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Economics, Technological Change and the Knowledge Problem

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ABSTRACT

Computers and other microprocessor technology lead the world of technological change. Nevertheless, the real advances in the world at large are not necessarily in the computer industry, but in the industries whose economics benefit most by the advances that this computer revolution makes possible. The minerals industry has always been in the forefront of this advance.

Technological change in the era preceding the industrial revolution, and the mining industry's part in it, provides an instructive lesson for what is happening today. Strong parallels can be drawn for predicting future advances. With each technological advance allowing more efficient production comes a re-alignment of economics — absolute and relative changes to prices, to quantities demanded, and to other market characteristics. This re-alignment applies not only to the mineral industry, but also to the world at large. Adaptability, rather than technical advancement per se is the key to survival and growth in a changing world.

'Adaptability' as a concept is easy to support. As an operational philosophy it is not so easy to implement. As a goal for planning, it is much harder to quantify. A fixed scenario of a future world may provide helpful guidelines, but a scenario that demands adaptability to an uncertain future world is much less definite. Of course, everyone else in the world is also uncertain about the future, and they are making their plans using different assumptions. This virtually guarantees that our future will turn out different to our expectations. This is in part what Hayek (1945) calls the 'knowledge' problem. Until now, most of the planning and technical research undertaken in the world has ignored this problem. This ignorance is a luxury that we can no longer afford.

The paper looks at the history of technological change and highlights the characteristics of successful technological revolutions. 'Adaptability' to unforeseen circumstances is the key to success in this environment. The paper examines the knowledge problem from the perspective of the mineral industry, and suggests a number of directions for maximising the returns from application of computer technology in this important area.

HISTORY OF TECHNOLOGICAL CHANGE

'All we know for certain about the future is that it will be different from the present'.

In the world of computer technology and constant change, even this seemingly indisputable statement from Burgelman and Maidique (1988) bears re-examination. In the 1990s, change seems so endemic that it is hard to believe that the concept of change itself was a novelty just two centuries ago. An understanding of the changes in technology since that time, and society's reaction to it, offers powerful insights into what we can expect in the future.

From any vantage point in the future, past society always seems slow to accept new ideas. It seems hard to believe that 200 years ago there was no general understanding that the world did in fact change. Even the publication in 1687 of Newton's 'laws of motion', one of the greatest advances in the history of science, served to underscore rather than challenge this belief. 'Newton's universe was one of perfect predictability — a cosmic clockwork mechanism — where planets cycled endlessly along unchanging paths. Objects moved, but the 'laws of motion' never changed. In the stately order of the Newtonian universe, the future was indistinguishable from the past. History was meaningless in a world of endlessly repeating cycles' (Rothschild, 1992). In the Newtonian era, science could explain things, but the idea that it could change things was absurd.

The significance of this belief in total changelessness should not be underestimated. A precondition for any advancement, indeed any action, is the belief that changes are possible through purposeful human action. 'In the absence of this condition no action is feasible. Man must yield to the inevitable. He must submit to destiny' (Mises, 1966). Whilst the history of man's progress tends to focus on technological developments, clearly technological advancement can only be forthcoming in an environment where society at large acknowledges the need for and appreciates the value of change. Without this institutional support, change cannot occur. Advancement will be stymied. Looking into the 21st century it is essential not only to look at the scope for technological advancement, but also to understand the environment in which these developments are maturing.

What turned society's view about change from the Newtonian time to the time of the industrial revolution and beyond? What institutional forces are at work today that might provide clues for our advancement in the future?

History has shown that the mineral industry played a significant role in this change. Whenever there is change, there is a step into the unknown, and the first people to make this step incur the greatest risk. Even today, the mineral industry is perhaps the industry most associated with, and most capable of making decisions under uncertainty and risk. It is therefore not surprising that the mineral industry is frequently in the forefront of new technology application and change. A short chronology of this development during the industrial revolution is instructive to illustrate the mineral industry's significant part in it. The chronology also highlights the iterative nature of all developmental advancement and sets out five key points that are explored in the balance of this paper.

