MINING SAFETY - NEW APPROACHES NEEDED?

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SUMMARY

The paper examines trends in mining safety records from Australia and the United States. These records indicate that whilst mining safety has improved significantly in these countries over the past 50 years, worryingly, the rate of improvement has fallen off in the past few years. It is argued that new approaches are needed to produce a needed step improvement in mining safety. These new approaches might be based on new technology. The case is made that Australia is now a country at the forefront of new mining technology development and that marketing of this technology presents the nation with a significant business opportunity.

MINING SAFETY

The Problem

We begin this discussion by making a starting hypothesis that:

Mining safety and mining productivity have both improved tremendously over the past half century BUT today the rates of these improvements have fallen off.

We test this hypothesis by examining data from Australia and the United States. We then discuss the factors which have caused the observed improvements in safety and productivity. This leads us to ask where future improvements are likely to come from.

Figure 1, plotted from MSHA[i] data for all U.S. mining operations, supports the hypothesis from a mining safety viewpoint. There was a steady decline in both the fatality and the disabling injury rates in all U.S. mines from 1931 to 1977[ii]. The second order polynomial curve fitted through the disabling injury data emphasises the point that the rate of this improvement has plateaued.

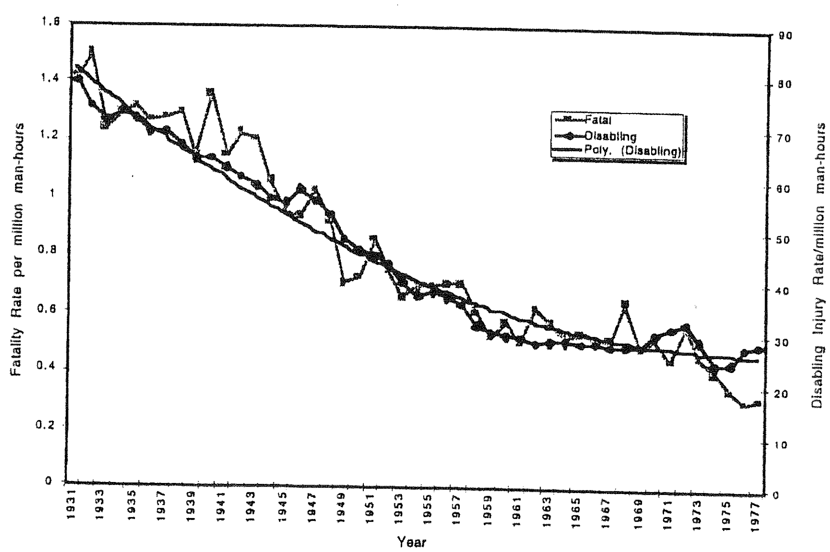

Figure 1 *Fatality and disabling injury rates at all mines in the USA (from MSHA data, World Wide Web, http://www.msha.gov/STATS/wq31am01.htm)*

Figure 2 is plotted from data published by the Department of Minerals and Energy in Western Australia. The fatality rate data (Figure 2a) clearly is very scattered (hence no attempt has been made to fit a curve through these data). However, there is a worrying indication that during the past four decades this rate has oscillated about, but not fallen consistently below, a value of about 0.3 fatalities per million hours worked.

The lower curve in Figure 2b shows the decline in the rate of serious[iii] injuries in Western Australian (WA) mines over time. This shows that, as with the U.S. data, the rate of improvement in serious injuries has, to a large extent, plateaued in recent decades. The upper curve in this figure shows the decline of all injuries (serious and minor) in WA mines. This shows a rapid improvement in safety performance between about 1962 and 1972 and a continuing, but more modest improvement since then.

