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MEMS news

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What is MEMS?

MEMS is a non-profit professional society for academic, industrial, private, and government specialists interested in the mineral sector. The scope of interests includes economics, finance, management, and public policy. The society's objective is to help members upgrade and maintain their professional skills by:

1) holding annual professional meetings;
2) collecting, exchanging, and publishing technical information and analysis in the area of mineral economics and management;
3) encouraging and facilitating the early identification of issues important in the mineral sector; &
4) supporting educational institutions that offer programs in mineral economics.

MEMS publishes a proceedings volume for each annual meeting, as well as a periodic newsletter. The society maintains a website to promote global exchange of minerals information.

www.minecon.com

FROM THE PRESIDENT

R. Anthony Hodge, Ph.D., P. Eng.
President, Anthony Hodge Consultants Inc.

Another spring is upon us and in the mining industry, mergers continue to sprout. The most recent block-buster is the acquisition of Phoenix-based Phelps Dodge Corp. by Freeport-McMoRan Copper & Gold Inc. of New Orleans creating a Phoenix-based mining giant with 25,500 employees and almost $17 billion in annual sales. Rumours fly that Barrick will gobble up Newmont; Alcan seems to be strengthening its defences; and in China, the government is moving to merge the miners of 15 minerals into fewer, larger groups to improve their efficiency and safety.

What does all of this mean for mineral economics and management? This is just one of the topics that will be discussed at this year's AGM in Golden, April 18 – 20. Other topics include long term trends, cycles, and forecasting models, what is the essence of a "fair" tax regime and recent activity on the commodity exchanges. We will offer the annual W. A. Vogley MEMS Award as well as recognize this year's wining student paper. We have had a record number of student submissions.

Our AGM has emerged as high quality, on-topic, and a powerful mix of the practical and the theoretical. The discussion is stimulating; the exchanges much fun. Golden is a delightful community to visit in the third week of April. This Year's co-chairs, Michael van Aanhout of Stratos Inc. and John Cuddington of the Colorado School of Mines along with the panel chairs and speakers have put an enormous effort in to create a very special event. So in sum, I urge you to join us.

This spring we initiated the Santiago Symposium for the first time. As with our AGM, Chair Juan Camus (formerly of Codelco, now with Rio Tinto) has done a remarkable job to see a very innovative event off the ground for the first time.

Last summer I set out four primary tasks for the year: (1) hold both the AGM in Golden and the Santiago Symposium in Chile; (2) expand membership; (3) re-think the web-site; and (4) nourish our Student Essay competition. On the first and the fourth we can justifiable claim much success. On the second and third, while some progress has been made, much remains yet to be done. We will carry these tasks into the upcoming 2007/2008 year, under the leadership of in-coming President Dirk van Zyl (University of Nevada, Reno).
I look forward to playing my part.

Regards,

R. Anthony Hodge, *MEMS President 2006/2007*

16TH ANNUAL CONFERENCE

MEMS 2007

Thinking past the next bump: Where is global mining going?

APRIL 18 - 20, 2007
THE GOLDEN HOTEL
GOLDEN, COLORADO

The global mining and metals industry is experiencing a significant boom fuelled by demand in Asia in particular. Even industry experts have difficulty distinguishing long-term trends from short-run booms and busts. What can we learn from past cycles?

What are the current forecasting tools and methodologies? What is the value of the current round of mergers? How are the profits from the current boom distributed?

These are some of the key questions being addressed at the 16th Annual MEMS Conference and Workshop. Hear presentations by some of the world's leading experts and participate in open, creative and stimulating dialogue. The MEMS annual conference is the premier forum to address economic and management issues facing the mining industry. Join mining experts, academics, and industry leaders at the Golden Hotel in beautiful Golden Colorado to explore the topics that will define the future of the global mining industry.

Conference/ Technical Chairs

- John Cuddington
  Coulter Professor of Mineral Economics
  Colorado School of Mines
  303-273-3150
  jcudding@mines.edu
- Michael van Aanhout
  President, Stratos Inc. Ottawa Canda
  613-241-1001 x 243
  mvanaanhout@stratos-sts.com

WEDNESDAY, APRIL 18, 2007

Pre-Conference Workshop: .... **9:00 – 2:00**
• • • Becoming a Knowledgeable User of Metal Price and Consumption Forecasts

The workshop will discuss alternative methods of forecasting commodity prices and quantities (production, consumption, changes in stocks, etc) using times series models, reduced form equations, and structural models. After an overview of the different forecasting approaches, there will be an opportunity to learn the basics of the EViews econometric modeling and forecasting software package for carrying out such forecasts. This will be done in a classroom where participants gain 'hands on' experience working with the software. The workshop is designed to help participants become knowledgeable users of various types of forecasts, not economic forecasters. **NOTE:** Please bring a laptop.

Presenter: John Cuddington, *Colorado School of Mines and JTC Economics + Finance LLC*

Tour: Coors Brewery (FREE) .... **2:00 – 4:00 pm**

Reception & Opening Presentation .... **6:30 – 8:30 pm**
Guest Speaker: Philip Maxwell, *Western Australian School of Mines, Curtin University of Technology*

THURSDAY, APRIL 19, 2007

Welcome/Conference Overview .... **8:30 – 8:45**

Session One .... **8:45 – 10:00**
• • • Long-Term Trends, Cycles and Forecasting Models

The opening session will set the context for the conference by providing an overview of past long-term trends and cycles in the mining and metals sector, as well as forecasts of future developments in the industry. It will also provide an overview and update of various forecasting methods and models currently in use.

Session Chair: Shane Streifel, *World Bank, Washington D.C.*
Speakers:
- Dr. Christopher L. Gilbert, *Prof. of Econometrics, Univ. of Trento, Italy; & Director of the Group for Research & Analysis in Development*
- Alan Heap, *Citigroup*
- Neal Brewster, *Rio Tinto*

Refreshment Break .... **10:00 – 10:15**

Session One (continued): .... **10:15 – 11:00**
• • • Panel Discussion

THURSDAY, APRIL 19 (CONT'D)

Session Two .... **11:00 – 12:00**

• • • *Thomas F. Torries Student Paper Award*

Winner: Marty Gaupp, *Colorado School of Mines*

Efficiently Sequencing the Extraction of Ore from an Open Pit Mine

Session Chairs: Jianping Zhang, *Natural Resources Canada*; and Rod Eggert, *Colorado School of Mines*

Session Three .... **12:45 – 2:00**

• • • *President's Lunch*

– President's Remarks
– Presentation of W.A. Vogely MEMS Award

Session Four .... **2:15 – 4:30**

• • • *What is a Fair Tax Regime?*

– What would be the objectives for taxation
– The linkages between development outcomes and taxation regimes
– The role of tax in investment patterns.

