Risk identification, assessment and management in the mining and metallurgical industries

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Synopsis

Risk assessment consists of a search for the answers to:

- What can happen?
- How likely it is that it can happen?
- What are the consequences if it does happen?

Perhaps the most important aim of risk analysis is to predict the likelihood that a planned profit will be achieved over a given period of time. A typical risk model employed for this purpose includes a stochastic connection between the dependent variable of an expression that describes a process and independent variables represented as random quantities. The output will be a probabilistic distribution.

The uncertainties in a planned mining operation include:

- Commodity market characteristics, particularly price
- Ore reserves and mineralogical composition
- Mining method
- Process performance
- Capital and operating costs
- Schedule duration
- Economic environment effects.

The processes employed in the probabilistic estimation of a project's outcome include both Monte Carlo simulations and simulations where variable correlation is considered important.

The risk model, once developed and tested, provides a framework for a rational approach to risk analysis and the testing of alternatives.

Introduction

In their 'Manual for the Preparation of Industrial Feasibility Studies' Behrens and Hawranek[1] note that the development of an industrial investment project can be regarded as a cycle comprising three distinct phases, namely;

- Pre-investment
- Investment, and
- Operational.

They suggest that increased importance be attached to the pre-investment phase as a project will succeed, or fail, on the marketing, technical, financial and economic findings and their interpretation, particularly at this stage.

The pre-investment phase comprises;

- Identification of investment opportunity
- Analysis of project alternatives
- Preliminary project selection
- Pre-feasibility and feasibility studies
- Appraisal and investment report.

Support and functional studies are pre-requisites, for, or in support of, pre-feasibility and feasibility studies. Such studies include:

- Market studies
- Raw material and factory supply studies
- Laboratory and pilot plant tests
- Location studies
- Environmental impact assessment
- Economies of scale studies.

According to Stermole[2] an overall investment analysis should involve three analyses:

- Economic analysis: involves evaluation of the relative merits of the investment from a profit and cost viewpoint
- Financial analysis: is concerned with the origin of funds for the project
- Intangible analysis: consideration of factors not easily quantified in economic terms.

Davis and Horvei[3], on the other hand, suggest that the economic analysis of a project attempts to assess the project from the national point of view whereas the financial analysis assesses the project from the viewpoint of the implementing institution (owner) of the project. The authors are particularly concerned with the efficient allocation of resources and suggest that projects fall into the following categories;

- where there are two, or more projects with the same objectives, the analysis should identify the least cost option, assuming both have similar benefits
- where projects with different objectives,

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or target groups are examined, they should be ranked on the basis of their net benefits

- where only one project is examined the estimated rate of return should be compared with the likely rates of return in other sectors of the economy.

Risk

Both economic and financial analyses rest upon a number of assumptions and predictions such as costs, prices and demand. The need for increasingly scientific approaches to the estimation of risk comes from the accelerating rate and quantum of investments in projects. As Stermole[2] pointed out in the 1980s, the estimate of capital investment requirements over a 10-year period in the '70s to 80s', in the U.S., amounted to between 4 and 5 trillion dollars, or more capital investment than was spent, cumulatively, in the first 200 years of the U.S.' modern economic history.

According to Merrett and Sykes[5] the selection and financing of capital projects are indisputably the most important and critical business decisions. Investment in fixed capital involves choices between alternative capital assets, dates of commencement and methods of financing. These choices are both complex and critical given the scope for, and very high cost of, erroneous decisions. If, for example, a major production facility is wrongly sited, or sized, the mistaken decision is largely irredeemable in that the cost of correcting it is greater than the cost of simply bearing the cost of the mistaken decision.

From the point of view of financial institutions the key to lending money is not simply to find a project that needs cash, but to determine which projects have risk profiles that will provide adequate assurance for the repayment of the loans advanced[6].

There are considered to be five major branches of institutional risk assessment, namely[7]:

Statistical;	considered to inadequately represent the judgements necessary in an increasingly complicated and interrelated world,
Modellers;	the computer-based assessment of the project's inter-relationships, considered to be of limited use due to the difficulty inherent in quantifying and representing the inter-relationships of risks,
Checklists;	considered to be useful as long as employed in conjunction with other risk classification processes,
Project financing;	is considered to have the most experience and best approach to the definition of risk categories. Opinions vary between project financiers and financing entities on the points of analysis. Points considered important, by 11 finance entities, provide the following ranking;

Reserves	1.00
Technical	1.00
Market	1.00
Completion	1.00
Political	0.91
Cost	0.64
Force majeure	0.55
Foreign exchange	0.55
Participants	0.45
Management	0.27
Infrastructure	0.27
Syndication	0.09

Insurance;	The insurance industry is concerned with asset loss/reinstatement and, as in the case of modellers, can overlook the interaction of risks.

The impact of project risk can be described in terms of cash flow parameters as follows:

Cash flow parameter	**Risk parameter**
Metal recovered	Reserves *Force majeure* Technical
times	
Revenue received	Market Infrastructure
equals	
Gross revenue	
less	
Royalties, Fees	Political
Operating costs	Cost Management Environmental
Interest expense	Funding Syndication
Depreciation/Amortization	Completion
Overheads	Participation
Taxes	Political Legal
equals	
Net after tax	
plus	
Depreciation/Amortization	Completion
less	
Capital expenditure	Engineering
Loan repayment	Debt/equity ratio Funding Foreign exchange

Risks can be divided into those within and outside of the company's control.

Risks outside of the investor's control

The following items are nominally considered to lie outside of an investors control and hence should be quantified with as much accuracy as possible and, where possible, provided with compensating mechanisms:

Ore reserves

The factors involved in the assessment of an orebody are many and include markets, prices and costs[8]. Economic value estimates are obtained from projected cash flows. Geological reconnaissance and pre-feasibility mining studies tend to generate a broad range of tonnage estimates[9].