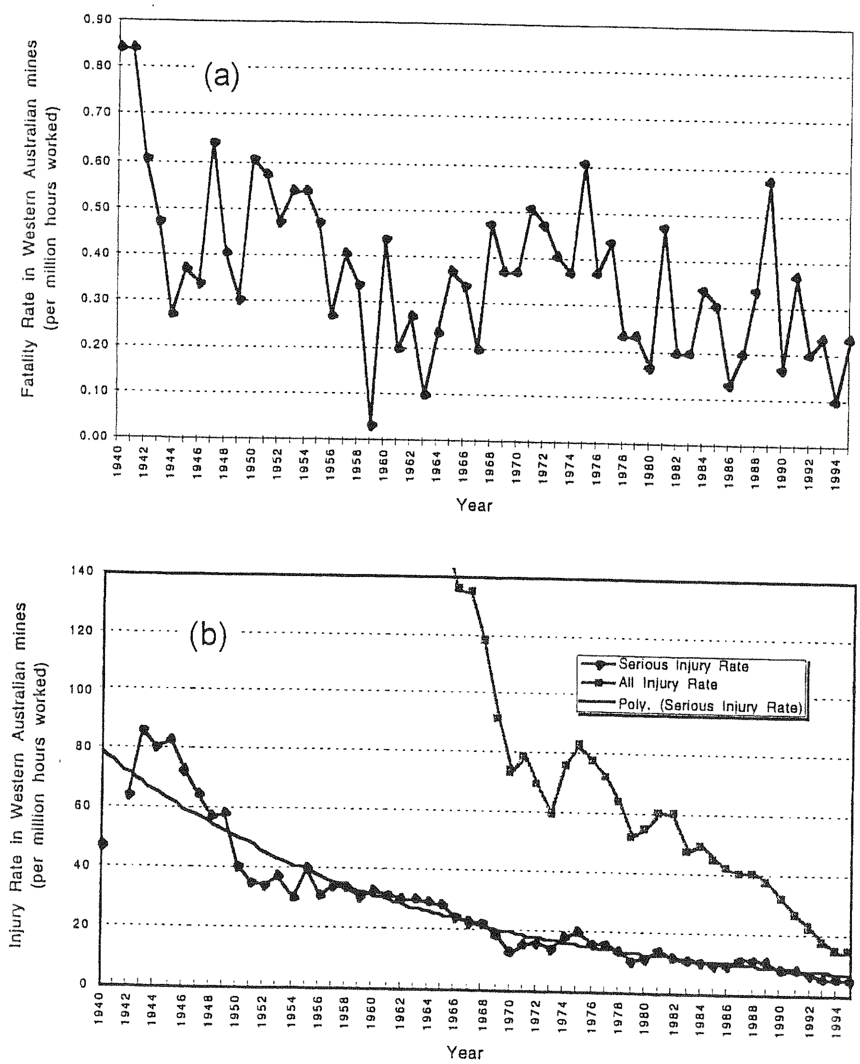

Figure 2 *Fatality and injury rates in Western Australian mines (from data provided by the Western Australian Department of Minerals and Energy)*

In summary there are indications that the rate of safety improvement in mining, at least for fatalities and serious injuries, has reached an asymptotic level. Also, it is of substantial concern that the safety performance in the mining industry remains about an order of magnitude worse than it is in other comparable heavy industry and nearly two orders of magnitude worse than Du Pont, a company which is regarded by many as a leader in safety excellence. In 1990 Du Pont's lost workday case performance was 0.035 per 200,000 exposure hours [1]. In that same year Consolidation Coal, then a Du Pont company, posted a lost workday incidence rate of 2.97. This was a factor 84 times worse than the Du Pont average. It should be noted that this Consolidation Coal safety performance was good by mining standards, being equivalent to about 15 injuries per million hours worked. Inspection of the upper curve in Figure 2b shows that in 1990 the injury frequency rate in WA was twice this value, although now safety in these mines has improved to be about this value.

