Mining is one of the oldest industrial activities. Its products are essential to modern civilization. Paradoxically, and despite a deep-rooted belief to the contrary, mining is not a lucrative industry—at least not in the aggregate. This assertion is true not only for recent years, one of the weakest periods in terms of metal prices, but also for a long time past. In 1776, Adam Smith said in *The Wealth of Nations*:

> “Of all those expensive and uncertain projects, however, which bring bankruptcy upon the greater part of the people who engage in them, there is none perhaps more perfectly ruinous than the search after ... mines. It is perhaps the most disadvantageous lottery in the world ... Projects of mining, instead of replacing the capital employed in them, ... commonly absorb both capital and profits.”

Despite the technical advances that have occurred in the intervening years, the profitability of mining still falls short of that obtained by most other industries. Figure 1 depicts the financial performance for three mining sectors and contrasts them with a global index.¹ The information is provided by Morgan Stanley Capital International. It relates to monthly price equity indices for the 21-year period from December 1979 to December 2000. The data is produced in a consistent way across all countries, encompassing 23 developed markets, 28 emerging markets and almost 6,000 companies.

Among the various factors that could explain the low profitability of mining, one seems crucial. It is the little attention that practical mining management of mineral resources

Juan P. Camus, member SME, recently joined Codelco-Chile as managing assistant to the vice president of operations, Huerfano 1270, OF. 714, Santiago, Chile 6500 544.

¹Share prices in the equity indices in Fig. 1 are properly adjusted for corporate actions such as stock dividends, rights offering, stock splits, spinoffs and the like. As share prices are expressed in constant US dollars, the series can be used as a performance metric of US$100 invested in these portfolios on Dec. 31, 1979.
gives to the unique economic principles that govern the exploitation of mineral resources, and their implications in the management of mines. As an attempt to mend this shortcoming and bring into more prominence the importance of the subject, a core managerial function is suggested — the management of mineral resources.

A business model for mining

Mineral resource management is aimed at making the exploitation of a mineral resource a more profitable business. It brings together the existing knowledge in management and mining. Management is seen as a tool to make this knowledge productive. Mining is seen as the business of separating the valuable content of a mineral deposit in the most effective and efficient way. The mineral resource management could be used in many of the world’s largest mine, such as Antofagasta Minerals’ Los Pelambres copper mine in Chile. The mine began operation in January 2000. In October 2000, it increased its copper production to 141.2 kt (155,600 st). Los Pelambres’ production has increased Antofagasta Minerals’ copper output to 167.7 kt (184,800 st), from 30.5 kt (33,600 st) in 1999.

A conceptual model that captures the essence of mineral resource management is presented in Fig. 2. It takes elements from the various management schools — from the classical approach to more recent management theories. The model considers the technology, market, mineral resource features and the legal framework as given factors that make up the business environment. The business performance is the dependent variable. It is determined by the actions resulting from two core variables that are under the firm’s control: the business strategy and the organizational design.

The business strategy defines the organizational goals and how the mining firm intends to respond to its business environment. Organizational design addresses such questions as how the mining firm is structured, how people are compensated, how performance is measured, and how people are hired, trained and developed. A central concern is the linkage of these two core variables. The assertion is that both aspects have to be perfectly aligned for the firm to be able to accomplish its goals. Indeed, the misalignment of both variables is claimed to be a major cause of the dysfunctional practices observed in many mining operations.

The business strategy

In tackling the business strategy, the organizational goal issue is addressed first. The stated goal is then coupled with the finite feature of mineral resources. This coupling sheds light on the intrinsic economic principles inherent in mining eco-
nomics. These principles are then linked with the technical variables that make up the mining strategy.

Organizational goals. The basic premise of this approach is that a mining organization comes to life when the entity that possesses the property rights over a mineral deposit mandates its exploitation. This decision suggests that the owner is better off by mining the deposit than selling or keeping it for future use. The surplus is what economists name residual income or, simply, economic profit. To operate in a competitive market, the overriding goal must be financial; otherwise, the mining organization would jeopardize its own existence and become a target for takeover.