Session Chair: Paul Mitchell, *International Council on Mining & Metals (ICMM)*

Speakers:

- Peter van der Veen, *World Bank – Invited*
- Kathryn McPhail, *ICMM*

MEMS Dinner .... **6:00 – 9:30**

Keynote Speaker: Dr. Christopher L. Gilbert, *Professor of Econometrics*, University of Trento, Italy and *Director of the Group for Research and Analysis in Development* (GRADE)

FRIDAY, APRIL 20, 2007

Session Five .... **8:30 – 10:00**

• • • *Markets and Trading*

The prices for many metals hit all-time highs in 2006 -- and what goes up will eventually come down. Commodity exchanges such as the London Metals Exchange (LME) and New York Mercantile Exchange (NYMEX) offer consumers and producers the opportunity to manage risk arising from volatile metals prices. This session will provide an overview of the activities of the exchanges as well as review recent developments in the metals markets.

Session Chair: Lisa Morrison, *CRU*

Speakers:

- Patricia Cauley, *NYMEX* (invited)
- Donna Walters, *Commodity Metals Management Co.* (invited)

Refreshment Break .... **10:00 – 10:15**

Session Six .... **10:15 – 12:00**

• • • *Mergers in the Mining Sector*

In light of the current round of intense merger activity, this session will explore differences in national review processes, efficiency gains, and the decision to payout shareholders vs. investing in new capacity.

Session Chair: Brett Humphreys, *Towers Perrin*

Speakers:

- David Harquail, *Executive Vice President, Exploration and Business Development, Newmont*
- Monica Bonar, *Director at Fitch Ratings, responsible for mining and metals for North America*
- Diana Moss, *Vice President, Director, Senior Research Fellow of the American Antitrust Institute*

Networking Lunch .... **12:00 – 2:00**
Continuing Discussion and Academic Abstracts

• • • *An Analysis of Metal Prices Cycles*
Mark Roberts, *Michigan Technological University*

• • • *Rise & Fall? Considering the Recent Evolution and Prospects of the Phosphate Industry*
Philip Maxwell & Rami Rawashdeh, *Western Australian School of Mines*

• • • *The Effect of Dynamically Limiting Scrap Production on Industry Concentration: An Examination of the U.S. Titanium Metal Industry*
Janet Koscianski & Stephen Mathis, *Shippensburg University*

Join MEMS!

Info at:

WWW.MINECON.COM

Pre-conference Workshop • Program Description & Updates
Course Registration • Become a Member: Join MEMS

What Have You Done for Me Lately?

EXPLAINING THE GAP BETWEEN THEORY AND PRACTICE IN MINERAL ECONOMICS

By: Graham A. Davis, ***Colorado School of Mines***

In 1984, University of British Columbia economist Paul Bradley wrote that academics studying the optimal extraction of ore had to date discovered little of relevance to the mining industry. He was right. In 1989, I entered graduate school in mineral economics after a brief career in mining. The models I was being shown were so divorced from real-world applicability as to be useful only for broad brush insights into mineral markets and firm behavior. These models excluded important realities such as fixed mine capacity and the lumpiness of investment, and were not of a granular enough nature to influence mining operations. Not surprisingly, there was little demand by the industry for the services of academic mineral economists. Governments had contracted some academics to study tax design and market structure, but other than that, the mineral economics that was being done in universities was largely ignored by industry.

Over the years that pattern has continued. Today, mining engineers would rather contract with a research lab for a study to reduce the cost of mine rope inspection than spend that same money on a study to examine the economic decision making processes that they use. As a result, there are now very sophisticated automatic sensing instruments that can detect rope deterioration well in advance of failure, while mineral economic practice has remained relatively unchanged from the days of pencil and paper. Engineering economics, for example, is the same today as it was when desktop computers were first available; the 10th edition of most engineering economics textbooks looks very much like the 1st. The advocated practice of discounting cash flows at a constant rate was formulated in 1813 as a method of optimizing the timing of timber harvests. We now know, through theoretical research, that there are serious problems with this valuation model that inject substantial biases into project valuation, and yet it is still used by 75% of mining companies in North America (the others use payback period or value multiples). In another example, open-pit planning software and geological reserve estimation are highly statistically complex, but this is married to an economic analysis of pit limits and cutoff grades that is rudimentary.

As we approach yet another MEMS conference, the program reveals the continued absence of interest in academic work. Academics are for the most part participating as dinner speakers or in poster sessions, where they can't do much harm. The meat of the conference is being brought to you by speakers from the field, with real-world stories and real-world advice. This arrangement has the tacit approval of academics, by the way, since we have been participating in the program design from the start! Apparently, it is not only practitioners who feel that academics don't have much to offer the typical audience that attends these meetings.

From where I stand, we, in academics, do have much to offer these days. We look at complex problems that have large-scale impacts, and come up with intuitive understandings that can aid firms in negotiating their way through these problems. Real options, for example, a field that I know intimately, is about managing in ways that were not previously thought about, with the potential to create substantial added value. We have insights about mineral markets and price movements, optimal labor and equipment scheduling, merger and acquisition activity, sustainability, and political risk, insights that are founded on rational and scientific models, and based on examination of facts and data. This is not hand waving or crystal ball gazing, and nor is it ad hoc analysis based on seat-of-the-pants ideas that are devoid of scientific method. How fortunate we are, in our industry, to have a segment of economic study devoted entirely to our problems and opportunities. There is no such thing as airline economics or computer economics, and yet here we sit with mineral economics, a result of government initiatives in the mid 1900s to study the supply and demand of strategic minerals in the United States.

If you are not an academic you are probably thinking that the problem is the way academics communicate or, more correctly, fail to communicate. You have attended academic talks, you say, and you came away understanding nothing for your hour of invested time. What have you done for me lately?, you ask. These are reasonable comments, and the lack of a common language through which to communicate (do you know precisely what I mean when I say "optimal"?) does not facilitate technology transfer. Nor does the incentive system set up in universities, where faculty are rewarded for communicating with peers in academic journals and at academic conferences, rather than for communicating with industry via lectures, short courses, or consulting contracts. The latter is often an afterthought, agreeing to this request or that request, and rather than retool our presentation we bring to practitioners the same language and analysis that we present to our peers. After all, what's the incentive to spend time on technology transfer when success is not rewarded and failure is not punished.

