The implementation of new technology in southern African mines: Pain or panacea

by A.S. Macfarlane*

Synopsis

The introduction of new technology into mining operations is seen as a strategic necessity by many mining companies, in order to improve safety and to improve operational effectiveness.

Many attempts have been made in recent years to introduce new technologies into mining operations in southern Africa. Amongst these are noteworthy successes, as well as some disappointing failures.

Often, the reason for failure does not lie with the technology itself, but with the work system into which the technology is introduced. Such failures may come with a significant opportunity cost, and have a detrimental effect on future development, simply because the system has not been adequately engineered, and the risks have not been adequately assessed and managed.

This paper examines the reasons for such failures, and proposes a methodology to be followed to ensure successful and sustainable implementation of new technologies, such as to reduce technical and financial risk to the company, and to energize the workforce into ensuring the initial objectives of the project are met.

The paper also focuses on the application of appropriate technology, and the development of technological applications which are commensurate with the level of development of the work environment into which it is introduced.

The paper therefore focuses on the application of risk management, change management, systems engineering and feasibility analysis as being key elements of a successful and holistic technology implementation programme.

Introduction

The difficulty of successfully implementing new technologies into mines has been experienced by most mining companies worldwide. It is not just a South African problem, but one which has been tackled by other countries and operators, who have been able to develop methodologies for technology transfer and implementation which can be used in southern and South Africa.

It is widely recognized that technology has a vital role to play in the development and application of new mining methods, which will improve both safety and health, and operational effectiveness in our mines.

To successfully manage this will require systematic programmes and processes which will allow these technologies and methods to be implemented on a sustainable basis.

These processes rely on the application of change management principles and a systems engineering approach to the problem, and a holistic understanding of all the aspects and impacts of the change to the new technology and method.

Problem statement: the need for new technology

There is little doubt that technology is an essential component of any initiative to improve safety and operational effectiveness.

This is recognized by companies such as Anglogold, who stated in their 1999 Annual Report that 'We will remain at the forefront of technology and innovation to improve operational excellence in safety and health, to develop a 21st century mining workplace and to improve bottom line performance'.

The significant focus of this statement is that it relates the application of new technology to a holistic approach to workplace improvement, and to the translation of benefits right through the work system, ending up with quantifiable benefit on the bottom line of the business. This statement therefore establishes a clear objective for new technology and methods: improvement of the value of the business.

A perspective from the South African platinum industry was recently illustrated in the Presidential address of the President of the South African Institute of Mining and Metallurgy, Dr Larry Cramers, who said 'The Achilles heel of the platinum industry in South Africa is its high mining costs and, in this respect particularly, its high proportion of labour in those costs. The industry must break

---

* *Department of Mining Engineering, University of the Witwatersrand.*

 SA ISSN 0038–223X/3.00 + 0.00. First presented at SAIMM Colloquium: Mining methods and occupational hygiene for the new millennium, *Feb. 2001.*

out of the low level of training, the unskilled job content, and large numbers required underground—if not for survival at the lower end of the cost curve, then at least to reduce the exposure of men to underground conditions. Although the difficulties in automating narrow reef mining on which platinum mining depends are not to be understated, the technological breakthrough must be made'.

He went on to state that, in relation to the impact of new technology on recoveries, 'An improvement in mining or concentrator extraction efficiency of 1% for the South African industry is equivalent to some R500 million (current prices) in annual revenue: current extractions from *in situ* reserves to smelter feed are a paltry 75%–80%. Thus an industry prize of some R10 billion/annum awaits technical innovation.

What advantages and improvements will arise from non-explosive mining methods, robotics, process control, knowledge of flotation chemistry, new hydrometallurgical process routes, and automated or remotely controlled mining equipment?

Investment into, and the close management of these target areas are critical to the long-term survival of the industry. One need only look at South Africa's gold mining industry for an example of an industry that has not innovated fast enough to meet the falling real prices'.

These illustrate two perspectives from two sides of the mining industry, one in a margin squeeze, the other in a price upswing. Nevertheless, they both recognize the need to successfully implement new methods and technologies in order for the South African mining industry to remain globally competitive.

This paper attempts to highlight some critical areas which can help to advance the pace of successful technology development, and transfer, and attempts to provide methodologies to do this.

It is opportune at this stage to look at some practical examples of where and why technologies have succeeded or failed.

The author visited several coal operations in Germany in 1996, with a view to investigating the success achieved in the introduction of mantracking surveillance systems. Whilst the systems developed were probably the best in the world at the time, introduction into the mines had failed because of suspicion and sabotage on the part of the workforce. The technology was initially aimed at safety, in terms of knowing the whereabouts of people at work, but later became linked to pay and productivity. Thus, once the workforce perceived the technology to be a policing mechanism for management as opposed to a tool for enhancing personal safety, the technology failed.

A similar experience occurred in the gold operations of Anglo-American in Brazil in the late 1970s.

Before being taken over by Anglo American, the mines operated extensively with dry drilling, especially in the deep workings of the Morro Velho mine. Anglo American management found this to be an unhealthy and unsatisfactory practice, and introduced service water through a reticulation system. Extensive sabotage of the system occurred, and it was found that this was due to a perception amongst the workforce that the application of cold water on the hot rock face caused rockbursts. It took some time and careful deliberation to convince the workforce otherwise.

These two examples illustrate the importance of establishing the correct motivation for change, in a transparent manner.

In the mid 1980s, the gold division of Anglo American pioneered the introduction of a comminuted waste backfill system at Western Deep Levels (Macfarlane[1984]). The objective of this joint project with COMRO was to engineer an ultra high quality backfill system that had the potential to enhance or even eliminate the use of reef stabilizing pillars.

The technology that was developed and introduced indeed produced an extremely high performance fill, but tolerances on quality control were tight, with regard to size distribution, pumpability and placement. These tolerances and the level of technology eventually were the downfall of the system, since normal underground operations were unable to operate to the designed quality.

The system failed because of inappropriate technology for the work system into which it was introduced. Nevertheless, a great deal was learnt which contributed to current knowledge and application of backfill.

A further example of a system inadequately prepared for a capital intensive technology has been the experience of the impact ripper. This technology, initially developed in the late 1970s, has undergone some twenty years of research and development, and still remains unproven. The author remains convinced that this is an appropriate technology for mining soft reefs on a continuous basis, but only provided the entire work system is adequately engineered. It is valid to compare how this is done successfully with continuous miners and shortwall shearers in the coal industry, with the impact ripper which was essentially introduced into a work system appropriate for manual operations only. 'Structures and systems are perfectly engineered for the results you get' (anon).