The declared goal then is to maximize the economic value of a mineral resource. In mining, this only occurs when the ongoing economic profit and the long-term value are maximized simultaneously.

Mining economics. Mineral resources are usually referred to as finite, nonrenewable resources. This is in the sense that, for a particular deposit, there is a limited amount of the resource in the ground. And once removed, it cannot be replaced. The development of the optimum exploitation strategy, therefore, is a problem of dynamic allocation. This relates to the way in which, and the pace at which, the deposit is mined. In practice, it means dealing with certain technical variables that affect the life of the mine and, therefore, the economics of the business (the methods of mining and processing, the rate of extraction, the mining sequence and the selective cut-offs that separate the worthy part of the deposit).

Time is important in the analysis because a unit of resource extracted today means that less is available for tomorrow. This, in turn, implies that each period is different because the size of the remaining reserves changes as the deposit is exploited. This is illustrated in Fig. 3, which depicts an idealized ore body.

Let $C$ in Fig. 3 represent the cash flow that arises from the fraction $r$ of the resource $R$. For a given cost structure — which in this case depends on the business environment — the cash flow depends on the adopted strategy. This strategy, however, not only affects the cash flow $C$ but also the present value $V$ and time $t$, which is the time required to mine the fraction $r$. This, in turn, affects the point in time at which the following fraction could be mined. Because of this time dependency, the cash flow $C$ cannot be optimized in isolation from the rest of the deposit.

The solution of this problem calls for a special economic analysis.

\[ F = kV - \frac{\Delta V}{\Delta T} \]

where the first term is the capital gain foregone by being in production and the second is the change in present value as time goes by. Due to market volatility, the value of an in situ resource may change depending on the time at which the valuation is made. See Lane (1997) for a complete discussion of this subject.

Pioneers in this field are Gray (1914) and Hotelling (1931). The optimality principle is known as Hotelling's $r$ percent rule. It states that the resource should be consumed so that the rate of growth of value of the extracted resource should equal the discount rate $r$ ($k$ in this text). Honoring this rule, Lane (1997) stated that the optimum exploitation strategy of a mine based on a finite resource could be determined, at any stage, by maximizing the expression (1) with respect to the variables included in the exploitation strategy.

\[
\max \{C - Ft\} \]

In this expression, $v$ is the economic profit, or value added when mining the fraction $r$ of the resource $R$. It depends on the cash flow $C$ minus an additional fixed or time cost, $Ft$, to be borne by the operation. This is a no-
tional cost related to the discount rate \( k \), present value \( V \) and variations in present value as time elapses. The value \( V \) is also a decision variable. So a practical way to maximize simultaneously \( v \) and \( V \) is through a recursive procedure in which an arbitrary value for \( V \) is initially used as a seed. The later case study shows how it works in practice. Nonetheless, the following example illustrates how Hotelling’s rule operates in theory.

Suppose that the value of the deposit depicted in Fig. 3 is estimated to be $500 million, that the fraction \( r \) is mined in one year and that the cash flow \( C \) at the end of that year is estimated to be $60 million. If the price and costs are considered stable, the term \( \Delta V/\Delta T \) in expression (1) becomes null and the opportunity cost relates only to the financial loss of not receiving the proceeds had the value \( V \) been invested at the alternative cost of capital \( k \) during that year. Under these assumptions and for an annual discount rate of 10%, the value added \( v \) at the end of year one is $10 million. That is $60 million less the opportunity cost of $50 million, which would be the proceeds had the $500 million been invested at the alternative cost of capital in that year.

At the beginning of the following year, the value of the in situ deposit is only $490 million since $10 million was already subtracted in the previous year. Thus, if things remain the same for the second year, the value added \( v \) at the end of year two would be $11 million. This corresponds to $60 million less the opportunity cost of $49 million. In this case, the rate of growth of value of the extracted resource matches the discount rate. This is the principle that should be considered at the time of devising the whole mining strategy to exploit a mineral resource, although, in practice, calculations may be more intricate.