But I would suggest that there is a more fundamental reason for the continued lack of communication between us. Academic investigations of mineral economic problems have become increasingly more sophisticated and complex over the past 20 years, with computer modeling extending the power of our

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relatively linear brains. Pick up any economics journal issue from the 1960s, and you will see a well-written story on an interesting topic, with very little mathematics or jargon. Pick up a recent issue of that same journal and you will probably see pages and pages of mathematical formulae. To misquote Richard Nixon, we are all physicists now (and some of us really are physicists!). With the state of mineral economic practice staying more or less the same over the past 40 years—I challenge anyone to describe one major advance in applied mineral economics over this period—the gap between applied theory and practice is now breathtaking. Practitioners who listen to academic presentations have come to appreciate this, as have academics who listen to practitioner presentations. With the gap so large, the cost of bridging it is also large. Practitioners, being rational economic agents, weigh up benefits and costs before undertaking any activity, and the cost of undertaking an endeavor to find out about and apply current mineral economic theory has surpassed any reasonable hurdle. Academics, likewise, choose not to invest their time in bridging the gap, other than in the classroom, where we are paid for such endeavors. Even there, taking an engineer and bringing them up to a point where we can start to communicate about economic ideas, and through this start to transfer technology, takes 12 to 18 months of full time graduate study. Becoming proficient in basic academic thinking about mineral economics now takes investment in a Ph.D. degree. The result is that academics see industry sticking its head in the sand, while practitioners see academics as separated from real world issues and focused on problems of little value. Practitioners instead opt to learn about mineral economics from each other, from the deluge of publications put out by the analysts and investment houses, and from industry associations that have their own journals. Little of this information transfer is peer reviewed by experts in the area, and so little of it is reliable.

If it were not for the mining industry's poor record in managing capital, enhancing social welfare, and protecting the environment, the three so-called pillars of sustainability, we could say "So what?" and call it a day. It is my belief that mining can do much better than its poor record to date, and rather than being lumped with tobacco companies and big oil, we should be seen as keeping company with advanced manufacturing and renewable energy.

What is to be done? Well, maybe nothing. Economists are big on cost-benefit analysis, and if the costs of closer collaboration and more technology transfer are greater than the benefits, such collaboration should not be attempted. We know that the costs of technology transfer are large, not only for academics, but also for practitioners. It will require that the industry become increasingly conversant in economics, perhaps through graduate training of mining engineers in economics or mineral economics, or through an increased hiring of and promotion of economists into decision-making positions. Journals like Resources Policy and Minerals and Energy - Raw Materials Report, both offered to MEMS members at a discount, will have to become standard reading for industry managers so trained in the language of economics. Industry will have to seek out collaboration with academic economists, funding economic technology transfer through collaborative research much in the same way that collaborative research parks facilitate scientific technology transfer.

Academics, for their part, will have to receive incentives from their employers to take on such technology transfer initiatives. Sabbaticals, for example, could be spent in-house at mining firms, rather than in-house with other academics at other universities. Indeed, on my own initiative I have spent most of my sabbatical this year on a self-funded mission, in collaboration with Michael Samis of AMEC Americas, to transfer the technology of advanced mine valuation to industry through a series of company visits and short courses. My initial impression is that there has been some success, with a warm reception to our efforts and even some movement away from standard two-century old valuation practice in some firms. I, on the other hand, am learning of the issues that concern industry, issues that are not always within my scope of analysis because I have inadvertently assumed them away. This makes my research more appropriately focused. I and a former student have just written a paper, for example, on the reasons for the perpetual cost overruns in mining development projects, a phenomenon that I was not aware of two years ago.

Finally, the many applied academic economists around the world who focus considerable effort on the specific problems of the mining industry will have to find increased financial support if they are to divert a portion of their effort away from the performance of academic research aimed at academic journals. Within the academic universe those departments that garner the most external funding, and through this attract the brightest and largest cohorts of students, are those that limit their research to that which can be published in the top academic journals. Sadly, it would be the death knell for any academic or department of academics to take on as its mission technology transfer without substantial additional financial support from the mining industry. External funding from traditional sources would shrink, student financial aid would shrink, and ultimately student numbers would shrink. I would propose that the relatively applied nature of the several mineral economics programs in the United States in the last half of the 1900s, along with their meager funding from traditional research sponsors such as the National Science Foundation or the Environmental Protection Agency, is the reason that only one or two are left standing today. What of the benefits? Based on some of my own work and the work of my colleagues, I would think that there is at least a 3 percentage point increase in return on investment that is up for grabs. That 3 percentage points is equivalent to a 25% reduction in the cost of building a mine, or a 15% reduction in operating costs. These are big benefits.

My observation of the market for academic ideas, however, causes me to be pessimistic about our ability to make great strides in bridging the gap between theory and practice. Despite our being well into the third commodity price boom in the last 100 years, enrollments at mineral economics educational programs are still declining, and membership in MEMS and attendance at MEMS conferences is stagnant. The number of recognizable academic mineral economists who work on applied mining problems has shrunk to no more than a handful. Proposals by myself and my colleagues to engage the industry in mineral economics research are no more successful today than they were 10 years ago. Environmental group and NGO pressures appear to be focusing industry attention elsewhere. Whereas my colleagues in the sciences at the Colorado School of Mines each raise hundreds of thousands of research dollars in an average year, a mineral economist might raise $20,000 from the mining industry in a good year. To put this in perspective, it costs $60,000 in funding for a professor to be able to support one Ph.D. student for one year of study.

Economist Brian Arthur has written extensively on a subject called technology lock-in, where substandard technologies such as the QWERTY keyboard get locked in, pushing out better technologies when they come along simply because the earlier technology is firmly routed in place and the costs of moving to the new technology are too high. The overall absence of interest in mineral economics research reflects such a technology lock-in in the mining industry, where existing practice has become just too costly to shift.

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My projection is therefore that the next decade will be more of the same. Efforts like those of Mike Samis and I will continue. MEMS will also continue to have some impact; CSM's John Cuddington is offering a 5 hour pre-conference workshop on using metal price forecasts at the MEMS conference this year in conjunction with an ongoing initiative by MEMS to facilitate the type of technology transfer that I am advocating. Selected mining companies will collaborate with academics as various needs arise. One or two will gain a competitive edge through this work. But look for the industry on the whole to continue its trend of offering shareholders below-average returns for above-average risk by combining the latest scientific technology with decade-old economic ideas in the finding and extraction of ore. And look for academics to continue to write esoteric papers that have no measurable impact on the way the industry carries out its business, but that help ensure that the next time they apply for funding from the National Science Foundation they have something of academic merit to put on their resume. ◆

The Mineral Wealth of Nations

By: Paul Mitchell

Enhancing mining's development impacts requires concerted joint action and new forms of partnership between governments, companies, civil society and donors like the World Bank, argues Paul Mitchell, President of the International Council on Mining and Metals (ICMM).