Returning to backfill, in 1992, Western Deep Levels South experienced unparalled levels of seismicity and consequent serious and fatal injury. Great effort was put into introducing cemented backfill, only two metres from the working face (Macfarlane[1995]). Eventually these efforts met with significant resistance from the workforce, who felt on the one hand that the working area was too confined, should there be any seismic activity, and on the other who felt the lengthened shift time for placement was excessive. Both concerns were valid, and taken into consideration, but there was also a preference amongst the workforce for the use of timber packs. Much work was needed to overcome the resistance to change, but it is interesting to note that today, Tau Tona mine boasts an 80% fill ratio, and that the workforce are unwilling to work without backfill, because of the work environment improvement that they observe and experience. This has been well documented, and reported in terms of measured quantifiable improvement in underground recoveries, safety and productivity. (Russo-Bello and Murphy[2000]).

Stope drill rigs have been introduced into the mining environment with limited success, despite clearly quantifiable advantages and benefits (Tarr *et al.*[2000]). This has been due to factors such as:

- resistance to change
- unnecessarily complex technology

- poor ergonomics in terms of the movement of the equipment in and out of the stope
- a Hawthorne effect due to heavy management thrust, out of balance with worker resistance to change
- a fear that such technology will, when coupled with other limited mechanization, lead to job loss.

Trials have often been singularly successful, but implementation has been limited, often dwindling to a return to tried and trusted means.

Electronic delay detonation technology has taken time to become accepted. The initially high capital cost and operating cost of the units were seen by management as excessive, which when compared to conventional systems they were. However, it is only now that the full system benefits are being translated to the bottom line that the individual unit cost is being seen as unimportant.

Ergonomics and ownership of technology design by the workforce has been shown to be important in a number of instances. Experience by the author at the Boulby Mine of Cleveland Potash Ltd in the United Kingdom, and recent experience by a number of international operators and suppliers of mechanized and automated equipment, has shown the importance of ownership and involvement of operators from the early stages of design. At Boulby Mine, for example, operators and maintenance staff were involved from the beginning in the development of auger boring technology. They had a clear understanding of the purpose of the development, and the impact of the technology on the success of the mine, and contributed positively by participating in the ergonomic design of the machinery, with management and the supplier of the equipment. The prototype machine was welcomed onto site because of the ownership created by this approach.

There are many other quotable examples of success and failures, but lessons to be learnt from this brief summary are as follows.

- Technology to be introduced must be appropriate to the level of development of the work system
- The technology to be introduced must have a clear objective which is identifiable in terms of bottom line benefit
- The introduction of new technology must be part of a common vision shared by all
- The work system into which the technology is to be introduced must be adequately engineered to ensure its success
- The workforce who will operate the new technology or work process must be involved every step of the way in its design and implementation
- Off the shelf technology may not be mineworthy in our conditions: time must be allowed to establish mineworthiness through redesign and retrofitting
- Quantified benefits must be documented, and mechanisms for sharing experience must be developed.

These broad statements are probably fairly well understood, but the remainder of this paper explores how these factors should be managed, practically.

New methods and technology: a change process

Often, the failure of new methods and technologies can be ascribed to some kind of sub-optimal intervention, where the aspects identified above have not been taken account of, in what is essentially a change process.

New technology or work methods involve doing work differently. Such a statement immediately implies change, which will bring with it resistance to such change, unless managed adequately. Thus a change management process which is applicable to the introduction of new technology and methods is necessary.

Change management processes are not new any more. Many have been developed and introduced, usually for macro-change, involving a change in strategic direction for a company. These processes have generally been sequential, stepwise programmes, some of which have been glowing successes, while some have been dismal failures. Lessons to be learnt from these large-scale interventions are that firstly, 'the change process goes through a series of phases that, in total, usually require a considerable length of time. Skipping steps creates only the illusion of speed and never produces a satisfying result. A second very general lesson is that crucial mistakes in any of the phases can have a devastating impact, slowing momentum and negating hard-won gains.' (Kotter[1995]).

It is interesting to consider such a process that has been identified for the introduction of production monitoring in open pit mines,by Wenco International Mining Systems Ltd. A conclusion born out of years of introduction of information technology into these mines was that 'Many mines worldwide have implemented production monitoring and dispatch systems. An honest assessment would rate a few installations as highly successful, a few near failure, and a large number languishing somewhere in the middle. Success or failure seems relatively independent of the technology or vendor selected.

The holy grail of optimum performance is not found in technology—the technology is only an information tool. Throwing more technology at a problem to "see what happens" only generates cynicism and resistance to valid change initiatives. Significant gains can be realized only by combining information technology with performance management.' (Richard[1998]).

Richard developed a seven-stage change process for the introduction of this technology, based on case studies, which covered the following.

- Understand the corporate culture in terms of readiness and capability for change. In some situations, change is not optional, but mandatory for survival.
- Communicate continuously with all levels that will be affected by the implementation. Continuous involvement by the foremen is essential since they are the front line users of the system who will make the difference.
- Provide superior executive championship for the project. Senior management must participate hands-on by asking the right questions and setting goals, and rigourously tracking progress.
- Ensure that the project manager and eventual system administrator is capable of dealing with authority and respect between all affected parties, bridging operators, foremen, supervisors, engineering, management etc.
- A degree of change management is required. Do not

expect to keep doing the same things and expect different results.
- Expect problems to arise: commit to the change. Your shareholders expect it and deserve it. As changes are brought in, the process can follow three steps: Denial—hope it goes away; Medicinal—it won't go away, so lets do it quickly and get it over with; Ownership—lets do it for ourselves.
- Users must clearly understand the business case.

Richard goes on to advocate the use of the Balanced Scorecard approach (Kaplan[1996]) as an appropriate performance management system to enhance and motivate the technology implementation.

His approach is essentially a multi-stakeholder, inclusive process, which recognizes the importance of engineering the whole system, to be receptive to the new technology, and as such is a holistic change management process.

Another example of a holistic change management process that could be used for the implementation of new technologies and methods, is advocated by Kotter[1995].

His eight-step process covers the following elements:
- establish a sense of urgency, by examining the market, and competitive realities
- form a powerful guiding coalition, by forming a group with enough power to lead the process
- create a vision
- communicate the vision
- empower others to act on the vision
- plan for and create short-term wins
- consolidate improvements and produce still more change
- institutionalize new approaches.

This approach highlights the need to create a vision which has quantifiable benefits which are attractive to all the stakeholders. This is not easy—invariably a perception exists that new technology or methods are designed to reduce jobs, or to exploit the workforce.

A third model which has been successfully used in South Africa, and which can be adapted for technology transfer is the 'Wheel of Change' (Malherbe[1993]).