Minimum economic average grades tend, approximately, to be inversely proportional to the third, or fourth root of the associated tonnages and some combination of tonnage and grade should be economic. Valuation differences are likely to be deposit specific.

Narrow vein deposits, for example, cannot be adequately valued by drilling alone and cannot support too much exploratory underground development. Their estimates must, therefore, be classified as drill-inferred.

A typical process of verification and validation of a mineral resource is shown by the following[10]:

Activity	Process	Data
Sampling	Diamond drilling Reverse circulation Channel-chip Sample preparation	Core logs Sections and plans
Assaying	Atomic absorption Spectrophotometry	Assay certificates Density report
Drill hole logs Scan lines	Diamond bit coring Reverse circulation	
Geotechnical data	Rock mass classification	Rock density
Metallurgical data	Ore testing	Recovery Work index
Data base	Data storage, retrieval and compositing	Metal grades Rock densities Survey data Lithological data
Geological model	Interpretation of data	Mineral controls Metal zoning and trends. Mineralization continuity
Geological units	Frequency curves Variograms	
Estimation	Block model construction Geostatistics	3-D coordinates Lithological units Rock densities Grade interpolation
Declaration	Resource classification	Kriging variance Sampling distance Drilling density

From a financier's point of view mineable reserves should, generally, be twice as large as the reserves to be mined during the loan repayment period.

Market Risk

Market risks are associated with:

- Commodity price variations
- Market share variance (entry of lower cost producers)
- Variance in demand for a product
- Variance in the quality of the product.

Harold Hotelling[11] demonstrated that the price of an exhaustible natural resource, net of extraction cost, is expected to rise at the prevailing rate of interest. This expectation is due to intertemporal profit maximization by the owner of the resource. A greater increase in the net price would accelerate extraction by the owner in order to invest the proceeds in interest-bearing assets. Jamal and Crain[12] confirmed that there is a strong relationship between the value of a mineral resource and the net output price.

There is, however, increasing competition for metals from new materials such as plastics and ceramics. Malenbaum[13] and Tilton[14] found that there is evidence of a declining intensity of use of raw materials due to shifts in consumption patterns, technological change and movements in relative prices of materials.

The notion of exponential growth in the consumption of key metals, such as copper, lead, aluminium and zinc, has given way to depletion alleviation considerations such as replacement by plastics and composites, increased recycling and material-conserving technical change[15].

The variability in metal prices has always been a central problem for the metal industries[16]. There would appear to be two characteristics of such variability;

- the extent of variation in price is very large
- the duration of the periods of expansions and contractions in prices are long but irregular in length.

Labys, *et al.*[17] examined the volatility, chronology, frequency, duration and amplitude of some eight international metal prices over the period 1960 to 1995. Their main findings support evidence for cyclical behaviour in the expansion, contraction and duration phases for a number of commodities. There appears to be a predominance of two kinds of cycle. The first cycle usually has a periodicity of less than 12 months while the second cycle has a periodicity greater than one year.

Volatility is a term used for the day-to-day, week-to-one week, month-to-month, or year-to-year variation of an asset price. It measures how much the price changes about, either its long-term level, or about a long-term trend. A price, for example, can be very volatile, but change little in the long-term, or show very little volatility, but change considerably over time through occasional discrete adjustments[18].

The main impact of volatility is in causing uncertainty to producers—in relation to revenues, consumers—in relation to costs and stockholders, in relation to margins. Brunetti and Gilbert[18] have noted that high volatility tends to be associated with periods of tight demand. Short-term fluctuations in metal volatility appear to be associated with speculative movements.

Since cyclical instability is a defining characteristic of the major metal industries, business processes must be found to deal with same.

The techno-economics' characteristics of the supply side of the minerals/metals industry stem from long lead times, capital intensive plant and largely continuous process technology. This industry does not find it commercially, or technically attractive to vary output in response to demand signals. On the other hand the consumption of the products, of the mining industry, is linked to economic sectors such as

construction, consumer durables and business fixed capital spending which tend to fluctuate more than the economy as a whole. It is suggested that these components approximate the characteristics of perfect competition in which prices are set according to marginal costs with a very large absolute difference between short-run and long-run marginal costs[19].

The basic management tool for commodity cycle management has been cost reduction. However, cost reduction will only work if the cost reduction potential is greater than that of competitors thus promoting a downward movement on the cumulative cost of production curve.

Resource Strategies suggest that operating costs can be divided into:

Avoidable costs:	those operating costs from which the operator will escape during the first year of a temporary shutdown.
Quasi-fixed costs:	these are all operating costs that are not avoidable.

Some 2% to 2.5% of estimated replacement-capital cost comprises medium-term cash costs. These must be paid in cash and the above proportion represents a reasonable allowance for minimum sustaining capital expenditure.

It is the control of capital and overhead costs, according to, rather than the control of net operating costs, that is the key to managing the business cycle. There can be large differences between avoidable costs and net operating costs causing the operation to continue to generate cash, although not enough to pay debts, so unpaid interest is added to principal debt at an ever-compounding rate. The effect can be mitigated by:

- reduction in the capital cost repayment obligation
- restructuring net operating costs
- entering into risk-sharing arrangements with suppliers and customers.

Capital payment modification

An ideal capital structure, in the commodity markets, is 100% equity since companies are under no obligation to pay dividends during depressed commodity price cycles, for which they compensate with larger payments during boom periods. However, the tax deductibility of interest payments and the taxation of dividends discriminates in favour of debt financing. Equity capital is usually more expensive than debt capital.

The increasing scale of modern mining and the tendency towards the employment of capital-intensive technology further exacerbates the bias in favour of debt financing. However, less capital intensive, multiphased and flexible projects, using intermediate technology, may be more appropriate in an environment of volatile commodity prices. Since it is total cost that matters in a project, the costs to minimize are the fixed costs as they have to be paid under all circumstances

After the correction of investment bias, if possible, the next step is to look at reducing fixed capital costs. To do this, and avoid the tax system bias, sources of loan capital must be derived with equity-type characteristics.