Minerals and metals prices have soared in recent years, generating higher revenues for governments of resource-rich countries. Yet academic debates have been raging in policy circles about the so-called 'resource curse', the theory that mineral (and also oil) wealth often holds back rather then accelerates economic and social development

This proposition flies in the face of the experience of countries such as Australia, Canada, Chile and the United States where mining development opened up a path to prosperity. But the recent record in natural resource dependent countries is mixed. What then are the conditions needed to ensure such outcomes? How can they be created in practice? These are the questions that have formed the focus of a major, ongoing policy research initiative sponsored by the International Council on Mining and Metals, a CEO leadership group of global mining firms and associations. To help ensure an objective approach, the research was overseen by an independent advisory group. The initiative has been conducted jointly with the World Bank, and the United Nations Conference of Trade and Development.

The research was conducted by expert consultants, overseen by an independent advisory group, and the methods and country findings were critiqued in two multi-stakeholder workshops, including governments, non-governmental organisations (NGOs), and academic institutions. Its recommendations are now being taken forward in pilot projects in Peru and Tanzania.

So what exactly has the project found so far? First, that, mining can actually provide countries with a powerful boost to economic growth and poverty reduction – provided the underlying conditions are right. Particularly for the poorest developing countries, which often find it hard to attract investment in other sectors, mining can generate an essential economic kick start. It can also drive poverty reduction: in Ghana and Chile poverty has fallen particularly fast in mining regions.

Even in countries that have successfully managed mining projects, more efforts are often needed to capture the full potential benefits from the sector. Companies have a key role to play here of course, not just in minimising the local adverse impacts of their activities on the environment, but in training and employing local people, sourcing inputs locally, and supporting community projects and contributing to national poverty processes. But also needed for successful outcomes is the effective utilisation of tax revenues from mining by central governments, regional agencies and local communities. This in turn depends on improving governance, particularly within mining regions themselves. This is a challenging task, and requires new partnerships between companies, governments, international donors, and other parties.

Both conclusions became apparent from four in-depth case studies undertaken as part of the research. These analysed mining's impacts – both nationally and at a local level – in four separate mineral-rich developing countries: Ghana, Tanzania, Peru and Chile.

Ghana, for example, provides an illustration of the first point: its impressive economic revival since the mid-1980s developed in parallel with a resurgence of mining investment in the country. Over US$5 billion has been invested in new mining projects since 1986, just as real GDP growth has run at almost double the average rate for Sub-Saharan Africa for much of this period (following a dismal few decades for Ghana's economy prior to that).

While mining still only accounts for a small proportion of Ghana's GDP, making it difficult to prove any direct cause and effect, it has contributed 10-17% of total tax revenue since the mid-1980s, and by the mid-1990s had overtaken cocoa as the country's leading export earner. Mining has clearly also responded more quickly than many other industries to economic and governance reforms undertaken by the country. The effects on poverty in Ghana have also been striking: not only have poverty-levels fallen nationwide since 1991, but the four mining districts have both lower absolute levels of poverty, and have also experienced faster declines in poverty.

But in addition to improved company performance, there is often weaknesses in governance and institutions – particularly within mining regions them-

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selves. While the basic macro-level reforms necessary to attract mining investment and to capture some of the economic benefits had been put in place, these had not been followed through with sufficient reforms at the regional and local level. Regional state bodies often lacked the capacity to plan for, and to facilitate, local development. Tax revenues channelled back to mining regions had not always been spent wisely.

This helps explain much of the community dissatisfaction with public services. In some countries, regional authorities were failing to provide such basics as electricity and sanitation. Local people had then turned to the companies to provide these goods, leading to inevitable frustrations when the firms – themselves not responsible for such state provision – proved unable to satisfy all the local needs. In countries such as Peru, this dynamic has underpinned significant tensions between companies and communities. The limited capacity of public authorities has also held back other economic benefits of mining: for example, the development of a vibrant local mining supply chain, as well as general economic diversification, may require careful planning and support from state bodies.

Governance is clearly an issue primarily for governments. However, ICMM's research also highlighted the need for new partnerships to support governments in tackling such challenges. Joint efforts between companies, governments, donors (such as the World Bank), and also civil society groups, for example, could help improve regional development planning around mines, improve impacts on poverty, and also resolve tensions with communities. These are often complex challenges, requiring long-term remedies, and with benefits from better co-ordination between the parties.

Tanzania has also experienced some clearly positive macro-economic impacts from mining, albeit it opened itself up to international mining investment later than Ghana. Since 1996, however, mining has been estimated to add 0.3-0.4% extra GDP growth each year in Tanzania. More dramatically, in Chile – where mining accounted for a third of FDI between 1974 and 2004 – not only have there been major gains in prosperity and falls in poverty nationwide: poverty reduction (as in Ghana) has been particularly rapid in mining regions. In Chile's Antofagasta region, for example, there was a 60% drop between 1990 and 2003.

But ICMM's research also highlighted some basic conditions necessary if mining is to underpin greater prosperity in this way. Underlying the recent growth of countries such as Ghana and Chile, for example, was not only the development of a stable, welcoming regulatory climate for foreign investment, but also improved macroeconomic policies (designed to avoid seriously overvalued exchange rates, for example) and also some improvements in macro-level governance, such as control of corruption. Weak performance on such issues is precisely what has prevented other developing countries in the recent past from harnessing their mineral wealth to achieve an economic turnaround of their own. ICMM does not intend to leave its own work there. Implementation is crucial. Companies, governments, donors and other stakeholders must form new partnerships. Learning about how such partnerships should be designed is the purpose of the planned pilot projects. For ICMM members, there is clear recognition that companies should play a leadership role on a critical public policy issue: when more than one billion people are living on less than 1 dollar per day, a better understanding of how communities and countries can enhance the benefits from mining investments is an imperative. ◆

More information on

International Council on Mining and Metals (ICMM) and its Resource Endowment initiative can be found at **www.icmm.com**

Student Paper

~ 2006 Thomas F. Torries ~ STUDENT PAPER AWARD

One part of the annual MEMS conference is the presentation by the winner of the Thomas F. Torries Student Paper Award. The winner of the 2006 prize was Juan Guzman whose paper appeared in the fall newsletter. Second prize was won by ***Louis Archambeault*** of McGill University, his paper appears on the following page.

MEMS would like to recognize all students who submitted papers for the competition. As usual the quality was excellent and selecting winners was a difficult process. In recognition of their work, MEMS provides a one year free membership to all students who submit papers.

