mining conditions are not readily available to the developers of machinery and are usually remote from the design and construction facilities. Development also requires highly-trained engineering manpower and obviously, the more manpower that can be brought to bear on a development programme, the more rapid the progress will be. In many instances in history, such as in the development of the atomic bomb or in space research, the duration of revolutionary development was shortened to a few years by the employment of many thousands of men in separate, but complementary, development programmes. In modern times, the worldwide shortage of skilled manpower in the heavy-engineering industries imposes a great limitation on the rate at which development for mining can be carried out. The costs of development are high, and can account for more than 80 per cent of the total cost of engineering R&D[1].

In the technical performance-and-production trial phases of development, failure may arise from inappropriate design or from technological barriers. Where the failure is a matter of design, it may be necessary to repeat the development cycle or, at worst, revert to an earlier phase of development. Where the failure is due to a technological barrier, appropriate applied research has to be conducted before the programme can be continued. If the applied research is not successful, the whole development programme has to be abandoned, the risk of this obviously being much greater in revolutionary development than in adaptive development. Sometimes it may be necessary to halt a programme in order to conduct collative research to obtain a better definition of objectives.

In the implementation phase, the risks are mainly of a competitive nature, where one solution may be superceded by another, or in the inability of the mine to provide the manpower and technological infrastructure to support the new development.

Extraneous Factors Influencing R&D

In every R&D programme, there is a great diversity of tasks, many alternatives that have to be explored, and many blind alleys. Continuity of effort is important to the achievement of optimal results, particularly in the development phases. Interruptions cause the loss of unique experience, and much effort is wasted in re-exploring old approaches.

Changes in the economic climate are frequently the cause of interruptions to R&D. These changes usually occur in cycles lasting some years. In adaptive development or in light industry, development phases can be completed within an economic cycle whereas, in mining and heavy industry, the development phases are often of longer duration than many economic cycles. In the latter case, interruptions in response to economic cycles are extremely damaging to a development programme. Moreover, persons whose main involvement is in production tend not to be concerned with the early stages of R&D. However, as the work reaches the late developmental phases, the costs mount, and the practical implications and problems in application become more apparent, their desire to influence the programme increases. The net effect is that, as a development programme proceeds, the likelihood of an interruption in the programme increases.

It is important to maintain a balanced view of R&D. Over-optimism or undue pessimism can be very damaging. It is essential that research personnel should be optimistic and enthusiastic so as to stimulate creativity and to carry them past the many blind alleys in their work. Sometimes this optimism is conveyed to sponsors, and may evoke either over-optimism or scepticism on their part. This, in turn, leads to false expectations, disillusionment, the incorrect ranking of priorities, or misdirection of effort, and eventually detracts from the enthusiasm of the research personnel.

A common pitfall is premature implementation, which can arise from many causes but usually from over-optimism in the later phases of development, or from fear of competition on the part of a manufacturer. Such premature implementation can lead to failure on a grand scale, and usually causes a major setback in the development programme.

A further pitfall that often arises at the implementation phase is the expectation of immediate economic benefit. Newly developed equipment is relatively more expensive than equipment that has evolved in routine use. Experience has to be gained before the innovation can have full effect, and the infrastructure of the mine may have to be altered to provide the necessary support for the innovation. In general, the more revolutionary the innovation, the greater will be the economic impact, but the longer it will take to have full beneficial effect.

At various stages during a development programme, research personnel are required to provide economic motivations for the continuation of their work. For the following main reasons, such economic analyses are fraught with uncertainties.

(i) Costs cannot be estimated with any degree of reliability until the production-trial phase has been reached. In this stage, designs can be produced that allow for cost-effective manufacturing processes and so permit the operating costs of a particular design to be assessed. Also, the extent of cost reductions resulting from refinement after implementation can be estimated only in the earlier phases of development.

(ii) Assessments of the performance of new developments are often based on small-scale experiments under ideal conditions, and estimates have therefore to be made of efficiencies, reliability, and availability under actual working conditions.

(iii) The analysis depends on the economic environment in which implementation will eventually take place. The longer the development programme, the less reliably can the economic environment be foreseen.