Until the 1980s the only commodity risk management tools available were exchange traded futures and options[20]. These have a limited range of maturities seldom extending more than one year into the future. This is inadequate for most commodity cycles. A rolling futures hedge could be employed to fix a series of different prices over a succession of shorter periods, which is not the same as fixing a single price over a longer period. There is, however, a lack of long-term commodity price protection, which has probably limited the employment of commodity futures and options.

More recently interest rate tools, like swaps, caps, collars, swaptions and options on commodity swops, have become available in more sophisticated markets.

The starting point for constructing most commodity derivatives is the commodity futures market. The creation and marketing of any derivative financial product requires a hedging mechanism, otherwise the market maker would be burdened with unacceptable risk. Hedging with the underlying commodity is inhibited by a reluctance, on the part of financial institutions, to include tonnes of metal among its assets. Commodity futures obviate this by providing a clean, liquid and low-cost method of hedging exposure to the underlying commodity.

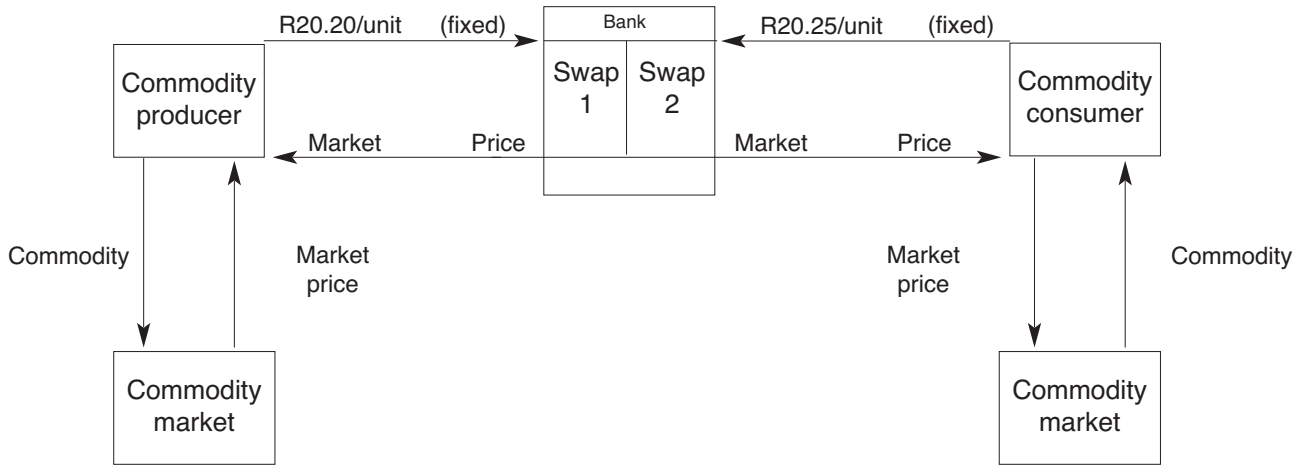
The price of many commodity futures is related to the spot price of the underlying commodity. The relationship between commodity future prices and cash market prices is much more susceptible to the laws of supply and demand than that for financial futures. When the demand for a commodity rises the future price will be higher than cash-and-carry arbitraging would suggest. This condition is known as contango. Similarly when supply outstrips demand the future price will be lower and may even fall below the cash market price, a situation known as backwardation.

Commodity futures and cash prices do move in unison. If prices in the cash markets rise then so do commodity futures and by a proportionate amount. This means that commodity futures can be used as an effective proxy for the underlying commodity when hedging other commodity derivatives.

Commodity options may be priced using the standard Black Scholes, or binomial models and dynamically hedged by buying, or selling commodity futures contracts for an amount equal to delta times the amount underlying the options contract.

A typical structure for a commodity swap is shown below[21]:

- the commodity producer enters into a commodity swap, as the fixed price payer, agreeing to receive periodic payments at a fixed price of e.g. R20.20 per unit, on a nominal quantity of commodity, against paying the market price
- when the producer actually sells the commodity into the market he delivers the commodity and receives the prevailing market price
- the producer's cash flows, linked to market prices, will net out and the effect of the swap is, therefore, to fix the price at which the producer sells his commodity
- the commodity consumer enters into another commodity swap with the bank, this time paying the fixed price of e.g. R20.25 per unit and receiving the market price
- the consumer then, in turn, pays the market price when he buys the commodity in the spot market
- the market-related cash flows cancel each other out



and the commodity consumer ends up paying a fixed price for the commodity, irrespective of the market rate

- both producer and consumer have eliminated their exposure to fluctuating commodity prices and the swap ensures price certainty for both timings
- assuming the bank can match the timings and nominal sizes of both swaps it will profit from the margin between the fixed prices on the two swaps
- the bank can also hedge each swap separately in the futures market
- no exchange of the physical commodity ever takes place. The commodity swap is based on a nominal quantity of the underlying commodity, which is only used as the basis for calculating the swap payments
- periodic payments are normally settled by a single net payment from the debit counter party to the credit counter party.

Restructuring net operating costs

Metals and mining operations minimize their net operating costs by maximizing production rates. This could result in an exacerbation of the cycle in that increased production leads to increases in stocks and a concomitant decline in the commodity price.

Companies also tend to raise grades to reduce the unit cost of metal produced. Since the concentrator capacity is fixed, the higher grade throughput results in a higher metal production rate.

The cost problem can be tackled by creating a two-tier cost structure. Thus, lower costs can be obtained on part of the facilities output, even if higher costs are involved on the balance of the output.

An interruptible power strategy can be employed to lower power costs as power utilities, replacing plant expansion with interruptible power supplies, can defer both capital investment and the operation of more expensive generating facilities and are prepared to lower tariffs to co-operating consumers.