Mining productivity is the other parameter of interest. Figure 3a shows the change in productivity in Australian coal mines from 1942 to 1995. Figure 3b is an equivalent plot for U.S. coal mines over a similar time period. Figure 3c is a plot of labour productivity in the U.S. copper industry from 1973 to 1994. These plots all show that the starting hypothesis — that mining productivity in recent years has decreased to an asymptotic level — is wrong. Although the time periods examined are not the same, these plots show that during the initial periods productivity rises were modest and that in more recent times productivity in these three industry sectors has increased sharply.

Different sectors of the mining industry will have different explanations for these productivity changes. Production practices in the U.S. copper industry were changed in the early 1980s as a result of increased competition from lower-cost mines in Chile. In Australia from the end of the 1960s to about 1980 the development of the Bowen Basin coalfield caused a substantial increase in the quantity of coal produced and a change from coal being mined by predominantly underground to predominantly surface methods. In the United States the amount of coal produced from underground mines has remained about the same from 1950 to today (approximately 350 m tons/y). However, as shown in Figure 4, there was a steady increase in the coal produced in surface mines from 1949 to 1969 and then a rapid increase in surface-mined coal during the decade of the 1970s.

Also plotted in Figure 4 is the total (both surface and underground) U.S. coal mining productivity curve. It is interesting to note that the dip in this productivity curve occurred from 1969 to 1979 during the period when surface coal mining was expanding rapidly. This is counterintuitive, since surface mining generally is more productive than underground mining it might have been expected that an increase in the proportion of surface-mined coal would be accompanied by an increase in productivity.

An explanation for this dip in the productivity curve can be found in Figure 5. This shows that the size of the workforce increased rapidly during the 1970s; a period when the price of oil increased substantially and there was much concern in the USA about the need to produce energy domestically. Only when the price of oil, and energy generally, fell in the 1980s did the workforce size decrease and productivity increase.

Despite the different explanations these productivity increases have been achieved largely not by new technology but rather by increasing the size and power of machines and by improved management.

In concluding this discussion on mining safety and mining productivity we note that mining methods generally have not changed over the last 50 years. Surface mining in hard rock mines is still carried out with drills, shovels and trucks; and in coal with draglines, drills, shovels and trucks. Today underground metalliferous mining uses more bulk extraction techniques (eg open stoping) than selective techniques (eg cut-and-fill) but it is still carried out by drilling and blasting.

However, two important changes have been made during this period. One is the preference for surface, at the expense of underground, mining. Surface mining typically is both more productive (Figure 3b) and more safe. The other is the use of much greater levels of mechanisation. This replacement of people with machines has increased productivity greatly and it has also increased safety, but to a lesser extent [2].

The overall point is that the current approaches towards improving mining safety have reached a point of diminishing returns and other approaches are needed if we are to move the rate of change of this parameter from the existing, asymptotic curves onto other, steeper curves. Also whilst, almost certainly, there is much that still can be done to improve mining productivity by improved training and management, ultimately the constraints imposed by the existing systems will limit this approach. Summarising, new approaches to improving mining safety and productivity are needed because:

- not all deposits are susceptible to surface mining methods,
- even though surface mines are safer than underground mines, the injury frequency rates in surface mines still lag substantially behind world's best practice in other heavy industries,
- it follows that underground mines generally have an even greater step to make to reduce their accident rates to world's best practice in other heavy industries,
- in recent decades the trend with mechanisation in both surface and underground mines has been to increase the size and power of the machines and this brute-force approach is reaching an upper limit.