(iv) The full impact of the innovation on industry or society cannot be foreseen. This is perhaps the most important cause of uncertainty. Forecasts made by the developers of electronic digital computers will illustrate this point. Developers in Britain foresaw that 'two or three machines' would be required to meet all the needs for computation in that country and, in the USA, the need for only 'a few' was foreseen[2].

Unwarranted fear is a common obstacle for innovative R&D. This fear may take many forms. There may be fear that an industry will not survive long enough to benefit from the R&D, but history shows that industries that fail to innovate do not survive. There is sometimes fear that workers will not accept or cope with innovation. Here again, history shows that, in time, even revolutionary development can be assimilated by industry using ordinary workers. Perhaps the fear for safety is the greatest obstacle for development; the fear of nuclear power is a fine example of this.

Case Histories

The purpose of the following case histories is to illustrate some specific aspects of R&D in a mining environment. The examples given show that the R&D process can extend from a few to many years, depending on the nature of the problem that is being addressed. Similarly, the implementation of R&D results on a significant scale can be rapid or spread over many years. Organizational and infrastructural requirements can have a major impact on the successful implementation of R&D results and therefore need to be addressed at an early stage.

The examples show that R&D had a major impact on the technological and economic viability of the industry and that, without R&D, many of the achievements of the industry would not have been possible.

Rockdrills

By the time the Witwatersrand goldfields had been discovered in 1886, many different makes of rockdrill existed, some of which had been used successfully in various parts of the world. All these rockdrills were of the heavy reciprocating-piston type, having solid drill-steel attached to the piston and a mass of 200 kg[3].

Early problems arose from the great variety of makes of rockdrill, their great size, and their severe dust generation. As early as 1891, the Chamber of Mines was called on to evaluate the various makes of rockdrill independently. In 1903 and in 1907, the Chamber of Mines arranged competitions to stimulate manufacturers to develop rockdrills that created less dust and that had a mass of less than 45 kg. As a result, light, reciprocating-piston drills with solid drill-steel and water sprays were introduced in 1908[4].

Rockdrills were introduced on the Witwatersrand a few years after the opening of the goldfields, and their use increased steadily until 1937, when they displaced hand-drilling completely[4]. Table I shows the rate at which they were introduced[5].

TABLE I

ROCKDRILLS IN USE AND THE PROPORTION MINED USING ROCKDRILLS[5]

Year	Rockdrills in use	Proportion mined using rockdrills %
1894	518	?
1903	1577	?
1910	3567	?
1915	5675	42
1920	5716	58
1925	4474	78
1930	5612	96

Concurrently, a major advance in drilling technology came with the development of hammer drills. These drills were conceived in 1897[3] and were introduced to the gold mines in 1912[4]. The drills had a free piston, which struck a hollow drill-steel through which water was passed, greatly improving drilling speeds and aiding dust suppression. The hammer drill had a mass of about 45 kg, was mounted on a rig, and was fed either by screw or compressed air. Hammer drills were introduced very rapidly. The jackhammer, a small hammer drill without a feed mechanism and designed for use by hand, was introduced in 1913. Its introduction was relatively slow because certain mining authorities believed that the vibrations of such handheld machines placed too great a strain on operators; later, it was found that more powerful jackhammers could be operated without detrimental effect[4]. Table II shows how the hammer drills displaced the reciprocating-piston drills, and how the popularity of the jackhammers increased at the expense of hammer drills[5].

TABLE II

MAIN TYPES OF ROCKDRILL IN COMMISSION[4]

Year	Heavy, reciprocating-piston	Light, reciprocating-piston	Hammer, screw feed	Hammer, air feed	Jack-hammers
1915	4 741	1 995	2 068		319
1920	917	1 530	2 498	1 019	2 490
1925	152	17	2 081	483	4 383
1930	0	0	1 427	270	7 071
1940	0	0	2 356	295	13 300

As the implementation of jackhammers progressed, development aimed at the refinement of the drills continued at a great pace. The most important refinements were concerned with water-feed arrangements, methods for thrusting the jackhammers, and new forms of drill-bits. The great diversity of rockdrills in use, each in various states of modification, continued to cause much inconvenience to mine operators. As many as ten different types were in operation on one mine in 1924[6].