The restructuring of labour costs, by placing a greater reliance on subcontractors, permits the avoidance of severance costs associated with own labour. Thus, labour costs can be reduced when production is curtailed.

Risk sharing

Risk sharing involves entering into arrangements with suppliers, customers, employees and host governments to share the 'pain' associated with troughs in the commodity price cycle.

A good example of this is the aluminium industry where the raw material (alumina) is;

- sold as a straight percentage of the prevailing metal price
- bartered, or swapped for metal at an exchange ratio
- tolled for fees that are both fixed and variable
- sold at fixed prices
- sold by long term put and call options at prices that are fixed, or related to the metal price.

In addition to linking electricity prices with commodity prices, electricity supply utilities have introduced variable rate supply agreements in which a lower tariff rate is provided at the initial stage of the project giving way to a tariff surcharge, or 'claw-back' arrangement at a more mature stage of the project.

Risk sharing by customers is another approach. A possible arrangement would be as follows:

- the mining company offers to supply a customer at a price with a specified cap (upper limit) set so as to provide the consumer company with an adequate return. This upper limit would be binding
- the consumer would not be obliged to purchase at this price and could shop for a better deal
- the mining company would always be able to supply the customer by offering material at a best third party price plus a nominal premium (= long-term option)
- the consumer would have to put money up-front to pay-for this option
- the 'option' aids management of the business cycle since capital repayment obligations can be reduced
- the small premium-over-market may also aid the mining company in surviving the downturn
- the consumer is now assured that he will pay only marginally above the lowest market price available, when prices are low
- the consumer will also be protected from disruptive commodity price spikes.

Generally speaking banks require the net present value of the sales proceeds, net of operating costs, to be at least 1.5 times the amount of loan outstanding.

Infrastructure risk

Transportation comprises an important component of many mineral projects and assurance is required that the chosen infrastructure will remain technologically and economically competitive over time, particularly with regard to developments in other production areas. Not only transportation, but also port capacities, can become limiting factors in the profitability of projects.

Where transportation facilities are built and operated by the government then higher freight rates and user fees can constitute a form of additional taxation impost on the project.

Environmental risk

The less favourable and more controversial aspects of mining are secondary and tertiary side effects[22]. These can be grouped into:

- environmental and land use impacts
- accident and health hazards
- economic-political-social-psychological impacts.

Physical, chemical and biological changes in the environment are often the results of mining. These include;

- disturbance of the surface
- subsidence
- water and air pollution
- consumption of irreplaceable resources
- threat to endangered species
- pre-emptive use of land.

There are also a variety of indirect effects associated with mining. These usually result from the initiation, or termination of mining operations when drastic changes occur in manpower-employment levels.

Because of the far-reaching consequences of environmental legislation to the mining industry it is advisable for project investigators to conduct an environmental study at the earliest possible stage.

Pollution control, in mines in the U.S., currently costs the mining industry 17% of its total capital expenditure, or some three times that of other industries.

Political risk

Political risk is a concern of any investor considering an investment, particularly in the mining industry due to the magnitude of the sunk cost investment concerned[23]. A non-renewable natural resource producing company cannot choose where a suitable deposit is located, it can only decide whether to develop same, or not.

Once a mine is in place the investing company is tied to that mine until depletion, or until an ownership change. This amounts to a hostage situation. For example, after the capital investment, a company may be presented with changes to the original contract, resulting in higher government revenues at the expense of the company. In extreme cases under-, or un-compensated expropriation, or nationalization may occur.

At the beginning of an extractive project the investing company holds the majority of the power because the host government, owing to a lack of capital and expertise, is unable to adequately develop the project[24]. After the project is on line and profitable the power structure changes. Domestic workers move up a learning curve and the government develops an appetite for a greater share of what is perceived as a national patrimony. Because the mine cannot be moved it is used as a bargaining point to renegotiate the original contract. The investor is faced with the choice of a slower pace of realising the company's investment, or of foregoing all future revenues, possibly without compensation.

Instability models have been widely used as a measure of risk. However, events show that more benign acts may lead to political risk due to non-market, or political forces. The testing of the relationship between annual country risk premiums and political risk rankings have been econometrically tested for 46 countries between 1972 and 1984[25]. The results have not indicated a consistent relationship between a political risk premium and political risk indices.

Many companies choose to generate their own risk assessment profiles of countries. General Motors use a primarily qualitative technique oriented towards policy issues. BP's risk assessment strategy involves identifying the nature of the risk, assessing which risks may be manageable, ranking countries on the base of riskiness and estimating the minimum level of benefits necessary from a project to offset the political risk involved. The Bankers Trust has an approach based upon economic and political analysis.

The negotiation of the 'most fair' contract between host government and investing company is suggested as a means of minimizing risk. This involves a Ricardian type rent tax on profits in excess of a pre-specified rate of return to the investing company. There is, however, a lack of incentive for the investor as additional risk is usually incurred when there is an acceptable probability of higher profits, a process brought about by an acceptable rate of return on their investment.

The use of project financing is also seen as a way of minimizing the political risk of the investment. A structure of lenders can be developed for a specific project. Such a structure would have the ability to pressure a host government that strays from the original agreement, by withholding other loans made to that government.

Where financial institutions decide they cannot absorb political risk then recourse is made to government-sponsored export-credit agencies.

Risks within the investors control

These risks are regarded as being subject to project management intervention.

Reliability and availability of mining systems[26]

Reliability is an important consideration in the planning, design and operation of mining engineering systems. Increasing mechanization, escalating equipment costs, the size and complexity of modern mining systems and an increasing application of new technology suggests the

application of reliability theory to achieve the desired levels of production and productivity, under the prevailing economic circumstances.

Reliability is the probability that a piece of equipment, or a system will perform its intended function for at least a given interval of time. Availability figures give estimates of the up-time of the system and are generally more useful than reliability data for maintained systems, such as mining equipment.