CHARACTERISTICS OF TECHNOLOGICAL REVOLUTIONS

The industrial revolution traditionally dates from about 1800, when factories powered by Boulton and Watt steam engines were built in large numbers. If there is a date when society's view of a changeless world changed, this is it. Yet the fundamental technological advancement that ultimately resulted in the industrial revolution actually started some 90 years previously. In 1712 the mining industry became the launch customer for what was arguably the world's first great advance in technology — when the first Newcomen steam engine was installed at a coal mine in Staffordshire, England. The Newcomen engine remained unchallenged as the world's only self-powered machine for more than 60 years. By 1775 when the superior Boulton and Watt engine became available there were nearly 600 Newcomen engines driving reciprocating pumps throughout Europe (Rolt and Allen, 1977). The chronology of the development of this technology is too detailed for this paper, but the key aspects of this advancement summarised below are significant:

Technological change

Economics

Economic returns underpinned each step in the development and implementation of the engine from 1712 until the 1800s. In 1724, a 16 horsepower model cost £1200.00 — a princely sum — but was justifiable on the operating cost savings. In 1730, a

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French coal mine reported that two men operating a Newcomen engine could accomplish the work previously undertaken by 50 horses and 20 men. In 1752, the economics of pumping using the engine were reported to be 30 to 40 per cent cheaper than muscle power. Nevertheless, the cost-effectiveness of the engines was not universal because they were not very fuel-efficient. Most engines were installed in coal mining, where unsaleable poor quality coal was a cheap source of fuel.

Iterative nature of technology development

Just as the computers of today are helping design superior computers that will ultimately render them obsolete, so too did the Newcomen engine sow the seeds of its own demise. Cheap coal and increased production from the mines that benefited from the lower pumping costs ultimately led to substantial advances in the iron industry — improving the quality and precision of iron manufacture. Coupled with James Watt's improved condenser the improved manufacturing precision in the new Boulton and Watt steam engine gave it efficiencies with which the Newcomen engine could not compete.

Rewards from new technology — who benefits?

The first developer of any new technology cannot just relax and reap the rewards. The technology itself assists competitors too — possibly more than it assists the incumbent. Neither can the first users relax. The first users of Newcomens technology — the coal mines — were rewarded by . . . cheap coal. As surely as a new technology lowers the cost of production, some competitor will seek to gain advantage by lower prices and increased output. There is no escape from these market forces. First users seldom make big profits for long — the best they can do is expand into a market vacated by their competitors who do not have the technology. The main beneficiaries are in the world at large who have lower supply costs with no additional technology investment costs.

Order of magnitude changes characterise technological advances

The 'second generation' engine of Boulton and Watt was an order of magnitude superior to the Newcomen engine. For the same power output, it used 75 per cent less coal. It wasn't restricted to reciprocating applications. When coupled with James Watt's flywheel and double-acting piston, it expanded the application of steam power to factories requiring rotating power. The size of market grew by an order of magnitude. More steam engines were built in the ten years between 1790 and 1800 than in the previous 90 years.

Dual nature of investments in technology

New technology always provides a dual service. Firstly, it provides a measurable, or quantitative service whereby tasks previously undertaken are accomplished cheaper, better or faster. Secondly, it allows tasks which were previously impossible to now be undertaken. I refer to this second service as an inceptive service, since it marks the beginning of some new service, or frequently, the inception of a whole class of hitherto unavailable services. Because they do not currently exist, inceptive services are frequently difficult to quantify because there is no benchmark to assess their value. The earliest tasks of a new technology are invariably of the first kind, since in these tasks value is easiest to assess and the applications are already in place. The earliest applications of the Newcomen engine were in coal mining made cheaper and more efficient by the introduced technology. Yet it is the inceptive service provided by a technology that usually yields the greatest value, and frequently this value does not materialise until the second or later generations of the technology. In the case of the Boulton and Watt engine — the 'second generation' of the technology — the first installations were again in mining, in this case to open up the tin and copper mines in Cornwall. These mines could not be developed without a better mine pump, regardless of the economic savings associated with its more efficient use of fuel. The installation of Boulton and Watt engines in factories also allowed factory development in areas of England previously excluded from industrialisation due to their distance from running water.

Institutional change

The above five points characterise the technological change prior to the industrial revolution, but what about institutional change? No doubt people in the mining industry were aware of change throughout the 1700s, as were the people involved in manufacturing the new engines. But it is almost certain that this perception was not shared by society at large.

> *The fact is, that society is always changing, but the rate of change has been accelerating all through history. It was only with the coming of the industrial revolution that the rate of change became fast enough to be visible in a single lifetime (Asimov, 1988).*

The technology for an industrial 'revolution' was already well in place by the start of the 19th century. It was only when this institutional pre-condition was satisfied, *viz* broad popular support for the idea that purposeful human action would bring about (wanted) change, that the 'real' industrial revolution commenced in earnest.