The history of drill-bits is worth considering since their development led to a major improvement in drilling performance[7]. Tungsten carbide was discovered in France in 1895 in research aimed at the making of synthetic diamonds. The first attempts to apply it were made in Germany, and were aimed at the making of dies for drawing tungsten wire to be used in electric lamps. By 1926, development was aimed at the machine-tool industry, and interest in mining applications followed soon after. In 1936, the first German-made tungsten-carbide-tipped drill-steel was tested in the South African gold mines, but it proved unsuccessful in the hard rock. Testing of tungsten-carbide-tipped steel resumed in the gold mines in 1945 and, by 1950, had proved successful in many production trials on different mines. Although the initial cost was high, it yielded immediate operational benefits, so that its introduction into the industry was very rapid.

In the meantime, experiments with detachable bits were yielding promising results[8]. These bits had been developed overseas and were first tested in 1937. The P&M detachable bits were very successful, and their manufacture in South Africa started in 1939. At the time that tungsten-carbide-tipped drill-steel first proved successful, P&M bits were in widespread use, but they were soon displaced by drill-steel tipped with tungsten carbide.

Scrapers

The history of scraping is not as eventful, and has not been as well documented as that of rockdrilling. Many different systems of rockhandling in stopes have been used in gold mining, the choice of system being determined mainly by the dip of the gold-bearing reef. First used in mining in Idaho before 1900, scrapers were introduced into South African gold mines in 1924, the motivation for their introduction being a trend towards the mining of narrower stoping widths in the less steeply inclined seams of the East Rand[4]. The first winches were powered by compressed air and could generate 7,5 kW. Gradually, electrically-powered winches were introduced, and by 1940 most winches were powered by electricity. Unfortunately, statistics on the rate at which they were introduced are not readily available. Originally used with shrinkage and semi-shrinkage stoping, where they eventually displaced shaker conveyors, scrapers were applied gradually to face scraping, and were used over a wide range of dips up to 35 degrees and face lengths up to 300 m. By 1945, face scraping and back-of-scatter pile scraping[4] were used equally.

The application of scrapers received great impetus with the thrust towards concentrated mining that started in about 1957. Many investigations into alternative methods of rockhandling were carried out, but it was concluded that 'there was no mechanical rockhandling equipment available which could effectively compete with conventional scrapers' for stoping[9]. The spread in the application of scrapers was rapid from this time, and increased from about 11 500 scraper installations in operation in 1962 to 20 700 in 1980. At present, about 90 per cent of the tonnage mined in stopes is handled by scrapers.

While scraping equipment has undergone much adaptive development, there have been no major technological advances. There have been numerous designs of scoop, but no one design has emerged that is notably superior to others. The quality of ropes has been improved, which has enabled more-powerful winches to be used, as did the use of electric power, and by 1940 22 kW winches were fairly common[4]. Different designs of winch have been used, but their performances have not differed markedly, the most successful being preferred largely on the grounds of reliability. Remote control has been attempted on many occasions and as early as 1938, but has not been sufficiently successful to be applied to any great extent. The main advances in scraping have come from improvements in the use of scrapers, rather than in technical developments. For example, stope configurations have been altered to make the best use of the available equipment.

Hydraulic Props

Interest in steel props was stimulated by the thrust towards concentrated mining in 1957. Although the primary objective was to permit caving of the hangingwall in the mined-out area, there was considerable interest in their use for controlling the hangingwall in remnant areas. Many mines conducted independent experiments with props of the various types and makes that had been used in European coal mining. One mine conducted a trial on a large scale using 11 000 props[10]. While the mines generally reported encouraging results in that hangingwall conditions near the face were improved and that caving did seem to yield some benefit, not all of the props used were suited to gold mining, particularly under rockburst conditions.

By 1965, interest in the use of props for caving had waned; however, there was serious concern for better support under rockburst conditions, and it was decided that the Chamber of Mines should promote the development of props for this purpose. Based on previous experiences with props, a realistic specification was drawn up and manufacturers were encouraged to develop props with technical support from the Chamber of Mines. An important feature of the specification was the requirement to yield rapidly under rockburst conditions.