The logical approach in reliability/availability analysis is to decompose the system into its functional entities. These consist of such sub-systems as extraction, support, materials handling, etc.

Most studies assume exponential failure and repair time distributions for equipment. However, if the effects of equipment ageing and component wear are taken into account, it is necessary to incorporate distributions with increasing failure rates in reliability data. The older some components are the more likely it is that they will experience failure more frequently, expressed as an increasing failure rate (IFR) distribution.

Alternatively, at the beginning of its life, a component can be regarded as subject to an early failure-period over which the failure rate decreases rapidly (DFR).

By combining measures of maintainability with reliability an adequate estimate of system availability can be established. The problem in estimating system availability lies in having access to data to describe the new systems.

The importance of system availability cannot be underestimated, particularly in the early stages of the project where a negative cash flow prevails and bridging finance for unplanned decreases, or cessation of production, is expensive and difficult to raise.

Technology

Technology innovation in the mining industry is slow as the following elements discourage change[27].

- Mineral commodity markets require product conformity
- The capital intensiveness of the industry leads to long pay-back periods for existing technology and extra high risks attached to the introduction of new technology
- The environment, particularly as regards safety maintenance, tends to promote a conservative management philosophy
- The minerals industry, unlike the manufacturing industry, is not driven by the technological obsolescence of its products
- Exploration, rather than technology, has been the key factor in maintaining the competitiveness of the industry.

Cost reduction can be divided into four main groups[28].

- increased scale of production
- mechanization and automation
- improved utilization of mining systems, machines, energy and materials, and
- process simplifications.

The principal effect of the drive for reduction in variable costs, primarily labour and energy, has been an increase in the capital needs of mining.

Up to the 1970s incremental innovations in mineral processing were sufficient to permit the treatment of ores of continuously lowering grades. However, pressure has now increased to increase recoveries and the response has been towards new unit operations, particularly chemical processing, on a large industrial scale.

Although cost reduction has also become more emphasized in the mineral processing stage more attention is being paid to increasing throughput and process control.

Comminution usually accounts for more than 50% of the total operating costs in the milling of most ores. This has led to such innovations as the stirred ball mill, high compression roller mills and high intensity centrifugal mills. The loss of energy inherent in over-grinding of minerals has been dealt with by the introduction of more efficient classification processes. Materials technology is also making a contribution in reducing costs due to wear.

The tendency for technological change is likely to intensify leading to increasing problems associated with technology transfer and the changing manpower and maintenance needs of more sophisticated equipment. Since the capital investment in technology will be considerable so will the pressure to optimize the performance and on-line status of the innovations. Thus the costs of new technology will have to be carefully measured against their benefits.

Risk evaluation

Minerals industry projects are, for the most part, designed on the basis of variables that are subject to extreme uncertainty[29]. This uncertainty is due, in part, to the nature of the variables and, in part, to the cost of obtaining sufficient information about them.

Risk analysis is a process of identifying the possible outcomes of decisions. Risk assessment is the quantification of risk in terms of probability and product. Processes for the evaluation of risk include the use of assessment matrices and simulation models.

A comparatively recent analysis of (Canadian) industries' approach to project evaluation suggests the following[30].

- Virtually all firms use some form of DCF calculation in evaluating projects. Their base calculations are often supplemented with sensitivity analyses for such key parameters as product price. Although some of the firms employed Monte Carlo techniques internally the results were not presented to senior management.
- Most firms used a long-run commodity price. There is, moreover, substantial agreement concerning the price. A possible reason for this coincidence is the tendency of most large companies to subscribe to the forecasting services of a small number of consultants.
- Most firms adjust for risk by using a hurdle rate, which comprises an upward adjustment in the discount rate. Although this hurdle varies across firms and across projects within firms the most common rate is 15%. Rates are adjusted upward to reflect extreme political risk and downward when there is competition to acquire properties.
- Most firms use real (uninflated) prices. These are often the prices prevailing at the time of the analysis.

The assessment matrix (such as the Leopold) plots activity type (on the x axis) against impact (on the Y axis). Each intersection is then further subdivided by a diagonal if the activity has an accompanying impact. Using a scale of 1 to 10 the magnitude of the impact is noted above the diagonal and the importance below the diagonal. The beneficial/detrimental effect of the activity impact is indicated by a +/- sign. The matrix can be further extended by allocating a probability to each activity/impact event.

Simulation is an attempt to mimic reality through the use of a system of algorithms. Probabilistic simulations replace 'best estimate values' with probability distributions. Thus financial criteria, such as net present value, or internal rate of return, are computed on the basis of distributions of values of technical and economic variables.

The simulation process can be extended to provide a more holistic approach to the evaluation of the venture in that the processes of mining and beneficiation can be simulated, as well as their attendant costs. The result is a model that will provide financial answers in response to changes in physical operating parameters, costs, commodity prices and financial structures.

In the simulation process one variable can be taken at a time and its values changed systematically. For each setting of the variable a corresponding value of the financial criteria would be obtained. This 'sensitivity analysis' is a common procedure in the spreadsheet evaluation of projects.

The development of simulation software now permits processes where all variables are allowed to change their values simultaneously in such a way that any correlation between variables are reproduced in their values. The values of each variable, in the process, are selected, at random, from distributions that provide a typical and expected distribution of values under the conditions envisaged.

This Monte Carlo simulation approach has several practical and conceptual problems[31]. It is, for example, extremely difficult to specify the underlying probability distributions associated with the individual variables as well as their interactions. Further, for the method to be useful, the sets of annual cash flow distributions need to be reduced to a single summary measure of value such as distributions of NPVs, or IRRs. A distribution of NPVs does not have a direct and easy interpretation.

It is most likely that the managers of mining projects will rarely stay within the bounds of the original design operating plans as per the original feasibility study. The comparatively long lives (up to 10 years and more) of mining ventures permits sufficient variability in the initial assumptions to ensure that the actual operating path will differ from the original plan. This particularly applies to strategies based on the ore reserves and commodity prices initially assumed in the study.