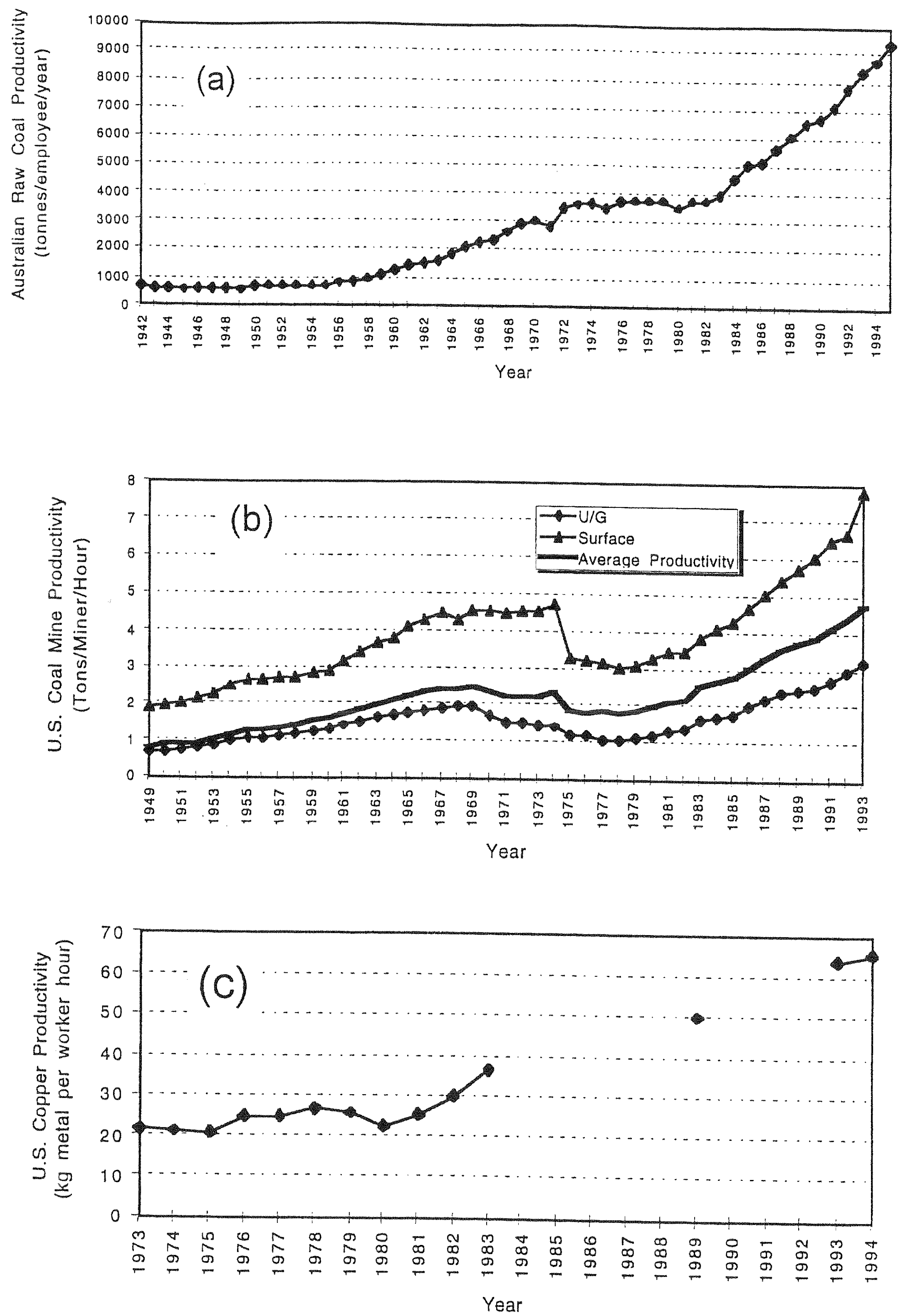

Figure 3 *Changes in mining productivity in:*

a) the Australian coal industry (data taken from 1995 Australian Black Coal Statistics, published by the Joint Coal Board and the Queensland Coal Board and personal communication with the Joint Coal Board)

b) the US coal industry (data taken from the World Wide Web, The Coal Data: A Reference Publication, ftp://ftp.eia.doe.gov/pub/coal/coallast.pdf), and

c) the U.S. copper industry (data taken from Mineral Facts and Problems, 1985 Edition, U.S. Bureau of Mines Bulletin 675, and World Wide Web, Minerals Yearbook, http://minerals.er.usgs.gov/minerals/pubs/commodity/copper/240494.pdf)