Only hydraulic props offered the potential for meeting the specification. The development of rapid-yielding props started with fresh designs and the establishment of laboratory facilities for evaluating the designs under simulated rockburst loading. Progress was such that, by 1968, initial underground trials were started. These trials proved that rapid-yielding props dramatically reduced the damage due to rockbursts and rockfalls. A decision was the made to proceed to a production trial, which started in 1970 and was completed in 1971. Despite the occurrence of mechanical problems that had to be corrected during the course of the trial, the props were highly successful and were well received by production personnel. A revised specification was published in 1972, and props manufactured to this specification were considered to be suitable for implementation in routine mine production[11].

Many mines started implementing these props almost immediately. Serious difficulties arose on some of the mines, and in all cases it was found that inadequate arrangements had been made for the management, control, and maintenance of the props. Nevertheless, the numbers in use increased steadily, and 60 000 were in use by 1976 and about 700 000 by 1986. Today, the view is held by many mine managers that it would not be possible to extract many of the highly stressed areas in deep mines without the use of hydraulic props.

Chilled Service Water

Problems with 'heat apoplexy' in gold mines were recorded in 1925[5]. Early efforts to alleviate these were directed at improving the ventilation and minimizing the use of water to control humidity. The first 'airconditioning plant' in a South African mine was installed in 1935.

By 1950, refrigeration plants with a combined cooling power of 15 MW were in operation. These plants were not very effective, and it was recognized that the cooling of the ventilation air entering the mines could never be fully effective[12]. Research aimed at a better understanding of the thermodynamic principles governing the cooling of mines was started at about that time.

These principles were recognized gradually and, in 1972, it was proposed that a significant reduction in stope temperatures could be achieved by the cooling of mine service water. The first experiments underground with chilled water were conducted in 1974. A full-scale trial was started in 1975 and completed successfully in 1977, providing the stimulus for the implementation by 1980 of additional refrigeration plant of a combined cooling power of 548 MW, of which 96 MW were used to cool the service water. Based on the aim to achieve temperatures of less than 28 °C wet bulb throughout the industry, it was estimated that 350 MW of cooling power would have to be provided by means of chilled water. By 1981, 40 per cent of this potential requirement for chilled water had been achieved—some five years after the full-scale introduction on the first mine.

Design of Coal Pillars

Following the catastrophic failure of several thousand coal pillars and the loss of more than 400 lives at the Coalbrook Colliery in 1960, a programme of research into the design of bord-and-pillar layouts for South African coal-mining conditions was initiated in 1963. In 1967 a formula was published for pillar strength. This formula was derived from the statistical analysis of 125 failed and unfailed bord-and-pillar workings. In the same year, the rationale for the design of bord-and-pillar workings based on probabilistic concepts was advanced and adopted by the industry and, since 1968, several million coal pillars designed on this basis have operated with great success. By 1980 it became apparent that the design concept had certain shortcomings when applied outside the range of parameters on which it had originally been based. Consequently, the formula for pillar strength was extended to cater for squat pillars; that is, pillars with width-to-height ratios greater than 4. This formula is now being applied to the design of pillars in deep-lying coal seams.

The rapid introduction of the pillar design concept to South African collieries was made possible by a number of factors. Firstly, a wealth of information on pillar behaviour was available for analysis. Consequently, it was not necessary to embark on a longterm test, monitoring, and evaluation programme. Secondly, the introduction of the new mine design concept was imposed on industry by legislation. Thirdly, the introduction of the new design principles did not require major changes in mine layouts and technology, and was supported by good design guidelines.

Pick Coal-cutting Technology

During the 1960s, the first continuous miners were introduced in the South African coal industry to assist with the mechanization of coal-mining operations. These drum-type coal-cutting machines utilized a large number of relatively small, closely spaced coal-cutting picks. Typically, the pick spacing was about 25 mm, and a single cutting drum had more than 120 picks. Because of the light mass of the machines and the large numbers of picks in contact with the coal seam during cutting, the depth of cut was very shallow, and the machines did not achieve their specified production performance in the hard and uncleated South African coal seams.