The state of these two determinants — of a technological advancement in the 'second generation' of implementation, coupled with institutional factors offering broad support for the change — is crucial to any scenario predicting the computer revolution in the future.

THE COMPUTER REVOLUTION IN THE MINERALS INDUSTRY

Let me state my proposition up front: Looking back from 200 years into the future, I doubt that historians will date the computer revolution as starting anytime before now. In 1995, the application of computers in the mineral industry is in the same relative state as was the application of self-powered machinery in England at the start of the 19th century.

There is no doubt that the changes associated with microprocessor technology are of significance akin to the changes associated with the development of self-powered machinery 200 years ago. Technological advances are characterised by order-of-magnitude changes in efficiency and market growth. The characteristic iterative growth cycle in complementary areas of the technology is certainly present. Each technological development step is supported by economic returns — at least for those companies which correctly anticipate where the returns are most likely to materialise and invest in a timely manner. Technology is driving down the price of most raw commodities and many manufactured goods. From a mining industry perspective, declining prices benefit the world at large much more than they benefit the companies themselves.

My contention that the computer revolution is still in its infancy is based on the relative under-development of the two remaining aspects described above — the implementation of the technology in inceptive applications, and the extent of institutional support for the fundamental change.

Quantitative, or inceptive applications?

To illustrate the first aspect, Table 1 sets out a number of common computer applications in mining, and in the world at large, grouped according to this categorisation. The applications on the left side of Table 1 are tasks that, in my view, would be undertaken whether we had computers or not. In these applications the primary use of computers is for faster, better, or larger quantities of work to be completed than would otherwise be the case. The applications on the right side of Table 1 are tasks that, in my view, are not possible, or would not have been possible, without computers.

The list in Table 1 is of course incomplete, and since every computer program contains elements of both services, the categorisation is fairly subjective. Nevertheless, the acid test of the categorisation is to identify things happening that would not otherwise be happening in the absence of modern computer technology. It is a safe bet that 90 per cent of computer usage in mines fits on the left side of Table 1. The ubiquitous spreadsheet that I have enigmatically placed on both sides of the table has doubtless been used on hundreds of applications that would have been inconceivable prior to its introduction. Nevertheless, even this powerful tool is probably used 90 per cent of its time on simple tabulations that are little more than the electronic equivalent of an earlier paper form.

Even highly technical applications like ventilation modelling and geotechnical modelling are questionably categorised as inceptive applications — the former being previously modelled on analog electrical devices, and the latter being modelled using physical models long before the ascendancy of the (digital) computer. There are some mines that would not have been discovered without this technology, but it is difficult to see any mines in the world whose fundamental operation is dependent on computers. Clearly economic refinement (profitability) of many mines would suffer in the absence of digital computers, and removal of computers would require a period of adjustment, but these are matters of degree, not scope.

The widespread appearance of mines and businesses whose scope is fundamentally reliant on this technology will mark a turning point for progress of both the mine technology and economics, and a watershed in broad management acceptance of the technology. The mineral industry is not there yet.

Institutional support for fundamental change

When technical personnel read about the industrial revolution, it is the technical advancements that grab their attention. When the rest of the world considers the industrial revolution, the image is the Dickensian 'Mr Scrooge' exploiting hapless workers. Child labour in the mines is a constant theme. Whilst professional historians have demonstrated that these populist themes were greatly exaggerated and often misrepresented (Hayek, 1954; Ashton, 1949; Hutt, 1926) there is no doubt that the period was one of profound institutional change. This institutional change had a penetrating influence on the adoption and efficacy of the new technology. The computer revolution yet to come will be no different.

TABLE 1

Categorisation of computer applications.

Existing Application (Quantitative Return)	Inceptive Applications (not previously possible)
Commercial Applications —	Geostatistics
Accounting, Production	Equipment/Process
Reporting, Information	Simulation
Management, Payroll	Geotechnical Modelling
Geological Modelling	
Mine Scheduling	
	GPS Positioning
Spreadsheets	Spreadsheets
Word Processing	Cellular Phones

To illustrate this point, I use just one example — of the implementation of 'continuous' miners for winning of coal in open pit mines in Australia. For at least the last 15 years, this technology has offered scope for improved economics, and for recovery of interbanded seams and highwall coal that would be otherwise unrecoverable. Yet implementation of it has languished primarily because of unresolved issues of who shall operate the machinery (ie which union). Broad institutional support — in this case, from management, investors, unions, and government — is a pre-condition to widespread adoption of any new technology. In my view, in most mining countries in the world, such broad institutional support is only now starting to surface.