Dynamic programming, or decision tree analysis, explicitly recognizes that an investment project is not confined to a single accept/reject decision at the time of evaluation. Rather, that the project evolves in a sequence of decision and chance modes defined as follows:

chance modes; represent states of nature whose precise outcome is not known but can be described probabilistically

decision modes; occur at points where a chance mode is resolved and management needs to make a decision.

The values attached to a project, as a result of dynamic programming, tend to be higher than under a static DCF analysis. This is a result of the value attached to the greater flexibility of the process to act in response to the changing situations.

Although dynamic programming is capable of modelling such aspects of uncertainty as price volatility, ore reserve estimation, technology changes, etc., any realistic specification results in a large and complex model. This is usually dealt with by oversimplifying the model specifications by reducing the areas of uncertainty and stages of decision.

Modern Asset Pricing (MAP) is a form of decision tree analysis in that a scenario tree is constructed with a structure defined by the underlying risks[32]. In each state of the scenario tree the project cash flow is dependent upon project and market parameters as well as management alternatives. The risk-adjusted mean, of each payoff, is first determined. Each payoff outcome, used in the calculation of this mean, is weighted according to a risk-adjusted, as opposed to the 'true' probability distribution, across the states on the scenario tree.

The MAP valuation approach achieves the appropriate risk adjustment by the weighting of states between the risk-adjusted and 'true' probability distributions.

Conclusions

Risk analysis is a compulsory element of all stages of mine feasibility studies, planning and production.

The most promising approach to the quantification of project risk lies in the area of simulation and the development of methodology to adequately perform in them is growing.

The intervention of managers and planners, for the better control of risk, is becoming more established practise, both in the simulation and operational phases of a project.

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Green Topics

South African mining engineer wins St Andrews prize

A mining engineer from South Africa, whose research has taken him to some of the world's deepest gold mines, is the winner of the St Andrews Prize.

Daniel Limpitlaw, 27, picked up a cheque for $25,000 for his dissertation on reversing the damage done by early mining technology, which he claims is partly responsible for blighting the urban environment in many South African cities.

Launched in October 1998 by the University of St Andrews and international energy company Conoco, the St Andrews Prize sought practical solutions to environmental problems.

It attracted interest from 450 individuals and groups from countries as diverse as China, Pakistan, Canada, New Zealand, Germany, the UK and the United States.

Mr Limpitlaw, who received his award at a ceremony in Parliament Hall, St Andrews today (Friday 21 May 1999) claims that, due to mining and the subsequent development of informal settlements, many South African cities have been left in a state of 'alarming environmental degradation'.

Giving an example, Mr Limpitlaw said, 'Johannesburg shows the effects of both mining and unsympathetic government policies. It developed haphazardly and rapidly from a mining camp into a city.

'As a result of conditions which were imposed during the colonial/apartheid era, many urban dwellers demonstrate a culture of acceptance of poor living conditions.

'Cities do not have the infrastructure to accommodate the flood of people from the rural areas. This lack and the land-hunger of the immigrants lead to unacceptable environmental conditions. People live on river banks below flood lines, on the perimeters of mine dumps, and any other available open land, unaware or dismissive of the dangers posed to them.

Mr Limpitlaw believes that donor funding should be directly targeted at environmental projects, but should not be diverted from other areas of funding.

He is also calling for First World representatives to be re-educated in the social, economic and political conditions of South African countries, an improvement in environmental education in schools and the creation of lobbies to pressure central government on housing issues.

Mr Limpitlaw is a lecturer in Environmental Engineering and Geographic Information Systems at the University of Witwatersrand, Johannesburg. He received an MSc in mining engineering from Witwatersrand in 1993 and then worked in the Witbank coalfields to obtain a Masters Degree with a dissertation on the effects of pollution on a natural wetland. His current PhD research, which he hopes to complete this year, deals with environmental impact assessment using satellite data and geographic information systems.

The St Andrews Prize was judged by an international committee of trustees led by Sir Crispin Tickell, Convener of the British Government's Panel on Sustainable Development and former Ambassador to the United Nations.

The runners-up are Dr Jack Barkenbus from Tennessee and Ronnie Horesh, an English agricultural economist who works in New Zealand. ◆

The environment in the southern African city

Shortened version of the winning essay, St Andrews Prize, 1999

A short walk through any southern African city reveals alarming environmental degradation. City-dwellers are both creators and victims of these environmental conditions. This dual role can be clarified by examining the effects of the growth of informal settlements in southern African cities and industries such as mining.

Traditional African land-usage systems were custodial and environmentally sound. However, under colonial regimes, indigenous populations were usually crowded into cramped reserves on marginal land where resources were unable to meet the demands of the population. Reserve dwellers had no choice but to deplete natural resources. It was a matter of survival. As the exploitation of minerals and the concomitant growth of industries led to increasing urbanization, the environmental problems and practices already present in the rural areas spread to the urban areas.

Southern African cities are relatively young, many having started as mining camps less than a century ago. These nascent cities developed for the benefit of investors who profited from the mines but did not live on or near them. Little attention was paid to town planning, so the poverty of the urban population was matched by squalid living conditions. This situation was perpetuated and aggravated by subsequent political oppression or economic exploitation. From the establishment of the cities to the current day, political and economic conditions have ensured that waste and pollution from the mines, aggravated by the growth of industries and informal settlements, became integrated into the urban landscape.

In most cases the liberation of African states from Western political domination has done little or nothing to improve the situation. African economies are marked by mismanagement. Producers, previously unwilling to invest in the environment, are now either under pressure, or are prepared, to do so. This willingness means little, as collapsing commodity prices have reduced the ability of industries to correct the wrongs of the past or provide a proper infrastructure for the burgeoning population. This problem will become more acute, given the increase in the rate of sub-Saharan urbanisation.