The wheel of change is a change management model which has been used on several mines and within several leading companies, with considerable success. The author was involved closely with the development of the model at some of these mines, and it became apparent that the model was useful as a framework process, which needed to be understood and modified according to the situation at hand, as opposed to a recipe book solution. The remainder of this paper will look at how this model can be applied to technology transfer, in the mining environment.

The wheel of change

Malherbe[1993] developed the wheel of change as a process model for managing change, itself a key focus dimension in the strategic planning process, the others being managing strategy, crafting the future, managing outputs and managing fitness between the elements.

The change wheel is a re-architecture model which interprets and translates the vision of the organization down into operational flows.

The model is ideally sequential, and ensures that all aspects of the organization into which the technology or method will be implemented are in balance. Each element will be analysed for its applicability in South Africa. This will illustrate also how the model works.

Vision

The visioning process forces individuals to look at the organization from different points of view, by identifying strategic thrusts, and establishing a common mindset in the implementation team. Kotter identified that an essential preamble to this is to establish a sense of urgency and to provide a powerful guiding coalition within the implementation team.

In terms of identifying and implementing new technologies and methods, this phase should stimulate questions such as:
- Is technology a strategic thrust for the company?
- What is the purpose of the new technology?
- Are there technologies which will produce quantifiable business benefit to the company?
- Are these technologies appropriate for the business at hand?
- What are the timeframes associated with implementation: are we looking at fundamental or applied research, or off-the-shelf technology?
- Are there strategic partners who should be involved?
- Does this technology offer competitive advantage?
- What are the risks associated with the new technology?

The answers to these essential questions provide the sense of urgency and the compelling vision that clarifies the direction in which the organization should move.

Strategic thrust

The need to develop and implement appropriate technology in the mining industry is supported by Government intent, which is stated in the Minerals and Mining Policy for South Africa White Paper as 'Government will undertake and promote research, technology development and technology transfer that will stimulate the optimal development of the country's resources in the longer term and ensure that the industry remains competitive' (DME[1998]).

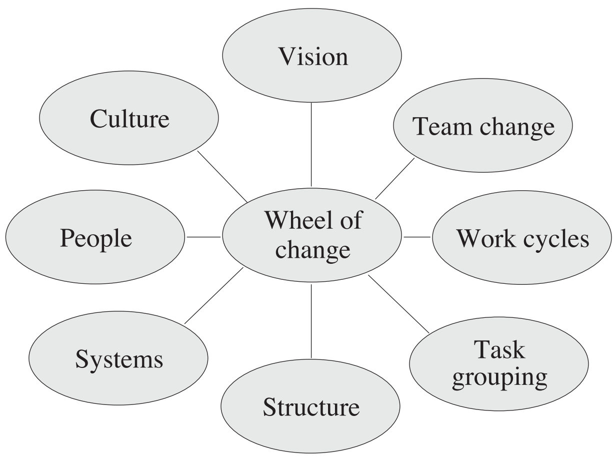

Figure 1. Wheel of change (Malherbe[1993])

This policy is underpinned by the concept of sustainable development, which supports the economic success of the industry and the social and environmental responsibilities of mining companies. In terms of technology, this establishes a focus on improving productivity and efficiency, and improving safety and health.

A look into the radar screen helps to establish this vision, whereby issues can be identified which are likely to impact on the industry of the future. Here, one can draw on experiences of First World countries, who are addressing issues now, which will impact on Second and Third World countries in the near future. There is, for example, no doubt that First World countries have advanced significantly further in the reduction of fall-of-ground accidents, through the application of new technology and stringent legislation. The development of automated roofbolting equipment has been necessitated by legislation that prevents entry into unsupported ground, even for the purpose of installing support. One can expect that globalization will place stronger emphasis on the need to develop automated equipment in stoping operations in South Africa, and therefore there should be a need to transfer some of this technology to local conditions. This process of technology and legislation transfer is recognized by Buchanan[2000] who advocates such a process of transfer from the United Kingdom Health and Safety Executive.

In the United States, 'Mine health issues are certain to be paramount in the mining industry in the coming decades. Noise, dust and diesel emissions, as well as heat and humidity will continue to be targets for improved technology. But others may arise as mining variables change. Some of these concerns come about from the increasing depth of mineral operations and the increasing scale of operations. Other concerns will come from new equipment, potential health problems and smallness of operations'.(Ramani[1999]).

The issues of economic competitiveness and productivity improvement have been highlighted by Cramer[2000], and Anglogold.

Whether the need for new technology is driven by economic or safety reasons, though, these examples illustrate the need for the identification of suitable technologies to address future needs, international transfer and collaboration, and the need to research and develop the appropriate technologies for South African conditions.

Business benefit

Any plan for the implementation of a new technology must have a quantifiable purpose and benefit to the business, whether in terms of economics or health and safety. Moreover, this analysis must take account of the system in which the technology operates, as opposed to the technology alone. For example, take the introduction of a stope drill rig. The objective of introducing the equipment could be improvement in health and safety, by removal of the person from the hazardous area, as well as improvement in advance per blast, fragmentation, stoping width and cycle time for drilling. Whilst each of these production issues can be quantified relatively easily, can the remainder of the system cope with these improvements in output, and will the benefits actually be realized?

Tarr *et al.*[2000] attempted to quantify these benefits in terms purely of advance per blast, indicating an improvement on existing methods of drilling on a sample mine of R8 689 million in contribution. While there is most definitely financial benefit to be gained, the financial analysis should be extended to show valid comparison between the two complete operating systems.

For example, downstream constraints may have to be removed, which will incur further cost in order to ensure a balanced system, and these need to be included in the analysis.

To fully evaluate the economic benefit, discounted cashflow techniques such as equivalent annual cost techniques should be used to compare equipment and methodology alternatives. It is important however, to ensure that the correct comparisons are made. In our example, if the introduction of stope drill rigs requires expansion in mine capacity, it is not valid to compare the unexpanded mine with the old technology with the expanded mine with the new technology: there must also be a comparison with the expanded mine using the old technology (in other words, could you not expand anyway?). In this case, the comparison must be reduced to the cost of the production system, probably best expressed as a unit cost of production (Runge[1998]).

Essentially, the analysis of business benefit must take the form of a feasibility study, for the economic life of the technology (Smith[1994]). Such a feasibility study should cover the following aspects:

- strategic objective and purpose of the implementation
- implementation schedule
- capital costs
- operating costs
- economic benefits analysis
- economic valuation
- system design
- risk assessment and management.

The benefits identified must be clearly measurable, and the study must become a working document to ensure that the benefits are in fact realized.