There are reasons why broad institutional support is slow to materialise whenever a new technology appears. People obviously need to be adaptable, but this is only part of the answer. As illustrated with the Newcomen steam engine, the first applications of a new technology invariably displace people from the workforce. It is the savings in wages that provide the justification for the technology. The 18 people and 50 horses who in 1730 lost their jobs after introduction of the Newcomen engine in the French coal mine would hardly be going to their friends supporting new technology. The negative impact of the technology is evident, but the greater positive impact of lower cost coal is a widely dispersed and less evident value. In the early stages of technological development, there may be only a delicate balance between the people displaced by the new technology, and the people employed in manufacturing and supplying the technology itself. Broad popular support — meaning: increasing jobs and rising standards of living — is probably a characteristic of the second phase of technology implementation more than the first.

This same trend is evident in the mineral industry today. Large mines have a planning staff of two people plus a computer where previously there were perhaps ten people. Whole layers of middle management — whose previous job was largely information flow — have been eliminated through the easier information flow possible through computers.

Say's Law — that supply creates its own demand — takes time to work. Prices of goods and labour have to adjust. People's expectations and perceptions of value have to change. Inventories have to change. During this time the net benefits made possible by the new technology are seldom obvious. The mineral industry is at best just emerging from this era.

Rate of change

Prior to the industrial revolution, the belief in a changeless world was widespread. Only during the industrial revolution did the rate of change become fast enough to be visible in a single lifetime. It is inconceivable today that a machine like the Newcomen engine should exist for 60 years before the next 'version' is introduced. Nevertheless, up until perhaps two decades ago, there was still a great deal of stability in how capital investments were viewed and assessed. This stability came about because the technical life of an investment was usually much less than its economic life. New equipment was introduced, but by-and-large, equipment wore out before it was superseded. This is no longer the case. The implications of this are profound, and form the basis of the argument set forth in the final part of this paper. This problem defines the agenda for research in mineral industry computer applications into the next century. Investments in both physical capital and human capital now demand uncompromising scrutiny before commitment. The approach to investment has to change.

Physical capital

Technology allows mining equipment to be built with higher productivity at lower initial and on-going costs, and longer life. The same technology allows newer versions to be developed with greater frequency. The newer versions offer economic efficiencies that make previous versions less cost-effective than their physical age suggests. Rope Shovels that can load waste at the same average cost from the day they are commissioned until they have over 100 000 hours of operating life are now idled at some mine sites after only 50 000 hours of use. The marginal cost of continuing to use the older equipment is greater than the average cost of loading with new shovels, even after accounting for the extra capital investment.

Does this mean that we should be planning for shorter life equipment — perhaps even forsaking the economic advantages of purpose built, robust, long life machinery for higher cost, more flexible equipment? Such a move would also be counter to the last 200 years of economic history where growth has been fueled largely by greater use of specialised equipment and the increasing division of labour. The challenge is surely to achieve this specialisation without sacrificing the ability to change. The re-programing of industrial robots is the most obvious contemporary example of this approach. The ability to even recognise when an asset can be re-configured and re-deployed in important. In the design and operation of equipment, 'adaptability', 'modularity', and 'asset management' are the keys to achieving this objective.

Human capital

Throughout all of human history, the concept of a 'career' has consisted of an initial investment in human capital (an education, a trade skill) that, with just minor updates along the way, is supposed to be relevant for the rest of life. Now, as with the rope shovel example, this human capital is frequently idled. The economic life of the knowledge is less than the physical life of the body in which it is resident. But there is a big difference between the idled rope shovel and the idled mid-life professional. Rope Shovels don't talk, don't think, and are in no position to influence the march of technology that is making them redundant. Without a mechanism for human capital to be maintained in a state of economic usefulness, the institutional forces that are an equal partner in forging society's advancement will be pulling in the opposite direction. Alertness to the importance of change is the starting point in addressing this problem.