As a result of conditions which were imposed during the colonial/apartheid era, many urban dwellers evince a culture of acceptance of poor living conditions. Cities do not have the infrastructure to accommodate the flood of people from the rural areas. The lack of infrastructure and the land-hunger of the immigrants lead to unacceptable environmental conditions. People live on river banks below flood lines, on the perimeters of mine dumps, and any other available open land, unaware or dismissive of the dangers posed to them.

Informal settlements, mostly spontaneous, are characteristic of southern African cities. These camps are an environmental affront in every respect—physically, biologically, chemically and aesthetically. The ignorance of most of the people living in these conditions makes them passive destroyers of the environment. They are unaware of the environmental hazards posed by their habitat and of the way in which they damage the environment. Compromised cityscapes are further degraded through environmentally unfriendly lifestyle practices. These practices arise largely from a lack of resources such as electricity, sanitation and efficient domestic waste disposal. Even where services such as electricity are provided, unsustainable practices such as the use of coal for domestic purposes prevails. Trees are felled, either to clear spaces, provide building materials or for use as firewood or conversion to charcoal. Charcoal manufacture is an environmental disaster in its own right as, for the convenience of smaller volumes of domestic fuel, half the calorific value of firewood is wasted. This loss of trees also reduces shade and pollution alleviation and exacerbates soil erosion.

Mining is a major component of the economies of most southern African states. Inevitably, mining was prioritised and also inevitably, it caused a significant degree of the environmental degradation which blights urban areas today. The best examples of interaction between mining and the environment are to be found in South Africa and Zambia, these being the countries with the largest contiguous mining regions.

Johannesburg shows the effects of both mining and unsympathetic government policies. It developed haphazardly and rapidly from a mining camp into a city, administered by a succession of white governments who showed little concern for urban workers. As the city's demand for land grew, communities were forcefully relocated to defunct mining areas. Coronationville, west of the city centre, is such a residential area. It borders on old mine dumps which were decommissioned in the 1930s.

When the Princess dump was decommissioned it was in the middle of the veld, and even its environmentally unfriendly design had little impact on the young Johannesburg. Urban sprawl and relocation forced people up against the dump. The original mining company had not envisaged such a possibility and the dump was neither designed nor decommissioned with this in mind. Houses were built right up against the retaining walls of the dump. The local authority, in spite of directives from the provincial Department of Minerals and Energy, allowed this development (Meintjes, pers. comm. 1999). Residents have been subjected to contaminated sludge washing into their homes. The dump is currently being reprocessed, so the locals are also exposed to heavy metal enriched sand and dust. Acid drainage from the dump seeps into a stream which runs through a small park, where it represents a recreational hazard to children. Current best practice is being applied to rehabilitate the dump, but over sixty years erosion and leaching have contaminated the surrounding soil, on which

houses have been built. Remediating this soil is practically impossible given the financial constraints of the local authority and the acute housing shortage in South Africa.

Elsewhere on the subcontinent, similar trends can be identified. Zambia gained independence in 1964, at a time when South Africa was still firmly ruled by the apartheid government. In spite of the fact that Zambia now had a government which had vested interests in promoting sustainable urban environments, the environmental policies remained as dismissive as those which were promulgated by the government in South Africa. In both countries the disregard for the marginalised people living in unsustainable environments continued.

From independence onwards, Zambian governments encouraged greater and greater copper production without requiring investment in urban sustainability. Cities were further affected by the drop in global commodity prices which removed the means of improving conditions in the urban areas.

In 1900, what is now Kitwe, Zambia's second city, was part of a featureless valley on the central plateau of southern Africa. This was transformed into one of the world's greatest copper-producing regions in just thirty years. Like Johannesburg, the young Kitwe was envisaged as a mining town whose sole function was to generate revenue for absentee shareholders. It also quickly exceeded this limited function and acted as a nucleus for the urbanisation of the surrounding countryside. Continuing population growth and urbanization in Zambia has rendered colonial town-planning ineffective, and suburbs in Kitwe and her sister cities on the Copperbelt swarm around old tailings dams. Like other contemporary tailings dams world-wide, these were not designed to reduce the impact on the ecosystem.

In Kitwe, impoundments were built in the sensitive headwater areas of streams. These polluted streams run through formal suburbs and then informal settlements which mushroomed on the outskirts of Kitwe. Children play in this water, which is rich in heavy metals. The same water is also used for washing, drinking and cooking. Poor sanitation means the streams are further polluted by sewage. Rapid and uncontrolled urbanisation has created an environment sensitive to pollution right next to the source of pollution. These polluted streams not only impact on their immediate environments but also join Zambia's principal water-source, the Kafue River, in this condition. The river transports metal-rich sediment some 700 km downstream (Bäckström and Jonsson[1996]), affecting countless other individuals and ecosystems.

In the early, 80s, before the new environmental awareness swept through the Copperbelt mines, an incident occurred along the Mwambashi River, a tributary of the Kafue and a major source of domestic and agricultural water in Kitwe. Mwale[1996] reports: '...chronic copper poisoning resulting in the death of about 270 cattle, 50 sheep and 140 goats from farms bordering the Mwambashi River—revealed that the source of copper were (sic) the sediments in the Mwambashi river bed, soil and grass from along the river'. This copper could only have come from the mines upstream.

Possibly the biggest impediment to sustainable environmental management in southern African cities is poverty. If this problem could be solved the problem of urban pollution would be greatly reduced and far more easily managed. However, the environmentalist has to work within this overarching restriction, and cannot afford to be intimidated by the fact that he can do little about it. Much can and must be done, on a micro-scale, to ameliorate urban environmental hazards.