The guiding coalition

As was identified by Kotter, it is essential to identify a project champion, and for the champion to have a multi-disciplinary team around him who will assist in the successful transfer of the technology. Ideally, the champion should be a senior line manager. It is unlikely that any other person will have sufficient power to see the project through, or be able to seriously influence the change to the new method or technology.

Many change initiatives have failed where senior or line management are perceived to be sitting on the fence, not fully supportive, or waiting to see what happens before making a firm commitment of support. These must be avoided at all costs, if the exercise is not to end up in a frustrating experience for all concerned.

The team responsible for the implementation should have an incentive to ensure successful technology transfer. This must include the operators and support staff, who need to be fully committed to achieving success. Exactly how this incentive is structured depends on the level of development of the technology (that is, whether this is still research and development, or transfer) as well as the nature of work. People engaged in research and development are those who have a penchant for this work. Often, they prefer recognition related to patents or intellectual rights, rewarded by royalty type payments, as opposed to the implementation team, who will prefer *ex gratia* type rewards on successful completion of the project, and the operators who should be rewarded by appropriate bonus schemes. It is important to ensure that these performance management aspects are applied correctly.

Appropriate technology

Technology initiatives have often failed because the technology was not appropriate for the work system into which it was introduced: perhaps it was too technically advanced for the level of skill available, or it may have required too radical a change in the way work is done. For example, early attempts to mechanize and automate shortwall coal faces were unsuccessful because there was insufficient maintenance expertise for the computerized shield and AFC advancing system. As a result these were retrofitted with manually operated systems.

This issue of appropriateness has been recognized by LKAB at Kiruna, Sweden, in work published by Hustralid and Nilsson[1998].

LKAB are amongst the leaders in world mining in the introduction of automation in loading and transport. They recognize though that to reach the level where they are now has been an evolutionary process. Even if the automation technology of today was available 10 years ago, it would not have been appropriate to introduce it at that time, because the whole work system needs to grow and evolve with the technology development.

Thus, they have described technology development as a function of time as a series of evolutionary, chronological steps over time, with lower rates of development between steps, which represent improvements on the existing step.

The graph (Figure 2) indicates diminishing returns on the overall curve, as it relates to a specific area of technology, with step improvements as individual breakthroughs are made, and then improvements occur on specific points. An example of this could be the introduction of mechanized tunnelling rigs. Level 0 would represent manual drilling, with the first, and major breakthrough to level 1 being the semi-mechanized pneumatic rig. This technology would be improved and be made more mineworthy until the next breakthrough to level 2, with the introduction of the railbound hydraulic drifter. The next breakthrough could be the trackless, diesel hydraulic rig, and the level 4 technology the fully automated electro hydraulic rig.

A further development of the appropriateness of technology is to define the level of development of technology that is appropriate now, and in the future, thereby indicating a strategy for research and development. This is illustrated in Table I, which is indicative of the appropriate technology for South African mines in the area of mechanization and automation.

This is drawn from a paper published by Pukkila and Sarkka at *Massmin 2000* in Brisbane, which illustrates the development of an intelligent mine research programme at the University of Helsinki, in collaboration with Outokumpu Oy, Tamrock Oy, Normet Oy, Lokomo Oy and the Technology Development Centre of Finland.

The paper also identified that a stepped process of adoption of appropriate technology should be developed, and this is illustrated in Figure 3 below.

The paper emphasizes the key issues highlighted previously that a balance must be found to ensure the application of appropriate technology now, and research and development of future developments based on acquired knowledge and experience, and collaborative research, where the urgency referred to earlier in this paper has been established from the radar screen.

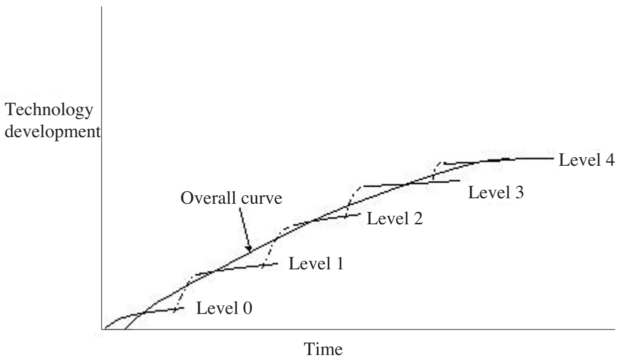

Figure 2. Technology development as a function of time (Hustralid[1998])

Table I

Level of development of automation

Level	Time period	Stage of development	Technology
0	Current	Off the shelf	Process control systems
1	1–3 years	Transfer technology	Mechanized machines
2	3–5 years	Develop and trial	Automatic processes
3	5–7 years	Research	Remote control machines
4	7–10 years	Concept	Remote control production

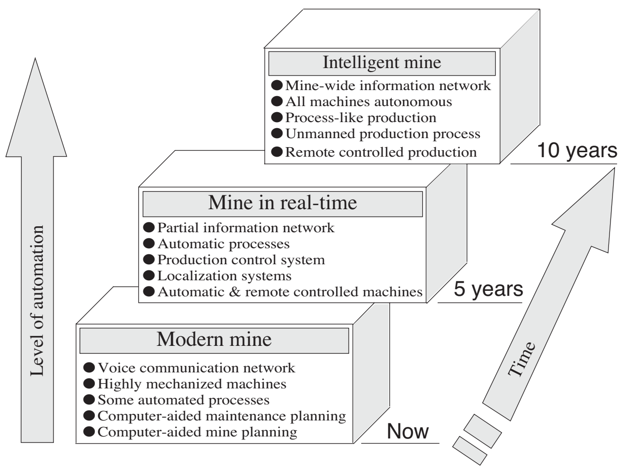

Figure 3. Development steps towards the Intelligent Mine. (Pukkila and Sarkka[2000])

An interesting observation on the programme was that 'Another important area of research and development in the mine automation program was human engineering. (Pukkila1999). Automation will bring new types of hazards and accidents and have an effect on work motivation. Although safety has been taken into account within each development project, the human role in the automated environment, especially in a mine, has not yet been extensively studied.'

A recent paper by Puhakka2000 also highlights the development path necessary in the introduction of full automation to loading equipment. This evolutionary process is exemplified by the experiences of Inco, who over a 12-year period have realized productivity improvements of some 250% as a direct result of automation (Inco1998). The full process involved a clear vision and economic feasibility, coupled with lifetime optimization of equipment.

These examples illustrate the need to identify appropriate technologies which take account of the level of development of the work system and the technology itself, while providing for the continued development and step changes that are necessary for the future, through appropriate research and development.

Risks

Within the visioning process, it is important to identify risks and derailers. This is essential, because many of these will be identified and raised by the team members and stakeholders, during the change process.