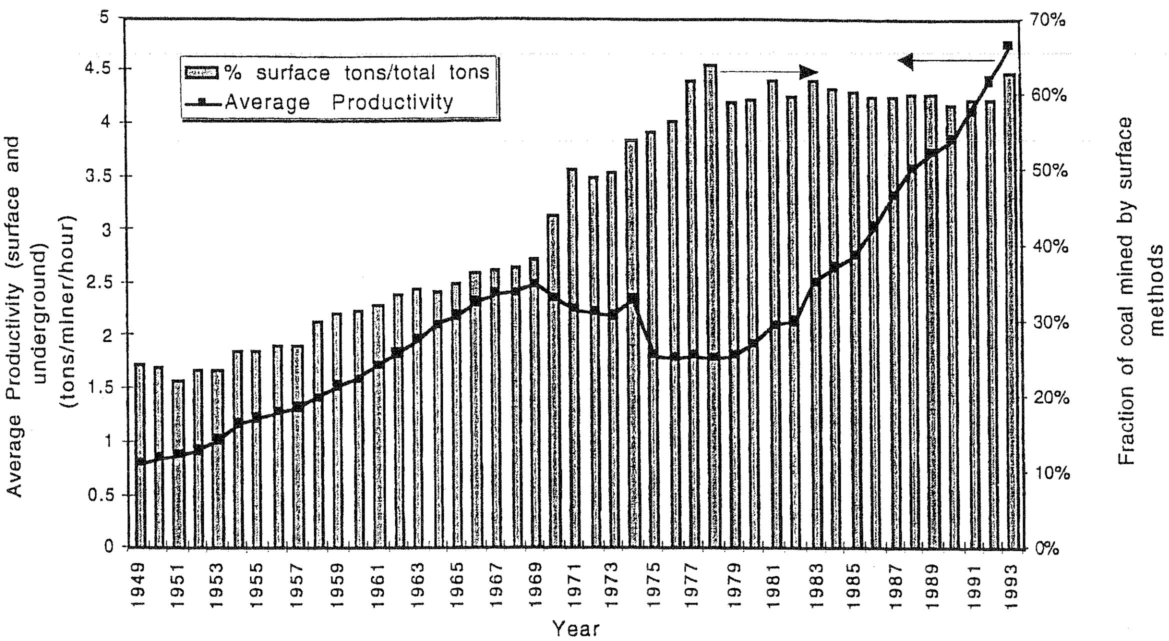

Figure 4 *US coal mine productivity and the fraction of the coal extracted from surface mines (sources as for Figure 4b)*