Application of Artificial Intelligence to Mine Optimization & Real Option Valuation

2006 Thomas F. Torries

STUDENT PAPER

By: Louis Archambeault

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ABSTRACT

This paper describes preliminary research on the application of Markov Decision Processes (MDP) to Real Option Valuation (ROV) and the optimization of mine scheduling. The MDP framework is a novel approach to option valuation and scheduling in mining operations. A learning agent is introduced into the valuation process of an open pit, where prices and block ore grades have probabilistic values. The prices are modeled using a mean reverting diffusion process and the block grades using sequential Gaussian simulation. The agent is asked to learn which production parameters should be used in order to maximize the overall value of the project. The introduction of the agent permits a real option approach to mine valuation, such that the value associated with the robustness of a design to uncertainty can be measured. A simulated example is used in which there are 10 blocks to be extracted under conditions of grade and price uncertainty. Using policy iteration, an optimal policy is generated and the value of production options is found. The potential financial gains from applying MDPs to mine valuation and optimization are substantial and warrant further investigation.

INTRODUCTION

Mining projects are characterized by high levels of uncertainty in ore grade estimation and by volatile fluctuations in commodity prices. Adjusting production parameters when working in such uncertain conditions is not a simple task. The aim of this paper is to study the application of Markov Decision Processes (MDPs) in the task of mine production optimization and Real Option Valuation (ROV). Using these tools, the value of having a design that can withstand estimation errors (robust design) can be measured, thus providing a tool to justify the extra costs incurred in creating the robust design. It is believed that with simulations and MDPs, parameters such as production rate and mine closure can be optimally adjusted in relation to commodity price fluctuations and uncertainties in ore reserves.

The development of ROV methods offers great insight on the potential value of operational flexibility and the benefits gained from generating robust pit designs. Yet, the mining industry is lagging on applying ROV concepts in project valuation practices. Traditional best practices prescribe that in order to maximize the value of a project, it is important to delay costs as much as possible and use "just in time" planning. However, using this approach is not very flexible and does not permit mine operations to react to market changes by increasing production when commodity prices are high. Many mines are currently faced with this problem. Due to the recent rapid increase in commodity prices, mining operations are trying to increase production to meet market demands. Yet, because of the "just in time" approach, there is insufficient accessible ore to effectively increase production as mentioned by Monkhouse [9]. The example presented by Monkhouse [9] made use of an open pit mine, but the issue of ore accessibility also applies to underground mines as well. Managers are starting to acknowledge the potential value gained by having accessible ore. This would allow increased production when prices are high; thus resulting in selling a larger portion of the mineral products at a higher price. Clearly, pre-stripping to expose ore generates additional costs. Managers are thus faced with the non-trivial question: do the potential benefits gained from having exposed ore outweigh the additional cost? MDPs and ROV provide an effective tool to answer this question.

In essence, reinforcement learning works as follows: A virtual probabilistic environment is generated in which the learning agent is asked to make decisions. At the end of each iteration "life", the agent evaluates, in hindsight, the quality of its decisions. After a large number of iterations, the agent will have learnt decisions that for all situations will maximize his reward. The set of decisions made to maximize the reward is called an optimal policy.

Using the MDP approach, we are accepting the fact that we cannot predict what our production parameters will be in the future. Instead, we provide an agent with a feasible range of production parameters and let it learn the optimal policy. The value of the project following this policy can easily be computed, thus providing a more representative distribution of project values. Furthermore, the optimal policy will serve as a guideline for managers once production has started. Incorporating option value during the valuation process could be misleading if there is insufficient information available for the planners to exploit the extra value during production. Therefore, an advantage of using MDPs to value real options is that not only does it provide the value of an option, but it also provides the policy that yields the maximum benefit from that option; thus providing the means of effectively exploiting the value of operating flexibility.

ARTIFICIAL INTELLIGENCE→

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By incorporating the option to close down an operation, it is also possible to evaluate the financial risk associated with premature mine closure. This information is very valuable for long-term mine planning and leads to a substantial increase in project value.

In order to evaluate the performance of an agent, a simulated example of a mine, consisting of 10 blocks, is examined. Models are used to describe the environment in which the agent must make decisions. For the purpose of this study, the environment is restricted to two stochastic variables, i.e., the mineral content of the blocks and the market price of the mineral extracted and sold.

In section 1, a description of managerial flexibility and real option value is presented. In section 2 the MDP framework is introduced. Section 3 describes the simulation methods used to model the mining environment in which the agent operates. A description of the optimization model is given in section 4. Section 5 describes the application of the model to our hypothetical example and section 6 presents and discusses the results, and highlights areas where additional work is required.

1. Managerial Flexibility and Real Option Value

Managerial flexibility only contributes value to a project in the presence of uncertainty. This concept is very intuitive, as there is very little value in having options if all outcomes are known with certainty.

Dixit and Pindyck [2] present a simple example showing how managerial flexibility adds value to a project. In their example, which has been modified for clarity, the option to postpone a risky investment is evaluated. In this example, management is faced with an investment decision in which the revenue (which is a function of price) is uncertain.

Assume an irreversible capital investment of $1600 with no operating costs. In the first year, the revenue is $200. In the following year, the revenue will either be $100 or $300 with probabilities of 0.5 each, and will remain constant thereafter. A graphical representation of the possible project cash flows is shown in figure 1.

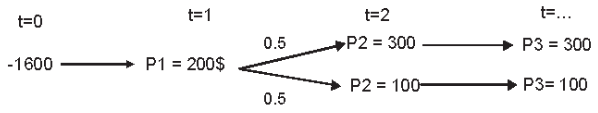

Figure 1: Possible Project Cash Flows (adapted from Dixit and Pindyck [2])

The manager has the option to invest today or to wait until the uncertainty in revenue is resolved in one year's time and only invest if conditions are favorable. The objective of this exercise is to determine whether the option to postpone the investment actually has value.

If management decides to invest today, the investment is done under uncertainty and the expected revenue is the weighted-average of the two possible scenarios, i.e. $200. However, if management decides to delay the investment, it would be made at the beginning of the second year only if the revenue is favorable. (1) and (2) determine the net present values (NPV) of the two scenarios described above using a discount rate of 10%.

Invest today:

$$\mathrm{NPV} = -1600 + \sum_{t=1}^{\infty} \frac{200}{(1.1)^t} = -1600 + 2000 = \$400 \qquad (1)$$

Delay investment:

$$\mathrm{NPV} = (0.5)\left[\frac{-1600}{1.1} + \sum_{t=2}^{\infty} \frac{300}{(1.1)^t}\right] = \frac{700}{1.1} = \$636 \qquad (2)$$

A comparison of (1) and (2) demonstrates that the option to delay the investment has a value of $236.