Amongst the risks are:

- premature application of unproven technology
- resistance to change from the workforce and supervisors
- fear of job loss as a result of the technology
- suspicion of management motives in introducing the technology
- poorly engineered work systems
- inadequate training and skill to operate the equipment
- new health and safety risks created by the technology or work system
- poor implementation, planning and control.

The remainder of the change wheel will adequately deal with all of these aspects.

Team change

Ideally, the team change component of the wheel, should involve all employees who will in any way be affected by the introduction of the new work method or technology. In a major change intervention, this would be essential, but in the case of technology, at least the influential people should be included.

The purpose of this process is to translate the vision and purpose of the new technology to all concerned, such that on the one hand their acceptance and support is gained, and on the other that their concerns can be raised and addressed. The latter part of the process is absolutely essential: if employees have concerns which are not voiced and addressed through a fully transparent and interactive process, they will cause the effort to fail.

Let us examine one of these concerns by way of example. A legitimate fear surrounding the introduction of new technology worldwide is that it will lead to job loss. Often, this is not the case, either if the main motivation is a health and safety issue, or if the productivity improvement realized by the new work method results in a decrease in costs to the extent that extra resource is brought into reserve.

As a hypothetical example of this, a small underground gold mine was modelled, on the assumption that a new technology could be introduced which would yield a 10% reduction in operating cost, an increase in underground recovery of 3% from 85% to 88%, a reduction of dilution of 5% from 15% to 10%, and an increase in daily output from 1000 to 1200 tons. In this case, there were no capacity constraints.

Using an operating cost of $52/ton, and fixed costs of $3 million per annum, the model was run in both cases, and overall cash costs reduced from the base case of $188/oz., to $170/oz in the case with the new technology.

This had the effect of improving the Net Present Value of the mine from $19 million to $34 million, and of improving the Internal Rate of Return from 34.5% to 72%.

These costs were then applied to the cutoff grade, and it was calculated that the cutoff grade for the mine reduced by 10.4%. The effect of this 10.4% reduction on cutoff grade is significant in terms of the tonnage of resource that now becomes economically viable.

Using a real grade tonnage curve of a mining company from their annual report, such an improvement could result in an equivalent 17% increase in economically viable tonnage.

The graph in Figure 4 illustrates this effect. Because of the shape of the grade/tonnage curve represented, a reduction in cutoff grade of 10%, effected by the use of the new technology, from a to a′, has resulted in an increase in resource tonnage above the cutoff grade of 17%, from b to b'.

For this mining company, this could realize an increase in production of 180000 tons per month, for a life of 20 years; the equivalent of a new mine employing 5700 people. Thus, provided the estimated improvements in efficiency and productivity are realized, the technology is actually a job creator as opposed to a job destroyer.

As will now be discussed, the new technology requires an increased level of skill, which, when provided through

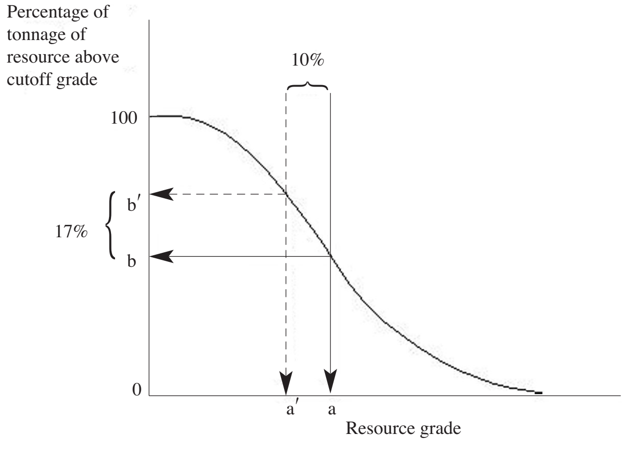

Figure 4. Effect of reduction of cutoff grade on available resource

accredited training, offers the individual increased earning power and portability.

Very careful preparation, coupled with extensive communication and interaction is necessary, to transfer information such as this, in such a way that it provides an attractive future for both the individual workman and the labour organizations.

If these initial hurdles are overcome, then a participative process can be entered into, which ensures that ownership will be created.

In order for the remainder of the change wheel to be actioned, it is important from this stage on to establish a team made up of the people who will be directly involved with the implementation. This will include operators, supervisors, support staff, maintenance people and management.

Work cycles

In this phase, the team mentioned above must examine the way in which work is done, through the utilization of the new technology.

To an extent, this phase begins to address the system, but in so far as the work is concerned. If, for example, we return to the use of the stope drill rig, how does work change in the stope as a result of the use of the rig? The kind of issues that would be raised here would be:

- the new drilling cycle time, and the extent to which this changes the total work cycle in the stope
- the effect of improved advance per blast on the cleaning cycle
- the number of units required, and how this is matched to the face length, and the other work in the stope
- the number of operating stopes that will now be required to meet production targets
- the work involved in moving the equipment in and out of the working area
- the power source to the machine, and other logistical support issues
- the maintenance requirements, and the maintenance cycle.

The answers to questions like these could indicate the need for a complete redesign of the work cycle, particularly if the technology is advanced and capital intensive.

This analysis should also tackle health and safety issues, and ergonomic design issues, so that the team has involvement in the design process from the start. It could for example highlight a noise problem, which could be referred back to the suppliers through the collaborative process.

Ergonomic issues are extremely important; if the equipment is ergonomically unfriendly, the operators will not be inclined to utilize it to its full potential.

Task listing

This part of the process looks at the tasks that need to be performed as a result of the new method or technology. This will start to identify how many people are required in the work cycle, and what levels of skill they require.

This is an intensive process of identifying each and every task in the new work cycle, and then clustering them together appropriately. Issues such as multi-tasking and multi-skilling may arise here, but this should not be a pre-requisite or predetermined goal. The team must generate a solution, which may or may not include this kind of issue. However, more advanced technology is likely to require higher levels of skill, but this is not necessarily multi-skilling.

One should be careful not to impose predetermined criteria which are likely to cause suspicion or rejection by any of the interested parties.

Structure

The work cycles and task listings will have an influence on the appropriate organizational structure. For small technological innovations this may be minimal, or even nothing.

More complex technologies, however, such as a move to continuous mining methods will, or should have an effect on organizational structure. This will be especially so if higher or new levels of skill are required, and there has been some fundamental work redesign.

Clearly a move towards continuous mining methods will place an emphasis on more engineering skills, and on a more process-based structure.

Structuring of mining organizations is a complex issue on its own, and has been dealt with by Malherbe[1995], based on the work of Elliott Jacques[1992]. This work should ensure that the structure conforms to the actual needs of the work cycles and task groupings, as well as to the requisite *levels of work* in the parlance of Jacques.