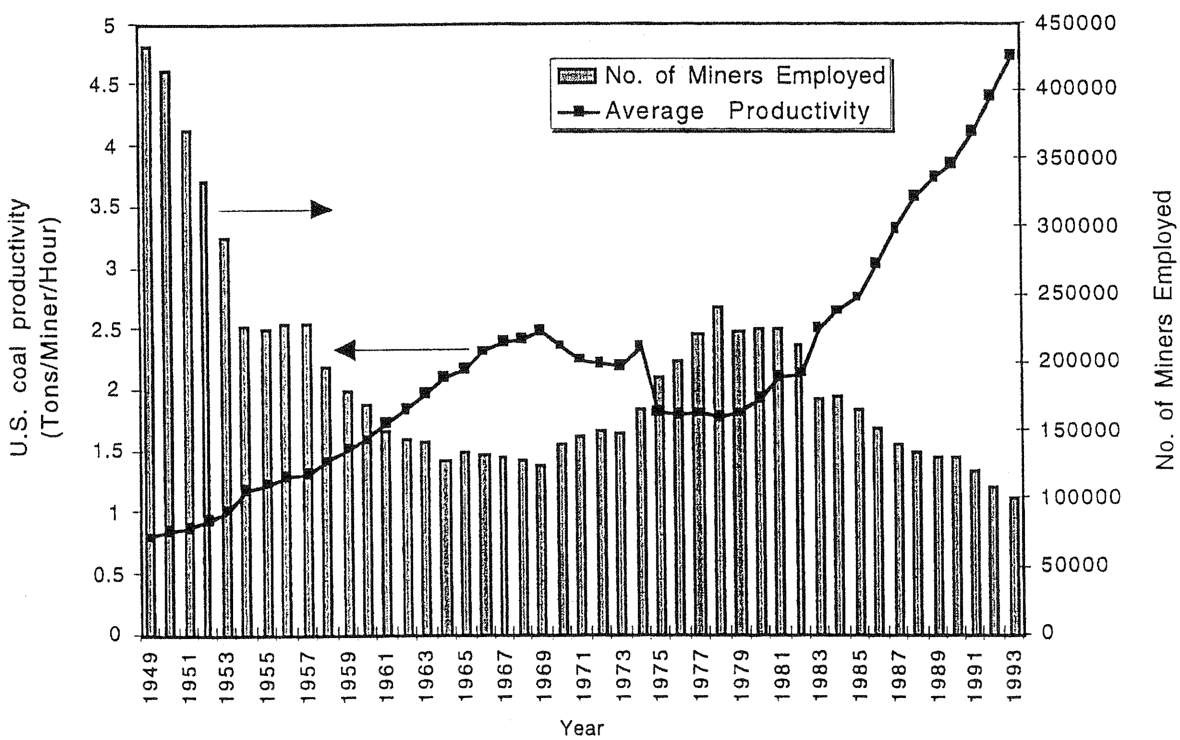

Figure 5 *US coal mine productivity and the size of the coal mining workforce (sources as for Figure 4b)*

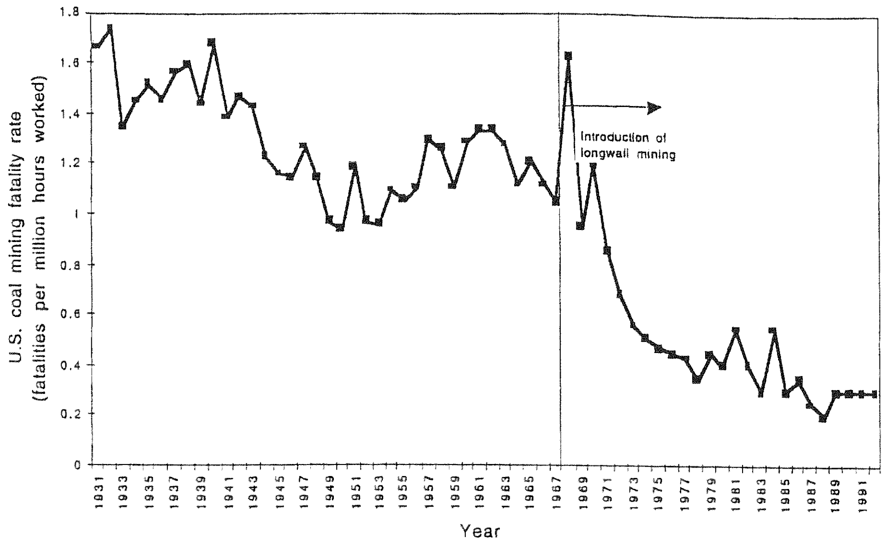

Figure 6 *Fatality rate at U.S. underground coal mines (from MSHA data)*

Possible Solutions

One of these other approaches could be the development of new mining systems. A new mining system which was introduced during the last half century and which now has come to dominate as the method of underground coal mining, is the mechanised longwall. In Figure 6 we have again used MSHA data to plot fatality frequency rates from 1931 to 1991. These data show a gradual decrease in fatality rates from about 1.7 to about 1.1 from 1931 to 1967. However, there was a rapid decrease from 1.1 to about 0.4 from 1968 to 1978 and a gradual but uneven continued decrease to about 0.3 from 1978 to 1992. This period of rapid decrease in fatality rates coincides with the introduction of longwall mining (the number of longwall faces in the USA went from about 10 in 1968 to about 95 in 1978, [3]).