In 1974 the Chamber of Mines Research Organization acquired an experimental continuous miner for an *in situ* research programme into coal-cutting processes. With this machine it was possible to study coal cutting over a wide range of drum speeds, pick spacings, and depths of cut. By 1980 the programme of research had been completed, and the potential advantages resulting from the use of longer, more-widely-spaced coal-cutting picks was demonstrated. This information was brought to the attention of the manufacturers of coal-cutting equipment and has found wide application. Today, the drums of standard continuous miners are equipped with larger picks, which are spaced about 75 mm apart, compared with the original 25 mm. With these newer machines, the production performance has increased significantly, and the limiting factor for the production performance of continuous miners is no longer coal cutting but the transportation of coal from the machine to the section conveyor. More than a hundred continuous miners are currently in use in local collieries and, in terms of underground coal-mining productivity, South African collieries rank second in the world.

Conclusions from Case Histories

The mining industry has never been slow in addressing itself to problems or in trying new ideas. Indeed, it has done much to stimulate innovation. Despite the industry's responsiveness, it has nevertheless taken a long time for new developments to be implemented fully, much of this slowness being due to the inherent protracted nature of R&D for mining.

Table III summarizes the approximate duration of the developments described here. The duration of the early research, particularly that done overseas, is not well defined in most cases.

Regarding the trial phases of development, individual cycles of development can be identified clearly for hydraulic props and chilled service water. These cycles lasted about 2 years. However, it must be noted that the shortness of the overall development period for props was due to the facts that props are relatively small, simple devices, requiring only adaptive development and that they could be evaluated in large numbers. In the case of chilled service water, the overall development period was very short because the concept could be evaluated merely by re-arrangement of the plant without the need to develop specific equipment. Thus, only a technical trial and a production trial were required.

The development of scrapers occurred in the implementation phase, and was an ongoing process of an adaptive nature and largely concerned with refinement. It is worth considering why there has been no revolutionary development in scraping. One reason is that alternative methods for rockhandling have been in use so that there has been no sharp focus on the problems of a particular method. Another reason is that the scraper scoop, which is central to the method, is not amenable to revolutionary develop-

TABLE III

DURATION IN YEARS OF R&D FROM CASE HISTORIES

Case	Research						Implementation	
	Basic	Applied	Coll.	Tech. trial	Perf. trial	Prod. trial	Period	Extent %
Rockdrills, all types		├──	──	40	──	──┤	45	100
Rockdrills, hammer types			├──	15	──	──┤	20	100
Tungsten carbide bits		├─ 30	──┤	├──	20	──┤	10	100
Scrapers		├──	?	──	──	──┤	55	90
Hydraulic props		├─ 5	──┤	2	2	2	10	50
Chilled service water	├──	25	──┤	2		2	5	40
Coal-pillar design	├──	5	──┤	Ongoing			20	100
Large-pick coal cutting	├──	7	──┤	├──	4	──┤	5	80

ment; for instance, the discovery of a new material could not improve its performance significantly, as happened in the case of rock drilling.

In view of the considerable part played by rockdrills in mining today, their rate of implementation is of particular interest; it took some 25 years before 50 per cent of the mining was done by the use of rockdrills. Moreover, despite their superior characteristics, the revolutionary hammer-type drills still took 15 years to displace reciprocating-piston drills, and were subject to extensive modifications in their first 20 years of implementation.

These case histories illustrate that implementation is fastest where the innovation causes the least physical changes in the stope and the least changes to the infrastructure of the mine. Drill-bits and chilled service water cause only small changes in the stope, while props required somewhat greater changes; rockdrills required more changes, and scrapers affected the layout of the stope most. Although chilled service water affects the mine infrastructure fairly considerably, this was not a serious factor in slowing implementation since it led to the significant rationalization of cooling systems. In the case of props, difficulty arose on some mines in providing suitable maintenance and control. A compressed-air reticulation system had to be provided for rockdrills, together with a special-purpose maintenance and drill-steel distribution system. In the case of scrapers, an electric-power reticulation system and a further maintenance system had to be provided.