THE KNOWLEDGE PROBLEM

The advent of faster and faster computers allows us to process more data, and to carry out more analyses than has hitherto been possible. In mining operations, the availability of on-line information from fixed processing plant has long been a valuable if not indispensable element of efficient operation in these plants. The growing availability of this same type of on-line information for mobile equipment promises similar gains in this area. There is no doubt that more information, and information in a more refined form, is an important element in advancement and efficiency in the industry.

Nevertheless, practitioners who have followed this path of ever-more complex data collection and analysis would have run across but perhaps not yet recognised a particular problem: beyond some point in the information-growth stakes, further information becomes pointless. Up until now, many of the promised benefits of computer technology have been stalled pending ever faster computers. The expectation is that faster computers will finally allow the 'optimisation' to be achieved. This is an understandable expectation but may be missing the whole point. For many problems, meaningful analysis requires a further set of information that is simply not available.

Envisage for example an operator who has a 'gut feeling' about the roof stability in an underground mine, and who expediently decides to place equipment in position 'A' rather than position 'B' in the event that his intuition is correct. Perhaps his action incurs a cost which he considers appropriate even though he knows that nine times out of ten his concerns are not warranted. How do you build this sort of 'knowledge' into a model? Most models are woefully inadequate in dealing with uncertainty. Pure quantitative information gathering is really only meaningful up to the point where its marginal value is equivalent to the value of the unavailable information evidenced in the operational example.

There are two forms of this unavailable information. The first is information like the example above — what Hayek (1945) calls the 'particular circumstances of time and place'. This form of information, even if it cannot be articulated, is at least knowable by somebody. The second is information relating to the future; definitely unknowable, but certainly not unimaginable. Both forms have to be addressed, but the latter form is much more relevant to decisions today than ever before. As stated by Drucker (1970): 'The question that faces the long range planner is not what we should do tomorrow, it is: What do we have to do today to be ready for an uncertain tomorrow?'

Regardless of the technical research agenda, the economic effects associated with the knowledge problem will pervade every aspect of computer applications in the mineral industry from now on.

Of course, it is not only the mineral industry that is affected by this problem. Interestingly, the mineral industry has possibly understood this problem better and for longer than most other industries. The whole field of geostatistics — one of the earliest computer applications — was built around orebody definition where the value of the improved precision was (is) traded-off against the cost of the additional information. Even today, very few economic models in the world account for any cost of information. Fewer still model decision-making under uncertainty — something that the mineral industry lives with daily.

To paraphrase Hayek (1945) again, it is perhaps worth stressing that these sorts of problems arise always and only in consequence of change. As long as things continue as before, or at least as they were expected to, there arise no new problems requiring a decision and no need to form new plans. But is it true that these sorts of problems only have to be addressed at long intervals, as when a new mine is being developed? From the time of the industrial revolution until perhaps just 25 years ago, such an approach was probably valid. Now it is not. How then can we better handle the knowledge problem from now on? What changes to our technical agenda are necessary to reorient our resources towards its solution?

Adaptation to circumstances of time and place

If our objective is faster adaptation to changes in the particular circumstances of time and place, it follows that this objective will be more achievable if the decision-making is undertaken by the people who are most familiar with these circumstances. The people who can react fastest to change are the people who know directly of the relevant changes and of the resources immediately available to meet them. The problem will not be solved by first communicating all this knowledge into some central computer system that, after solving some giant linear program, re-schedules the mine and everything in it. If this approach had worked, then the centrally planned economies in the Communist world probably would not have failed. Adaptability is the hallmark of decentralisation.

The objective of executive information systems should not be to collect and process ever-increasing amounts of information for the benefit of (central) management. The objective is to selectively extract key information for the attention of operations personnel who are empowered to act on this information with expediency. The objective that up until now has largely been for reporting purposes must change to one of decision support.

Nevertheless, this decentralisation only answers part of the problem. Clearly operations personnel cannot make their decisions solely on the basis of their limited but intimate knowledge of the facts of their immediate surroundings. There still remains a problem of communicating to them such further information as they need to ensure decisions are consistent with the long term corporate objective.

The 'corporate objective' normally means increased shareholder value. Subject to specific constraints, it means a healthy return on shareholder funds and consistency in achievement of this return. Yet advancement or reward-based remuneration, where it is in place at all, is normally based only on production or cost-reduction targets. Closer alignment of delegated objectives to corporate objectives is a parallel or even prerequisite condition to further advancement from computer technology. Of course, this pre-supposes that the larger corporate objective itself is well known. Refinement and stronger definition of this larger corporate objective is also a prerequisite to further advancement from computer technology. In this area, the mineral industry has a long way to go.