To do this a reconsideration of both environmental philosophy and practice is required. The economic reality is that many projects in southern Africa cannot be contemplated unless funded by donor organisations. These donors often perceive African priorities in terms of First World circumstances and attempt to apply First World solutions in environments where they are neither affordable, understood, nor always correct. Donor funding should be channeled towards capacity building in regional tertiary institutions, many of which have skilled staff, but are constrained by funding cuts. First/Third World partnerships between donors and these institutions would result in more appropriate models for African conditions.

Two aspects of this partnership are important if resentment or accusations of neo-imperialism, and a resultant unwillingness to participate on the part of the recipient country, are to be avoided. Firstly, funds should be specifically allocated for environmental projects, and should not be diverted from other areas of funding. Secondly, First World representatives must arrive at a sound understanding of conditions, social, economic and political, in southern African countries, so that the objectives of projects are rooted firmly in the realities of the recipient countries. Parameters governing environmental stewardship have been developed in line with First World realities. New parameters must be developed for Africa. Environmental controls must be balanced against much-needed industrial activity or the resulting economic collapse would have a cataclysmic environmental impact as people attempt natural resource exploitation for a livelihood. This is likely to have a larger environmental impact than long-term pollution.

The building of capacity in tertiary institutions will influence the practice of environmental stewardship in the region. With affordable technology, many previously insurmountable problems can be solved, not least among these the huge information deficit.

It is at the level of local authorities that this information deficit needs to be addressed urgently. Administrators need to know where environmental hazards occur within their jurisdiction, and the change in the distribution of these hazards over time. They also need to be aware of the dangers associated with each of these hazards. This information will prevent the sanctioning of development in dangerous areas and will assist in prioritising the relocation of informal settlements which are under threat. Knowledge of such hazards must then be coupled with knowledge of sensitive environments, so that both the impact of development on the environment and that of the environment on developments can be ameliorated.

Local authorities need to be made accountable for development decisions. Currently much development takes place along the lines of expediency and vested interests. There is little strategic planning, only short-term solutions to cash-flow problems. Local authorities must accept their custodial obligation, both in terms of people and the environment.

Local authorities are also appropriate agents for disseminating education as they are in touch with local community organisations. Education—sadly lacking—needs to be introduced at school level and at the work-place for those out of the school system. This will empower citizens and convince them that they too have a vested interest in sound environmental practice. Knowledge will also mean they will be able to demand accountability of the local authority.

The cost of information gathering and processing is a major impediment to the realization of a sustainable city. In the past, this task would have required an army of officials to collect environmental data and another to process it. Today this task is considerably easier given the advent of powerful, cheap, personal computers and the sophisticated software packages designed to manage such geo-spatial data. These software-computer-operator systems are commonly referred to as geographic information systems (GIS). They permit the rapid processing of historical data collected by a local authority with subsequent updating by sophisticated modern data capture techniques such as satellite remote sensing. With a few PCs, some inexpensive software, a scanner and a digitizer, a small team of professionals can accomplish what would have required the entire budget of cities like Kitwe.

In this paper, two major aspects of urban pollution have been discussed—mining and informal settlements.

Large-scale mining is essentially an export industry in southern Africa and international trade requirements force mining companies to improve environmental performance. Environmental costs are acknowledged as a significant component of operating costs, and mines dedicate large sums to rehabilitation and the practice of minimum impact extraction. The prospect of re-mining old dumps also bodes well for the environment. Historically, commodities were produced using low-efficiency extraction techniques. As these processes improved, the residual metal concentrations in old dumps became valuable ore resources. The Nkana slag dump in Kitwe is proved to be the world's largest cobalt deposit, and mining companies vied to reprocess it. Old tailings dams around Johannesburg are disappearing into processing plants for recovery of gold. This is both profitable and removes major environmental hazards as new waste from reprocessing has to be disposed of in accordance with modern environmental standards. Thus, either through economic forces or local regulations, the mining industry is being forced to adopt environmentally sound practices.

Dumps that cannot be economically re-mined, given today's commodity prices, present an ongoing problem. Most of these dumps are the responsibility of the state, which doesn't have the necessary resources to apply best-practice stabilization techniques. The new capacity of tertiary institutions can be used to guide community-based rehabilitation projects, thereby reducing the high cost of professional environmental services. Recently, the South African Minister of Water Affairs and Forestry successfully used unemployed people to clear exotic vegetation from rivers. This approach can also be applied to dump rehabilitation, thereby alleviating urban poverty, improving environmental conditions and educating members of the community.

Lobbies must be formed to pressure central government with regard to the provision of housing. Currently most, if not all, southern African governments prioritise prestige and/or defence projects over housing, even where, as in South Africa, housing is a stated priority. Pressure groups need to enforce this priority, and this can only occur if the population is environmentally educated and thus empowered by a body of knowledge in terms of which they can call central government to account. A number of sub-economic housing developments have been established, but much more could be done to make these environmentally sustainable. These developments invariably arise on the outskirts of cities in virtual dust-bowls. Greening must be a mandatory part of each development. Planting of indigenous trees must be encouraged, this being environmentally sound. Parks are essential. A mentor system can be initiated, where local nurseries take over a new housing development, educate its inhabitants and subsidize the greening of the area.

Sub-economic housing, in spite of its temporary appearance, invariably outlasts high-rise buildings, which are demolished as soon as they are obsolete or can be replaced by a more profitable building. Yet far more money is spent on the design and building of a high-rise than on a housing development. An initial development phase which holds out the promise of an improved lifestyle will encourage residents to value and nurture the lifestyle. On an individual and small community scale, people need to experience, for themselves, that it is profitable (economically and socially) to care for the environment. With the support of central and local government, local business and the community, a tremendous difference can be made at comparatively little expense.

Urban landscapes are going to become increasingly important environments of human habitation in the next century. The need to ensure that these cities are sustainable habitats is paramount. Urban rehabilitation must be incorporated into the idea of an African Renaissance, or there can be no Renaissance. The prospect of the nightmare cities of science fiction is the alternative to urban nurture.

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