Figure 2 is a graphical representation of option value relative to commodity price uncertainty. The straight diagonal line represents the value of the project without the option to delay the investment. The break-even commodity price is located where the project value line crosses the x-axis. The curved line, above the project value line, represents the value of the project including the option. Therefore, the difference between the two lines is the value of the option. The value of the option is at a maximum when the project NPV equals 0 (referred to as *at the money*).

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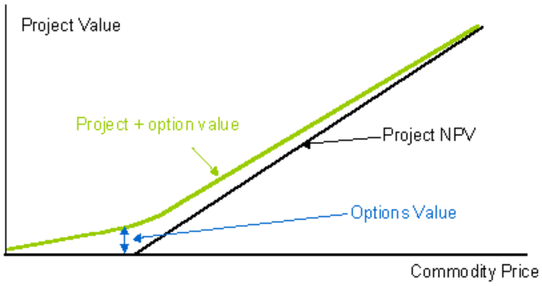

Figure 2: Option Value

As the price of the commodity increases and the project becomes more and more lucrative, the option to delay project startup loses value because starting the project earlier generates earlier revenues. At the other end of the spectrum, when the value of the project is very negative (*out of the money*), the option of implementing the project has little value because the probability of it becoming lucrative is very low.

The example above is a very simplified case in which only one decision must be made. However, during the life of a mining project, many decisions must be made sequentially, and MDPs offer a tool to evaluate such types of decisions.

2. Markov Decision Process Framework

When making sequential decisions, it is important to consider the short-term and long-term rewards. An action that seems bad in the current state may generate many positive rewards in the future. A simple example is the decision to invest in a project. In the short term, this seems like a bad idea because the instantaneous reward is negative. However, because the project will generate benefits in the future, the overall reward associated with the investment decision could be positive. MDPs offer a tool for sequential decision-making under uncertainty [10]. The MDP framework can effectively manage the instantaneous and future rewards in such a way that will maximize the overall reward.

An MDP is a representation of an agent interacting in a stochastic environment. It can be described as a reinforcement learning type algorithm such that the performance of the learning agent is improved through iterations until it plateaus [6]. It is composed of the four-tuple (*S,A,T,R*), in which S is the state space, *A* is the action set, *T* is the state-transition probability distribution function, and *R* is the instantaneous reward function.

The state space *S* is a set of all the possible configurations of the environment in which the agent interacts. The action set is a list of all the actions available to the agent within his environment. Actions allow the agent to modify his environment and move from one state to the other. For each state *s*, an action *a* has an instantaneous reward and a transition probability distribution to new states.

In a deterministic world, an action taken in a state will lead to a new state with a probability of 1. However, because the environment created for the agent is probabilistic, the agent may end up in a number of possible states following an action. The state transition probability function provides the probability of going from one state to another given a particular action. The state-transition probability function is defined as:

$$p_{ij}^{k} = \Pr(S_t = j \mid S_{t-1} = i, A_t = k) \qquad (3)$$

A policy π is a mapping from states to actions. Thus, it determines which actions should be taken in each state.

An infinite-horizon MDP is used in this paper because as stated in [1], it is established that for the infinite-horizon case, an optimal deterministic stationary policy exists. The optimal policy is denoted as π^*.

Kealbling, Littman and Moore [6] present a concise overview of policy iteration. They explain how the optimal value of a state is the expected infinite discounted sum of rewards that the agent will gain if it starts in that state and executes the optimal policy.

$$V^*(s) = \max_{\pi} E\left(\sum_{t=0}^{\infty} \gamma^t r_t\right) \qquad (4)$$

The optimal value function in (4) is unique and is the result of the simultaneous equations (5) presented below.

$$V^*(s) = \max_{a}\left(R(s,a) + \gamma \sum_{s \in S} T(s,a,s')V^*(s') \right), \forall s \in S, \quad (5)$$

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Equation (5) demonstrates that the value of a state s is the instantaneous reward plus the discounted value of the next state multiplied by the probability of reaching that state, using the best available action. Given the optimal value function, we can specify the optimal policy as

$$\pi^*(s) = \arg\max_a \left(R(s,a) + \gamma \sum_{s \in S} T(s,a,s') V^*(s') \right) \qquad (6)$$

The policy iteration algorithm modifies the policy directly. The agent starts with a random policy. The value of each state is computed following the current policy as described above in equation (5). When the value of each state is determined, the agent will make modifications to the policy in order to improve the value of each state as prescribed in equation (6). The agent will attempt to improve the value of the policy by making modifications to the first actions. In this fashion, strictly improvements will be brought to the policy. When improvements can no longer be made to the value of the state space, the optimal policy is found and the algorithm stops. The algorithm is presented below:

```
Choose an arbitrary policy $\pi'$
Loop
    $\pi := \pi'$
    compute the value function of policy $\pi$;
    solve the linear equations:
        $V_\pi^*(s) = \max_a \left( R(s,\pi(s)) + \gamma \sum_{s \in S} T(s,\pi(s),s') V_\pi^*(s') \right)$
    improve the policy at each state:
        $\pi'(s) := \arg\max_a \left( R(s,a) + \gamma \sum_{s \in S} T(s,a,s') V_\pi^*(s') \right)$
    Until $\pi = \pi'$
```

Kealbling, Littman and Moore [6] present a concise note on the complexity of the policy iteration:

> *Note: Since there are at most |A| |s| distinct policies, and the sequence of policies improves at each step, this algorithm terminates in at most an exponential number of iterations [10]. However, it is an important open question as to how many iterations policy iteration takes in the worst case. It is known that the running time is pseudo-polynomial and that for a fixed discount factor, there is a polynomial bound in the total size of the MDP [7].*

The MDP framework lends itself quite well to the task of valuing options. By comparing the value of a state space with and without the option, it is possible to determine the value of that option. This is easily achieved by determining the total value of the state space when a particular action is included in the action set and when it is excluded. The difference between the two results yields the value contributed by that option to the state space.

As stated earlier, an important advantage of using MDPs to value options is that the policy required to achieve the maximum value of the state space is determined. The policy can then be used as a guide in the optimization of the production process.

As mentioned by Kaelbling, Littman and Moore [6], the MDP framework is quite effective when a correct model is given. The following section describes the model used to create the state space.

3. State Space Model

Modeling of Block Grades

In order to portray the uncertainty of the mineral content (grade) of the mining blocks, geological block models are simulated using Sequential Gaussian Simulation (SGS).