Strategic planning for change

The adaptability talked about above is concerned with shorter-term aspects of mining efficiency. What about the longer term aspects? Writing his definitive treatise on economics over 200 years ago, Adam Smith (1776) observed: 'Projects of mining, instead of replacing the capital employed in them, together with the ordinary profits of stock, commonly absorb both capital and profit'. The same observations are valid today. The technology to understand orebody characteristics is definitely more sophisticated, but our ability to earn consistent profits from the exploitation of them remains no better than in Adam Smith's time. One explanation of this is that the uncertainty inherent in orebody definition and market pricing for mineral products has frequently led to a great deal of inconsistency in decision-making. When things do not turn out according to plan, the old plan is no longer relevant — but this commonly leaves us in a situation where alternative plans are not necessarily any more relevant. Decision-making is far from easy.

This is a delicate subject area. Genuine technical difficulties giving rise to poor performance are mixed with explanations that amount to simply poor management. The known uncertainty of orebodies has allowed us to hide our inability to adapt to changes in our environment when the likelihood of them should have been quite predictable. In other cases, the inability to quantify mine operating characteristics has allowed management to evade difficult decisions even when inefficient practices were otherwise quite evident.

To use just one example from two of my earlier papers (Runge, 1992; 1994), many mining projects were justified and commenced on the assumption of rising metal or coal prices, or at least, prices that were expected to keep pace with inflation. The trend is clearly for declining real prices. Yet, after two decades of involvement in these sorts of assessments, I am unaware of any new project whose base case economic analysis assumed declining prices.

The reason for this is understandable. Without the parallel assumption of declining real costs (an equally demonstrated trend), hardly any projects would be viable. Of course, if we knew a way now that real costs of production could decline in the future, we would plan to use it now. The reality is that the declining price of such important basic commodities (minerals and coal) is also a cause of declining prices elsewhere in the economy. Unfortunately we have no more ability to predict where these declining costs and changing technologies will manifest themselves than the central planners of the former Soviet Union had to predict what their centrally planned economy should do.

Lacking the ability to predict the future, the objective of long-term planning must be the next best thing — plan for an uncertain tomorrow. To paraphrase Lachmann (1991), 'Plans, of course, often fail. They may fail for a large number of reasons, but one of them, already mentioned above, is of particular interest to us: the collision of one actor's plans with that of others. Such conflict of plans, so far from invalidating the importance of plans for our understanding of forms of interaction, actually shows how important a help they are for our insight into the problems here arising'. In other words: stop focussing on mine plans as immutable guidelines into the future, deviations from which are 'bad' things. Start focussing on mine plans for their ability to yield insights into a host of uncertain tomorrows.

Prior to the introduction of computers, it was scarcely possible for long range planners to come up with even one meaningful plan. The number of blind-alleys encountered in the scheduling process barely allowed sufficient understanding of how to mine at all — let alone such a thing as an 'optimum' plan. With the introduction of computers, we set about 'optimising' the mine plan. Based on the same fairly weak and changeable assumptions used previously — which we took to be fixed — we merely calculated the same plan with ever more detail. This is hardly 'optimisation'. Furthermore, challenges to the assumptions upon which the plans were made were frequently defined to be outside the scope of technical professionals. These assumptions remaining unchallenged, the illusion of precision was conveyed upwards to senior decision-makers who were perhaps even less aware of the ramifications of some of the constraints.

In the pre-computer days, the level of detail in a plan — and the implied reliability of the plan — could be gauged by the weight of paper generated. With this gauge now thoroughly invalidated we have yet to replace the paper proxy with a technically more robust indicator. This too is an urgent task for the further application of computers in the mineral industry.

Computer application in mining must be refocussed on planning for adaptability and change. Rather than analysing a narrow range of scenarios to greater precision, the same efforts should rather be directed to analysing a broader range of diverse scenarios, to a lesser order of precision. 'Base Case' scenarios are still valid, but the analysis must also pre-plan for imaginable but lesser likely eventualities after commitment. Models must be focused not only on the scope for change but also on the economics and decision-making environment applicable in the midst of the unexpected change. More flexible mining schemes, deposits, and financing and management structures must be valued more highly than less flexible ones — even on occasions to the detriment of (the 'base case' expected) rates of return. Only when we are using computers in this way will we have moved to the 'second generation' of use of this powerful technology.

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