The development and acceptance of new mining systems is difficult to achieve and it occurs infrequently. Nevertheless work directed towards the development of these systems is worthwhile because of the major step change which these new systems can bring to both safety and productivity.

We argue also that more immediate improvements in safety and productivity can be realised through work which is directed to make better use of the existing mining systems. Examination of these systems reveals three areas where substantial improvements could be made:

- *Automation:* The mining industry is unusual in that while it is highly mechanised it is almost completely un-automated. The automation of other industries, such as manufacturing, which has occurred mainly during the past two decades, has produced significant improvements in productivity. In mining, a main target area would be the automation of tasks in the most dangerous areas of the mine, often around the working faces. This would result in improvements in both productivity and safety.
  However, the automation of mining systems poses a number of significant technical problems, which is the reason it has not yet been achieved[iv].
- *Geological Vision:* The effective extraction of the orebody or the coal seam with existing mining systems is made difficult because the miner (the person operating the mining equipment) has represented in the mining face only a two dimensional view of the valuable mineral and the structure of the rock mass. Changes in the third dimension (orthogonal to the mining face) in mineral grade, in mineral deposit thickness, in deposit continuity, and in rock mass quality, is information not available to the miner. This *blind mining* leads to three difficulties. One is that valuable mineral is not extracted because the miner is unaware it is there — by definition it is difficult, or impossible, to quantify the value of this *lost* mineral. Two, is dilution of the valuable mineral with waste rock because the lack of *geological vision* makes it impossible for the miner to guide the mining system in an

optimal manner. Three is the inadequate knowledge of structures — such as faults, dykes, and shear zones — within the rock mass. This leads to both operational (= productivity) and safety problems.
These problems are more severe in underground than in surface operations because the miner in a surface mine has a quasi-three dimensional view of the deposit. However, almost all surface mines would benefit greatly from an ability to *see* through the rock during the mining operation. It follows that underground mines would profit tremendously from this ability.

- *Equipment Reliability:* The utilisation of the existing, expensive capital fleets in mines is typically very low. There are two reasons for this. One, the harsh operating environment in a mine results in high rates of equipment wear and high incidences of machine breakdown. This translates to low equipment availability. Two, particularly in underground mining, the numerous unit operations involved in drilling-and-blasting complicate the task of scheduling all of the different pieces of equipment which comprise the mining system. This makes it difficult to utilise the available equipment efficiently. This problem is exacerbated by management's lack of knowledge of the locations of the mobile equipment during a shift.
The solution to the machine availability problem is to develop and implement improved systems for equipment maintenance. A part of this solution is to develop better methods for the real-time monitoring of the health of equipment components. Automation of the equipment also would help with this problem since automatic control will not allow the machine to operate in an overload condition. Also automation could provide the information to management on real-time location of the mobile equipment.

DO THESE MINING TECHNOLOGY IMPROVEMENTS REQUIRE R&D?

In all four of the work areas described above, namely the development of:
(i) new mining systems,
(ii) sensors and control methodologies for automating existing mining systems,
(iii) geological vision, and
(iv) new condition monitoring systems for equipment reliability,
new technology is needed. However, often large companies working in this mature industry find it preferable to purchase new technology and adapt it as needed than to develop it through in-house R&D.
These four work areas all can be advanced substantially through the adaptation of technology which has been developed by and for other industry sectors. However, even with this adaptation, substantial additional R&D of both a basic and an applied nature will be needed to develop useable mining systems.