This method is based on the decomposition of the multivariate Gaussian distribution into the product of univariate conditional distributions. These univariate distributions are normal with a conditional mean exactly equal to the simple kriging estimate and a conditional variance exactly equal to the simple kriging variance [5]. The simulation is done following (7).

$$\boxed{z\delta + \mu = x \qquad (7)}$$

z = Normal random number with mean 0 and standard deviation of 1

δ = Simple kriging standard deviation

μ = Simple kriging estimate of node value

x = Simulated node value

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The first step of the SGS is to create a random path that contains all of the nodes in the block model to be simulated. Once the path is established, the value of the first node is simulated by: 1) determining the conditional cumulative distribution function (ccdf) by applying simple kriging using all sample data, and 2) generating a value at the node by sampling the ccdf. The new node value is then added into the data set and the algorithm moves on to the following node.

Simulated block models were generated as described in Farrelly [3]. These block models are equally probable representations of the actual mineral deposit [5]. The block models are used to represent the geological uncertainty of the deposit.

Once the block models are created, it is possible to determine the probability distribution of grades in the next block to mine, conditioned on the grade of the current block. Using the grade conditional probability distribution function, the transition probability matrix for grades can be constructed.

Modeling of Commodity Prices

There are many time series models that may be used in price simulation. The most commonly used are the random walk, mean reverting and log-normal models. In the present case, a mean reverting diffusion process is used to simulate prices.

The simplest form of the mean reverting diffusion process is known as the *Ornstein-Uhlenbeck* process described below.

$$\boxed{dx = \delta\,(\bar{x} - x)\,dt + \sigma\,dz}$$

dx = Change in price over one period
δ = Reversion speed, i.e. force with which the price is pulled back towards the mean
$\bar{x}$ = Mean price (the historical mean is often used)
x = Spot price, i.e. current price of the commodity
dt = Change in time
σ = Volatility, i.e. the maximum change in price over one unit of time
dz = Normal random number

In order to model prices efficiently for an MDP, a discretized version of the diffusion process is required to reduce the size of the transition matrix. The transition probability matrix for prices can now be constructed

The Transition Probability Matrix

Once the transition probability matrix for the block grades and that for the prices are created individually, the overall transition matrix is generated. This is simplified by the fact that the transition probabilities of the grades and prices are independent. Thus, the combined probability matrix is simply the product of the probability matrices of the two parameters.

4. Optimization Model

This study focuses on the problem related to the optimization of the mine extraction rate with respect to fluctuations in commodity prices, uncertainty in grades, and depleting ore reserves. During periods when commodity prices are high, it is advantageous to increase production in order to sell the most material possible during these periods. When prices are low, managers should reduce production in anticipation that prices will rise again in the future. Therefore, we must assess the benefits gained from having a robust mine plan that will permit an increase or decrease in production rate according to commodity price and grade quality.

To simplify the problem, it is assumed that the sequence in which the blocks are mined is predetermined; thus avoiding complications related to slope constraints. This predetermined sequence also reduces the computational complexity of the problem by limiting the size of the action set. Without this constraint, the agent would have to determine which block to mine in each period as opposed to whether or not it should mine the next block. In the first case, the number of possible actions would be at the least the number of blocks in the pit, while in the second case; the actions are limited to a discretization of feasible production rates.

At each decision stage, the agent must determine the optimal production rate. The option to terminate production is also available. However, when a decision is made to terminate production, operations cannot be resumed. Therefore, the action to terminate production leads to an absorbing end state, as depicted in Figure 3.

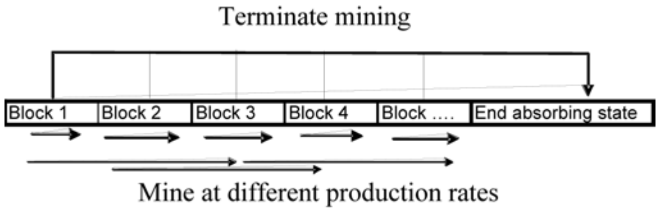

Figure 3: Description of actions available

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The MDP framework requires that the current state be fully observable. Accordingly, it is assumed that the sample cuttings from production drilling conducted prior to mining provide enough information to claim that the grade of the current block mined is fully observable. The commodity price is also fully observable in the current state as indicated by the current market price. The block to be mined in the current state is also known. Therefore, the current state is fully observable. Another requirement to apply MDPs is that the environment must be Markovian, which means that all the information from the past is contained in the current state.

It is assumed that there is no delay between the time at which a block is mined and the time at which the recovered mineral product is sold. This assumption simplifies the calculation of the reward generated from mining a particular block. This reward is obtained in the same period in which the block is mined and it is the revenue generated from selling the mineral product recovered from the block less the cost incurred. The reward function is:

$$R = \text{Grade} \bullet \text{Price} - \text{Cost} \qquad (9)$$

5. Simulated Example

The optimization model is applied to a hypothetical small-scale mine. In this example, there are 10 blocks to be mined, each of which has five possible grade values. The number of possible prices is limited to 6. Therefore, the total size of the state space is 301, including the end absorbing state.

Two cases are considered, i.e., a "just in time" design and a robust plan. In the first case, the actions are limited to two possibilities, either mine the next block at a rate of one block per period, or terminate mining. In the second case, the robust mine plan permits a second production rate of 3 blocks per period. Thus, there are three actions to choose from at each decision epoch: mine the next block, mine the next three blocks or terminate mining. It is assumed that the price remains constant between each decision and is only updated at each decision epoch. Comparing the values of the two cases yields the additional value of having a robust mine plan over a "just in time" approach.

The MDP is solved using an MDP toolbox in MATLAB [8]. The toolbox requires as input the state space, the transition matrix for each action along with the reward function for each state. The transition probability matrix is generated following the method described above in section 3, and the reward function is used as presented in section 4.

6. Results

The optimal policy for the first case is depicted on the 2-dimensional chart shown in Figure 4. The commodity prices are given on the y axis while the mining location (blocks) is given on the x axis. The interpretation of the chart is demonstrated by the following examples. First, assume that the mining operation is to begin and a decision must be made (i.e. mine the first block or terminate mining). The chart shows that if the current market price is at 1 or 2, the project should not be started. However, if the current price is at 3 or above, the project can go forward. Suppose now that block 6 has been mined. The chart shows that if the price is at 2, then the mining operation should be terminated, regardless of the grades of the remaining blocks or future prices. Nodes with superimposed icons indicate that the decision is a function of the grade of the block (there are 5 grade states at each node). A 3D representation of the state-action mapping would resolve this overlap but would lose much of its simplicity and readability.