Returning to our continuous mining example, it is likely the new work structure will have:

- a higher engineering component
- a process-based structure that ensures continuous flow of product
- a higher level of operator skill
- a structure that allows discretion of the operators and supervisors to make quick decisions
- a leaner structure for faster information flow
- support structures congruent with the new core structure and work method.

Systems

The systems must be congruent with the new methods or technology. A systems engineering approach must be embodied throughout the whole process of implementation, and is supported by the work described in the paragraphs above.

Specific systems that should be addressed include:

- performance management systems for measuring the performance of the technology against predetermined targets and milestones (which appear in the feasibility study), as well as for measuring the output of the work system, for incentive purposes
- maintenance systems to ensure timely maintenance and back-up in the event of breakdowns
- appropriate new standards, codes of practice, work rules and procedures
- new emergency procedures
- new safety rules and systems, appropriate to the new work system
- appropriate financial accounting systems, to ensure that the correct cost allocations are made. This may require a move to activity-based costing systems, for example

- New logistical supply systems, such as stockholdings, store procedures, etc.
- Communication systems to constantly communicate progress towards the defined goals
- Mining systems, which might include new support system design necessitated by the new methods, new blasting systems, downstream systems such as rock haulage, hoisting etc. This phase revisits the entire work system, in order to ensure that it is in balance. Often, individual technologies have failed because the system around them has not been adapted to the change in output created by the new technology. Increased advance per blast on a deep level gold stope, for example, as created by a stope drill rig, could result in choking of the face and reduction of overall output, as a result of increased cleaning time. In such a case the system has been thrown out of balance because the whole work system has not been re-engineered.
- Incentive schemes which must be redesigned to be congruent with the new work method or technology. As mentioned earlier, this should apply to implementation teams, as well as to the operators during the implementation phase, and then to the new organization once the technology has been successfully implemented. These may be different in structure: they need to reflect the work goal of the team concerned, and so move from royalty or cash payout type rewards for the project phase, towards more standard team bonus schemes during implementation and production, but modified from standard production bonus in order to align with the objectives at hand. The issue of designing appropriate *pay* systems is very important, and identified as being especially so by Gross[1995], where new technology introduction results in the establishment of more highly skilled, self-managed and multi-functional work teams.

People

It has been recognized throughout this paper that people are a critical component of successful technology development, transfer and implementation. Many of these aspects have already been addressed, but this phase addresses the need for training and development.

A critical component of whether the technology is appropriate is the issue of competency and skill level.

An early imperative is to assess the profile of the workforce required for the technology or new work method, and to provide selection procedures and training which will allow the development of the required competencies identified during work cycles, task listing and structure, to be done timeously. Skills development should be a collaborative process, done with the full involvement of the equipment supplier, and organized labour.

The training requirement should address issues such as:

- competency to operate the technology
- understanding of the business and contribution to it by productive and efficient work
- understanding of any risks and hazards associated with the technology
- adequate levels of cross-skilling, commensurate with the work system
- literacy, numeracy, engineering and computer skills as necessary
- team building and team effectiveness.

Another key element which will have been present throughout the process, but even more so in this phase, is the involvement of organized labour. New work methods and technologies will bring about new work practices. These may require new work agreements governing flexibility arrangements in terms of skills flexibility, time flexibility and geographical flexibility. Initial support of the labour organizations is essential, if this phase is not to prove to be the downfall of the whole process. Careful planning to link the economic benefits of the implementation to gain-sharing schemes and work practices which are of benefit to all stakeholders is essential. These must ensure that not only the shareholders gain, but that a win-win split of benefits is assured, provided certain threshold performance measures are met.

Culture

The culture phase gives the opportunity to check if everything has fallen into place. It is a review process to address results measured against planned outputs as highlighted in the vision and feasibility study, and to assess if each phase has been successful.

The process will normally highlight areas that need to be modified or revisited, and it will indicate areas of improvement or renewal, where either, as was illustrated by Hustralid and Nilsson[1998], small improvements need to be made, or major breakthroughs are indicated or necessary. This illustrates a fundamental component of the wheel of change: it is a continuous process which has no end. As the logical end of the sequence is reached, so the review process indicates the need to spin the wheel again, either in its entirety, or in selected parts. So one moves from level to level in the technology development paths indicated by Hustralid and Nilsson[1998].

The role of research

The technology development paths referred to earlier require that parallel work is undertaken to ensure on the one hand continuous improvement of existing methods and technologies, and on the other, a programme of trial, transfer and implementation, as well as a research and development programme which is targeting the next wave or breakthrough, which is indicated on the radar screen.

Looking into the South African radar screen, issues requiring either applied or fundamental research are not difficult to identify. They include:

- increased mechanization and automation for tabular and base metal operations, in order to remove workmen from danger areas
- issues related to the sustainable development of the mining industry
- automation of tramming and transport systems, to improve operational efficiency
- development of alternative power systems, to enable improved flexibility in underground layouts
- safety and health issues, including improvement in dust, heat and noise emission and control

- further work on seismic research and rockburst prevention
- mineral resource management and mineral economics issues, such as cutoff grade optimization, alternative funding mechanisms, etc.
- advance delineation of orebodies, grades, structures, etc.
- improvements in security and product tracking systems
- research into the effects of AIDS in the workplace.

The identification of these as strategically important, in terms of establishing Research and Development programmes is well recognized by the major mining companies, most of whom now devote a section of their annual reports to the subject of R & D. De Beers, for example, states that it has 'a network of research laboratories that work together to support all aspects of the value chain, from prospecting and recovery through to sales of rough diamonds, cutting, polishing and branding.'(De Beers[1999]).

'Anglogold's technology and innovation programme makes use of both significant in-house research and development capabilities, and also involves collaborative industry projects. Expenditure during 1999 amounted to R43 million ($7 million), and expenditure during 2000 is expected to be R52 million ($8 million).' (Anglogold[1999]).

Buchanan[2000] also recognizes the strategic need for a science and technology programme. He suggests that a failure to identify and address current and future needs is a liability on the business. He also highlights the difficulty of quantifying benefits, in order to assess appropriate levels of budgetary investment. He suggests that to solve this dilemma, collaborative programmes should be developed, where the outcome of the research is in the common good.

Such collaborative programmes have been instituted successfully in South Africa, notably with Coaltech 2020, Deepmine and the Simrac projects, and these provide good examples for extending research and development into areas outside the defined boundaries of these three projects.

Buchanan suggests that to do this, international collaboration is important, in order to transfer knowledge already gained in countries where technology is already more advanced.