Mining economics specify the manner in which a mineral deposit should be consumed, to maximize the ongoing value \( v \) as well as the long-term economic value \( V \). The measurement of the former considers the cash flow generated by the exploitation minus an opportunity cost. These optimality principles are general and could be applied to any business based on a finite life asset. In mining, they should be coupled with the intrinsic characteristics of mineral resources.

**The mining strategy.** From the point of view of mineral resource management, the important feature of a mineral resource is the variability and distribution of the valuable minerals within its confines. Thus, the whole mining process can be regarded as the business of managing two fundamental, intertwined activities — the way and sequence in which the deposit is exploited and the progressive separation of its valuable content.

Mine planning is all about this process. So to deal with these activities, two types of mine planning are defined: strategic mine planning and tactical mine planning. The former deals with the controllable factors that largely determine the value of a mineral resource. The latter is concerned with the operational tasks to actually achieve that value. Both types of planning advance in tandem. So, while one sets up the mining strategy, the other follows and transforms it into specific production targets whose realization creates the feedback to update the strategic mine plans.

An important ongoing task in strategic mine planning is the geologic reconnaissance of the mineral resource. The other major tasks are the determination and monitoring of five variables. These include the method of mining, the processing route, the scale of operation, the mining sequence and the selective cutoffs that separate the valuable content of the deposit, until obtaining the final salable product. These variables are intertwined in that none of them can be determined in isolation. Moreover, all have to be established taking into account the opportunity cost discussed earlier. Figure 4 shows a model to link these strategic mine planning activities.

As the management of these variables occurs in a dynamic environment, strategic mine planning is indeed an ongoing process. It should be alive throughout the life of a mineral deposit but with a special emphasis during exploration and development. The product is a life-of-mine plan that indicates the origin and destination of tonnage and grades to be mined from the deposit.
This long-term mine plan is critical in the final feasibility study because it sets out the ensuing stages and eventually the value of the venture.

At the production stage, the variables within the scope of strategic mine planning should be reviewed periodically in accordance with their operational flexibility. The selective cutoffs, for instance, must be synchronized almost online with the market and ore exposure at the mine. The other variables must also be monitored and fine-tuned as the knowledge of the deposit increases and/or market conditions change. In a decreasing degree of flexibility, these variables are often the mining sequence, the mining and processing methods and the scale of the operation.

The design of the organization

To this point, mineral resource management has focused on the business strategy. This task is at the core of the mining business. But it may become difficult, perhaps even distorted, if the organizational issue is not properly addressed. This subject refers to the way people are organized to create the business strategy from scratch and later monitor and improve it throughout the mine’s life.

The proposition here is that the design of the organization matters in the achievement of organizational goals. It must support and be harmonious with the business strategy in at least four aspects. These include the organizational structure, the reward system, the technical and control systems, and the selection, training and development of people.

Organizational structure. The traditional mining organization is known as a hybrid organization. It is made up of line functional areas to carry out the technical activities, coupled with a divisional staff to execute nonline functions, such as human resource management and finance. In this form of organization, mine planning is often executed through a planning or engineering subunit, which informally interacts with other units (Fig. 5).

To perform the strategic tasks already discussed, the proposition is to create a special unit, working in an overlay structure within the traditional organization. This structure is an adaptive form that is common in consulting firms where technically proficient and trained professionals interact with few formal rules and little supervision. A schematic view of this form of organization along with its boundary is shown in Fig. 6.

The argument to support this proposition is based on the so-called Gresham’s law of planning. This law asserts that routine or operational activities always drive out nonroutine or strategic activities. This structure is then an attempt to highlight and move up certain critical tasks that are supposedly executed down in the organization.

One specific duty of this new unit is to develop the strategic mine plans and steer the mining of the deposit according to these plans. This task should be done in compliance with corporate objectives and in harmony with the state of the operations and available resources. To ensure the easy functioning of the group’s activities, it should be overseen by a standing committee led by the top executive and integrated by key members of all functional units plus the relevant staff (Fig. 6).