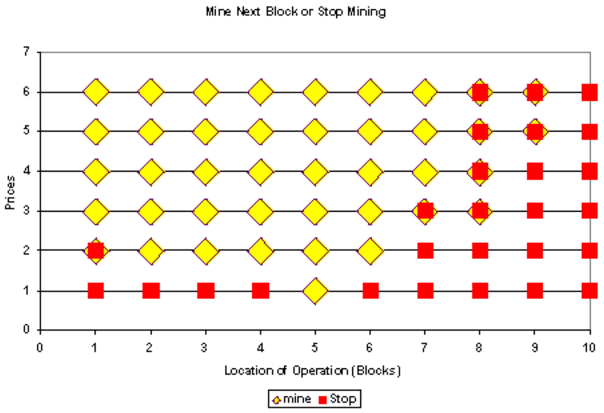

Figure 4: Policy for one production rate

The charts indicate the optimal action given a particular price, grade, and mining location. As shown in Figure 4, the operation should be closed down when the price drops to low levels. The bottom left section of the chart indicates a region of the state space where the project should not be started. The chart also shows that higher prices are required to keep the mine open towards the end of mine life.

Blocks 1 and 10 have identical grades. However, the value associated with mining block 1 is very different to that of mining block 10. This is caused by the fact that mining the first block gives access to the other blocks. This indicates that the value of each block takes into consideration extrinsic rewards associated with a particular block. In the short term, it may be a bad choice to mine the first block because it has a negative reward. However, because it gives the

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opportunity to mine other blocks with higher positive rewards, the action to mine the first block is justified. However, this is not the case for block 10. This block is the last block to be mined and does not offer opportunities to mine other lucrative blocks. Thus, it has no extrinsic value. This concept is clearly accounted for in equation (5), in which the last term represents the block value associated with providing access to the remaining blocks.

The optimal policy for the second case is depicted in Figure 5. Suppose that the mining operation is now at the point of mining block 6 and management would like to know which production rate would yield the highest return. The answer can be found by looking at column 6 in the chart. If the price is at level 3 or lower, the production rate should be set to 1. If the price is above level 3, then the production rate is set to three.

The results of the second case shown in Figure 5 behave as expected. The production rate is increased when the price is high and reduced when the price is low. It is interesting to note that the higher production rate option eliminates the red region on the bottom left corner of the chart in Figure 4. Thus, for any price, the project is commenced. Intuitively, it is logical to argue that the extra flexibility in production rates will reduce the risk related to changes in commodity prices.

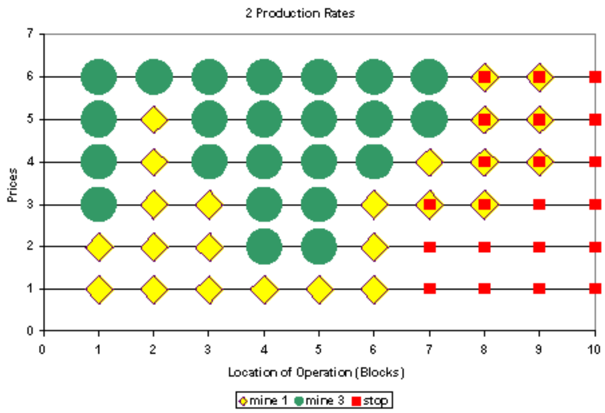

Figure 5: Policy for two production rates

The difference between the overall values of the two cases yield the value of having a robust mine plan over a "just in time" plan. In case 1, the value of the state space is 303.9. In case 2, the value of the state space is 775.1. Therefore, the option of increasing the production rate has a value of 471.2.

Conclusion

We have seen how managerial flexibility adds value to projects and should be taken into consideration in project valuation. A description of the methodology used to model the mining environment was provided. Through a hypothetical example, it was shown that MDPs can effectively measure the value of options. Furthermore, it was demonstrated that MDPs provide the policy that leads to the complete realization of the benefit associated with an option.

Future Work

As this is preliminary research, much remains to be explored in the application of MDPs to mine scheduling and option valuation. One of the first issues that must be addressed is the handling of the large size of the state space. A typical mine scheduling problem could have up to 60 000 states. Such a large state space cannot be optimally solved. The computation complexity of solving MDPs is addressed by Littman, Dean and Kaelbling [7].

In the case presented in this paper, the mining sequence is fixed and the transition probabilities for the blocks are deterministic. Although the given mining sequence serves as a good guideline for scheduling, this sequence is not set in stone and the agent should have the flexibility of temporarily diverging from that sequence in order to maximize profits. This extra flexibility can be achieved by increasing the number of actions available to the agent at each state.

The production rate is but one of the production parameters that can be optimally adjusted according to market conditions. Equally important, the cut-off grade is another parameter that needs consideration. The use of a multi-agent MDP algorithm would permit the interaction of two agents to derive an optimal policy for both parameters at-a-time.

Optimization using MDPs will generate substantial financial savings due to improved managerial decision- making. Application of MDPs to mine operation presents great potential. ◆

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MEMS TREASURY SUMMARY

AS OF DECEMBER 31,2006 • ALL FIGURES ARE IN USD.

Cash on Hand	**$5,002.71**
Money Market	$5,002.71
Receivables held by SPACE	$ –
less Paper Competition Travel Fund	*$1,500.00*
Available Funds	**$3,502.71**

2006 REVENUE SUMMARY

Member Dues (collected by SPACE)	$3,660.00
Corporate Sponsors (collected by SPACE)	$4,250.00
Conference Fees (collected by SPACE)	$12,060.00
Interest on Savings	$81.96
Total Revenue	**$20,051.96**

2006 EXPENSE SUMMARY

2006 Conference	$12,817.64
Website	$2,500.00
Newsletter - Print, Post, Design	$975.00
Post Office Box Rental & Postage	$72.00
Bank Fees	$248.50
QuickBooks Online	$169.10
Economagic Licence	$500.00
Misc Other Admin	$-
Total Expenses	**$17,282.24**

NET POSITION 2006	**$2,769.72**

2006 CONFERENCE SUMMARY

REVENUE (COLLECTED BY SPACE)

Conference	$12,060.00
Risk Capital Award Sponsorship	$1,250.00
Total Revenue	**$13,310.00**

EXPENSES

Student Awards (2)	$1,500.00
Venue	$5,283.32
Marketing	$3,487.85
SPACE Administration	$2,250.00
CSM Fees	$296.47
Total Expenses	**$12,817.64**

2006 Conference Revenue/Loss	**$492.36**

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