Estimated expenditure by mining companies in South Africa on Research and Development is 0.3 to 0.5% of turnover. By comparison, LKAB expends 1–2% of turnover on Research and Development (Hustralid and Nilsson,[1998]), while the intelligent mine development programme described by Pukkila and Sarrka[2000] has committed $8 million over a three-year period.

These figures would tend to suggest that South Africa should be increasing its commitment to Research and Development, through appropriate collaborative programmes, given the size of the industry, its technical challenges, its level of development, and its description as a sunrise industry (Mlambo-Ngcuka[2000]).

Vehicles for technology transfer

The internet has provided an ideal vehicle for the transfer of knowledge relating to technology, methods and research and development, where individual competitive edge is not an issue.

Many examples exist where wheels have been re-invented (sometimes square wheels) because transfer of information has not occurred or been available.

A brief visit to the internet reveals many technology transfer sites in North America in particular, where Institutions such as the Massachussets Institute of Technology or organizations such as the National Technology Transfer Centre (NTTC) offer information on technology transfer mechanisms, case studies and training and facilitation of technology transfer. The NTTC has, for example, identified 14 mechanisms for technology transfer, which they use to ensure any specific conditions or intellectual property rights are protected, whilst ensuring free and open access as far as possible.

While there are organizations in South Africa which do provide similar facilities, there exists a need for a wider linkage of industry, government, tertiary institutions and research organizations, to allow freer transfer of information for the advancement of the industry. Linkages to international technology transfer, as suggested by Buchanan then become possible.

Summary

This paper has attempted to illustrate that a holistic approach to technology transfer and implementation is necessary, if the industry is to capitalize on the opportunities offered by new technology. This process has to ensure a balance between strategic intent, business objective and purpose, and operational effectiveness.

New technologies must be introduced through a process which ensures that the implementation programme includes:

- a strategic component, such that the programme supports the strategic intent of the company
- a carefully developed feasibility study
- an inclusive change management process
- an understanding of the appropriateness of the technology
- a risk assessment and risk management programme
- an ongoing performance management system for people and technology.

Figure 5 shows, in summary, the steps to be followed, as described in the text. It illustrates the process is similar whether the technology is off-the-shelf, transferred technology or technology requiring research and development. It also shows that when the process is complete, at the 'culture' stage of the change wheel, two things should happen: the wheel must be revisited for continuous improvement, and the process must be revisited for the next wave of technology generation. These actions will ensure the necessary balance between current (off the shelf) implementation, and ongoing research and development for the future.

The technology transfer linkage is present throughout, whether for initial benchmarking, or for reporting of results of successful (or unsuccessful) implementation.

Conclusions

Successful implementation of new technology is vital for the future of the South African mining industry, in order for it to maintain its competitive position, and for its sustainable

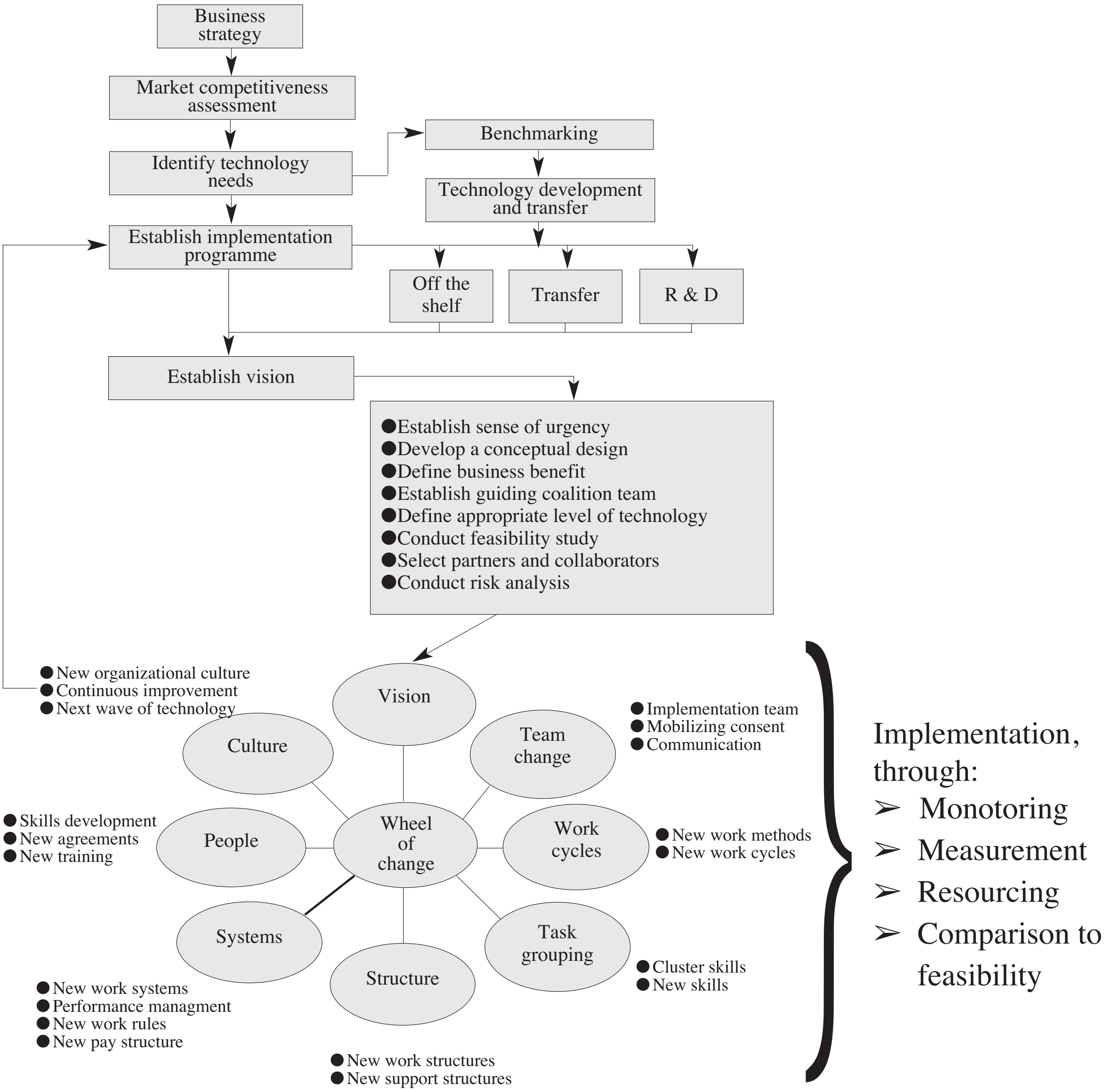

Figure 5. A holistic process of technology development and transfer

development. This must be done through an orderly, inclusive, transparent and holistic process, such as the one described in this paper, if it is to be sustainable.