In the case of the coal-mining examples, the research findings were implemented more readily since, in both instances, no changes were required to the existing infrastructure of mines.

General Conclusions

R&D is vital to the survival of the industry in an environment of cost pressures and adverse mining conditions.

A thorough understanding of R&D processes is required in order to take full advantage of R&D programmes and to avoid costly disappointment.

In work of a developmental nature, the R&D process tends to be time-consuming and costly. This is particularly the case in the development of mechanical equipment working under difficult environmental conditions. This feature has to be taken into account in the planning of R&D programmes.

In view of the time scales and costs of development work, much advantage can be gained from developments in other countries and industry. Collative research and information gathering is an important route to follow.

The development of mining equipment and methods is an evolutionary process, its rate being frequently governed by the rate of mining.

The implementation of the products of R&D programmes can be a demanding and lengthy process, particularly if extensive changes in the manpower, and in the technical and organizational infrastructure of a mine, are involved.

Recommendations

In order to obtain full practical and economic benefits from R&D, management should note the following points.

(1) The expected goals of R&D programmes should be clearly stated before the work starts and there should be general agreement on these by all the parties involved in the programme. Often the sponsor of the work and the R&D group have different views on these goals, and this can lead to misunderstanding, frustration, and wasted efforts.

(2) R&D is a lengthy process. For practical and economic reasons, the areas requiring R&D should therefore be identified at the earliest opportunity, and appropriate steps should be taken to plan the R&D programme well in advance.

(3) Research, and particularly the development of equipment, can be a very costly process. Before embarking on an extensive development programme, all the available knowledge should be collated and analysed. Only when management is satisfied that it has a unique problem for which solutions do not exist elsewhere, should a decision be taken to initiate and finance an R&D programme.

(4) R&D requires specially trained personnel with the necessary skills and infrastructure. R&D programmes often fail because of inadequate infrastructures and dependence of the work on a few individuals. This is particularly critical in the case of longer-term development programmes.

(5) It is in the nature of R&D work that the time taken to reach conclusions, as to arrive at useful results,

is often longer than planned. This aspect should be kept in mind when embarking on projects that depend on the results of R&D programmes.

(6) Because of the long duration of many R&D programmes, there is a temptation to make shortcuts so as to save time and money. The implications of these shortcuts should be carefully considered, and the possibility of reaching conclusions that are not entirely valid should be kept in mind.

(7) The introduction of newly developed technology often requires new infrastructures in terms of manpower skills and other resources. These have to be addressed well in advance of the planned implementation to ensure smooth technology transfer.

(8) In order to take full advantage of R&D work and to avoid frustrations, close communication between management and the R&D group should be maintained. This not only ensures better control of the work but also creates a climate of mutual trust and facilitates the implementation of the R&D results. Furthermore, through good communication, changes in the direction or priorities of the work can be agreed upon at the earliest opportunity.

(9) Management does not make enough use of R&D to improve mining methods and technology. Carefully planned and executed R&D programmes can result in significant improvements in the extraction of mineral deposits and increased efficiencies.

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AusIMM activities, March 1990

The AusIMM Annual Conference is to be held in Rotorua, New Zealand, from 18th to 21st March, 1990.

The Presidential Address will be delivered by Sir Arvi Parbo, and is entitled 'Mineral Heritage'. Keynote addresses will be given by M.R. Rayner, Comalco Limited, and Dr D. Tyrwhitt, Ashton Mining Limited.

A pre-Conference tour to the South Island and post-Conference tours to the South and North Islands will be arranged covering areas of mining, historical, and scenic attraction.

A symposium on 'Ore reserve estimates—the impact on miners and financiers' will be held in Melbourne, Victoria, on 7th and 8th March, 1990.

This will be the first ore-reserves symposium since the release of the new Australasian Code for Reporting of Identified Mineral Resources and Ore Reserves. The two-day concentrated programme is intended for a wide range of practitioners including geologists, mining engineers, consultants, bankers, brokers, resources lawyers and accountants, and regulators.

Further information is available from

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