WHO MIGHT CONDUCT THIS R&D?

For many decades mining research has been conducted by a number of organisations and by mining equipment suppliers throughout the world — although, notably, not significantly within Australia. However, during the past decade the mining research landscape has changed dramatically. Most of the traditional western-world mining research organisations have disappeared or been greatly scaled back (Table 1). This severe diminution in mining research activities has taken place for different reasons — depletion of reserves (UK, Germany, S. Africa), political (USA, Canada).

Country	Mining Research Organisation	Status
USA	US Bureau of Mines	Closed by the federal government effective January 1996
Canada	HDRK	Privately funded. Shut down by its partners 1995
Canada	CANMET	Scale of operations greatly reduced
UK	British Coal (TSRE)	Shut down 1994
Germany	Bergbau Forschung	Merged into DMT. Mining research greatly scaled back
South Africa	COMRO	Merged into CSIR. Mining research greatly scaled back

Table 1 — *Reduction in scale of international mining research organisations*

In fact, worldwide mining R&D has been scaled back to an even greater extent than Table 1 indicates. During this same period several of the large overseas mining equipment manufacturers (*eg* Atlas Copco, Ingersoll Rand) have reduced their R&D activities substantially. Also, many of the traditionally strong mining research and mining education programs at overseas universities are today much weaker than they were a decade ago.

In a contrarian move Australia, within the past five years, has reacted to this changing R&D environment by placing increasing focus on research aimed at developing new mining technology. A new Cooperative Research Centre for Mining Technology and Equipment (CMTE) has been established and a new Division of CSIRO, for Exploration and Mining, has been created.

THE OPPORTUNITY FOR AUSTRALIA

This situation poses Australia with a problem — we can no longer assume that new mining technology will be readily available from overseas — and an opportunity — we can seize the moment to invest in mining R&D and thereby develop better technology for our own mining companies while, at the same time, create new businesses in the areas of mining equipment manufacturing and mining engineering consulting.

This opportunity, if seized at this particular point in time, would enable Australia to move from its current position of supplying very little of the world's mining technology to one where it becomes the dominant supplier of that technology.

Conclusions

Our purpose in this paper has been to point out that:

(i) the rates of improvement of mining safety have fallen in recent years both within Australia and internationally,

(ii) the rates of improvement of mining safety and mining productivity can be increased both by enhanced management practices and by the introduction of new technology,

(iii) much of the technology used currently in Australian mines was developed by overseas research organisations and that most of these organisations are now in a greatly diminished state — this situation presents Australia both with a problem (it can't expect to continue to import new technology) and an opportunity (it can take the lead and become the new world provider of mining technology),

(iv) in particular, four technological areas hold the promise for substantial improvements in both safety and productivity,

(v) although all of these four areas can borrow and adapt technologies developed in other industry sectors, additional medium-long term R&D will be necessary to develop these technologies into useful mining systems,

(vi) if Australia decides to take the lead in conducting this R&D the benefits from the technology which are developed will flow to several different industrial sectors, specifically to: domestic mining companies, equipment manufacturers, instrument manufacturers, and consultants,

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[i] U.S. Mine Safety and Health Administration

[ii] Unfortunately the U.S. changed the basis for calculating injuries in the late 1970s and thus it is difficult to compare the more recent data with these more historical data.

[iii] In Western Australia a serious accident is defined as an accident which causes a worker to be away from the workplace for at least two weeks (Torlach, personal communication)

[iv] Automation of mining equipment is difficult for two reasons. One, this equipment operates in a hostile and unstructured environment. Two, although most mining machines can be considered as robots they are, in robotic terms "bad robots" because generally they are large compliant structures. "Good robots" by contrast are small with rigid linkages. Despite these difficulties it is possible today to develop and employ advanced sensing techniques and control strategies to automate compliant robots and even mobile equipment in unfriendly environments.