Technology implementation needs to be appropriate to the level of development of the business and its people, and needs to be part of a strategy of technology development that includes adequate research and development of future, appropriate technology, which meets the strategic objectives of the business.

Adequate resourcing of research and development must be assured through collaborative research programmes which address the future needs of the industry. This must include international collaboration.

Technology transfer vehicles and centres need to be established, to enhance successful development and transfer of technology in the minerals industry, and to ensure its future viability.

A final conclusion from Dasys and Aalto[1998] is that 'for technology transfer to be effective, people, technology and process must be properly addressed. To do this effectively, technology transfer must itself be placed within a project context with clear objectives and milestones'. This statement is supportive of the notion put forward by Puhakka[2000] and alluded to earlier, that increased levels of mechanization and technology, generally are accompanied by a move to a more continuous process. This in itself results in a change in the organization and its structure. It is because of this holistic change, that a change model is necessary for successful technology transfer.

Footnote

'To my mind there must be, at the bottom of it all, not an equation, but an utterly simple idea. And to me that idea, when we finally discover it, will be so compelling, so inevitable, that we will say to one another, 'Oh, how beautiful. How could it have been otherwise?' (John Archibald Wheeler).

References

Anglogold: *Annual Report 1999*, Johannesburg 2000.

Buchanan, D.J. Mining Health and Safety Research–Quo Vadis; *IMM* November 2000, vol. 3, no. 35, London.

Cramer, L.A. Presidential Address, *Journal, SAIMM*. September 2000, vol. 100, no. 5, Johannesburg.

Dasys, A. and Aalto, M. Mining automation technology transfer—hurdles to implementation; *Proc. CMMI*, Montreal 1998.

De Beers : *Annual Report 1999*, Johannesburg 2000.

Department of Minerals and Energy: *A Minerals and Mining Policy for South Africa*; October, Pretoria, 1998.

Gross, S.E. Compensation for teams; *American Management Association*, New York, 1995.

Hustralid, W.A. and Nilsson. J.-O. Automation and productivity increases at LKAB, Kiruna, Sweden ; *Proc. CMMI Congress*, Montreal, 1998.

Inco: 1998 Annual meeting presentations, Inco website www.inco.com.

Jacques, E. Requisite Organisation; *Cason Hall & Co*, Arlington USA, 1992.

Kaplan, R.S. and Dickenson, A.L. Using the balanced scorecard as a strategic management system; *Harvard Business Review*, January-February 1996.

Kendall, R.J. and Gericke, M. Mechanisation in stoping narrow tabular orebodies; *Transactions*, *SAIMM* vol. 100, no. 2, March/April 2000, Johannesburg.

Kotter, J.P. Leading change—why transformation efforts fail; *Harvard Business Review*, March-April 1995.

Macfarlane, A.S., Handley, M., Nefdt, J., Gibson, M., and Naude, F. Mining Strategies for the Ventersdorp Contact Reef at Depth; Association of Mine Managers of South Africa, Johannesburg 1995.

Macfarlane, A.S. The development of a hydraulic backfilling system for a deep-level gold mine; Association of Mine Managers of South Africa, Johannesburg 1984.

Malherbe, G. The Wheel of Change, *Virtual Consulting*, 1993.

Malherbe, G. Structuring mining companies; *Virtual Consulting*, Salt Lake City, USA 1995.

Massachussetts Institute of Technology website.

National Technology Transfer Centre website.

Mlambo-Ngcuka, P. Address to the 100th Annual General Meeting of the Chamber of Mines, Johannesburg, November 2000.

Pukkila, J. and Sarrka, P. Intelligent Mine Technology Program and its implementation; *Proc. Massmin 2000*, Brisbane 2000.

Pukkila, J. Implementation of mine automation : the importance of work safety and motivation; Civil engineering and building construction series, *The Finnish academy of technology*, 1999.

Puhakka, T. Optimising Mobile Equipment Resources in Massive Mining; *Proc. Massmin 2000*, Brisbane 2000.

Ramani, R.V. and Mutmansky, J.M. Mine Health and Safety at the turn of the millennium; *Mining Engineering,* September 1999.

Richard, P.L. Effective Production Monitoring in Open Pit Mines: Beyond the Technology; *Proc. CMMI,* Montreal 1998.

Runge, I.C. Mining Economics and Strategy : *SME*, Littleton USA, 1998.

Russo-Bello, F. and Murphy, S.K. Longwalling at great depth in a geologically disturbed environment—the way forward ; *Journal SAIMM,* vol. 100, no. 2, March/April 2000 Johannesburg.

Smith, L.D. Checklist for economic evaluations of mineral projects; *CIM bulletin*, vol. 87, no. 983, September 1994.

Tarr, R.G., Fouche, J., Rogers, T.C., and Pocock, J.W. How to leverage your bottom line with good drilling and blasting practice; *Journal SAIMM,* vol. 100, no. 2, March/April 2000 Johannesburg. ◆

SAIMM DIARY

Mining

COLLOQUIUM
Enterprise resource planning in the South African Mining Industry
26 July 2001, Mintek, Randburg

COLLOQUIUM
Mine closure
8 August 2001, Mintek, Randburg

COLLOQUIUM
Open pit and surface mining
29 August 2001, Mintek, Randburg

COLLOQUIUM
Competency transformation in the mining and minerals industry for the 21st century
23–24 October 2001, Mintek, Randburg

Metallurgy

SCHOOL
Pyrometallurgy School
22-23 August 2001, Mintek, Randburg

COLLOQUIUM
Ferroalloys and the environment
Date and venue to be advised

COLLOQUIUM
Nickel, copper, cobalt, and zinc recovery
16–18 July 2001, Victoria Falls, Zimbabwe

INTERNATIONAL CONFERENCES

RaSiM 5—Dynamic rock mass response to mining
17–19 September 2001, Magaliesburg, N.W. PROVINCE

The 6th International Symposium on Mine Mechanization and Automation
25–28 September 2001, Sandton, JOHANNESBURG

XIV International Coal Preparation Congress and Exhibition
11–15 March 2002, Sandton, JOHANNESBURG

Surface Mining 2002 - Modern developments for the new millennium
4–6 September 2002, Sandton, JOHANNESBURG

For further information, please contact:
The Secretariat, SAIMM, P.O. Box 61127, MARSHALLTOWN 2107
Tel.: (011) 834-1273/7, Fax: (011) 838-5923 or 833-8156, e-mail: saimm@saimm.co.za