This organizational form overcomes the intrinsic flaw of the purely functional grouping — its inability to manage efficiently the complex problems of coordination, appraisal and policy formulation. Moreover, it also offsets the problems of the divisional grouping. This is the lack of capabilities to integrate technical aspects that are not general but specific to mining. In fact, this new form makes use of the advantages of both forms of grouping. This is because it uses functional groupings for the technical activities that require specialization and divisional groupings to manage the interactions among units.

Reward and penalty system. The reward and penalty system should support the business strategy and be consistent with the structure already defined. The business strategy indicates what the organization is supposed to accomplish, the capabilities that are needed and the kind of performance measurements that are required to be effective. The structure of the organization, on the other hand, specifies how the firm is supposed to divide the work and assign decision rights. All of these aspects should be in harmony with the pay system if the organization is expected to succeed in achieving its goals.

Payment schemes must be designed to support the desired organizational behavior. In practice, it means a pay system based on performance. This is a radical change with respect to traditional reward schemes. They are fixed and based on the premise that employees’ goals are aligned with organizational goals.

The proposition of linking the level of compensation to business performance is based on Jensen and Meckling’s (1976) agency theory. Among other things, it

<table>
<thead>
<tr>
<th>Year</th>
<th>Cut-off Grade</th>
<th>Mill Recovery (%)</th>
<th>Ore to concentrator Tonnage (t/d)</th>
<th>Concentrator Grade (%)</th>
<th>Mining Rate (t/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP</td>
<td>0.70</td>
<td>91.7</td>
<td>8,000</td>
<td>1.04</td>
<td>160,000</td>
</tr>
<tr>
<td>1</td>
<td>0.70</td>
<td>92.5</td>
<td>85,000</td>
<td>0.99</td>
<td>170,000</td>
</tr>
<tr>
<td>2</td>
<td>0.70</td>
<td>92.5</td>
<td>85,000</td>
<td>0.96</td>
<td>204,000</td>
</tr>
<tr>
<td>3</td>
<td>0.70</td>
<td>92.5</td>
<td>85,000</td>
<td>1.09</td>
<td>203,000</td>
</tr>
<tr>
<td>4</td>
<td>0.70</td>
<td>92.5</td>
<td>85,000</td>
<td>0.91</td>
<td>186,000</td>
</tr>
<tr>
<td>5</td>
<td>0.70</td>
<td>92.5</td>
<td>85,000</td>
<td>1.00</td>
<td>175,000</td>
</tr>
<tr>
<td>6-7</td>
<td>0.60</td>
<td>92.5</td>
<td>85,000</td>
<td>0.82</td>
<td>141,000</td>
</tr>
<tr>
<td>8-10</td>
<td>0.53</td>
<td>92.5</td>
<td>85,000</td>
<td>0.75</td>
<td>141,000</td>
</tr>
<tr>
<td>11-15</td>
<td>0.50</td>
<td>92.5</td>
<td>85,000</td>
<td>0.72</td>
<td>143,000</td>
</tr>
<tr>
<td>16-20</td>
<td>0.50</td>
<td>92.5</td>
<td>85,000</td>
<td>0.67</td>
<td>144,000</td>
</tr>
<tr>
<td>21-30</td>
<td>0.41</td>
<td>92.5</td>
<td>85,000</td>
<td>0.70</td>
<td>109,000</td>
</tr>
<tr>
<td>31-56</td>
<td>0.40</td>
<td>92.5</td>
<td>85,000</td>
<td>0.66</td>
<td>155,000</td>
</tr>
</tbody>
</table>
asserts that business people in organizations will not act to maximize the long-term economic returns unless an appropriate governance structure and economic incentives are implemented. The idea is to make managers behave as if they were owners. That is, they should show a sense of urgency for the short-term as well as a sense of vision for the longer term. This integrative view is essential at the time of devising the mining strategy. Converting managers into owners, though, is not straightforward. It implies the design of a reward scheme that balances four simple, although conflicting, objectives:

- Alignment. Giving management incentives to think and act like owners so they can choose strategies and investments opportunities that add value.
- Leverage. Giving management an incentive to keep an eye on the long term, take the necessary risks and make unpleasant decisions, such as closing, temporarily or permanently, an operation and laying off staff to maximize shareholder value.
- Retention. Giving managers sufficient compensation to retain them in the firm, particularly during periods of poor financial performance due to downturns.
- Shareholder cost. Limiting the cost of management compensation to levels within market ranges, to maximize the wealth of current shareholders.

In a mining company, reward schemes for certain key people can be based on the firm’s stock grants or stock options. If this is not possible, they could be linked to the creation of economic value.

In this case, to deter short-term actions that could harm economic value and to encourage the long-term view emphasized here, the proposition is to create a bonus account reserve. This is an individual’s notional bank account managed by the firm, which is intended to work as a savings account. The idea is to divert part of the compensation to this account so that the balance is at risk and can grow (or shrink) in tandem with company’s profits (or losses) before being withdrawn according to a prearranged schedule. The purpose is to filter large bonus swings and defer the impact of short-term improvements until it has been determined that the bonuses are associated with permanent changes in shareholder wealth.

It is important to stress that the underlying message here is that only money spurs the creativity of people in organizations. Rather, it is the sense of ownership of the enterprise to which they give their attention. This is probably the idea that Andrew Carnegie (1903) hoped to express when he wrote:

“I never see a fishing fleet set sail without pleasure, thinking this is based upon the form that is probably to prevail generally. Not a man in the boats is paid fixed wages. Each gets his share of the profits. That seems to me ideal. It would be most interesting if we could compare the results of a fleet so manned and operated with one in which men were paid fixed wages; but I question whether such a fleet exists. From my experience, I should say a crew of employees versus a crew of partners would not be in the race.”

Technical and control systems. The term “system” refers to the mechanisms to monitor the activities that any firm must have in order to be effective. But it also includes the special tools that are required to make possible the management of mineral resources. These are intended to facilitate the enactment, implementation and monitoring of the mining strategy.

The first group of systems is the technical ones. They are aimed at gathering, editing and working the ongoing geologic information, which are judged to be crucial to the planning of mines. Current commercial applications are not intended to solve all the multifaceted problems that usually appear in complex mining operations. But they can assist in the developing of mining strategies.

The other group is related to the ongoing financial information of the business and the individual’s bonus accounts. Almost all mining decisions included in strategic mine planning consider an opportunity cost. It is often estimated from the present value of future cash flows and the cost of capital. Both estimates must always be at the planner’s fingertips. As these concepts depart from generally accepted accounting principles, some adjustments to common practices are then required. Traditional financial reporting is the formal account of what the firm did in the past, whereas mineral resource management is more concerned with what the firm is going to do in the future.

Selection, training and development of people. The proper selection and training of people to perform mineral resource management is critical in the organization’s design. The reward system is important because it influences people’s
behavior in the organization. But it is also important because it conditions the type of people who remain and are attracted to the organization. The same can be said about the other variables of the business model. Thus, a good business strategy, a sound organizational structure, and a proper system to monitor and control the organization’s activities are all to be perfectly fitted if one expects to boost the initiative and creativity of people.

The need for training and development of people appears clear. Many mining firms, however, underestimate the training requirements of work redesign. And they fail to put in place appropriate systems and practices to support the higher training demands. Mining firms, therefore, have to be aware that training needs to extend beyond the startup phase and that people need to be taught skills that help the group develop over time.

One key aspect to execute mineral resource management is the availability of qualified people. This is because the perspective about the mining business as presented here is not as common as it should be. This contention is not only relevant to corporate mining but also to the educational institutions that prepare mining professionals and to government agencies that regulate the sector.

The mining industry, in general, focuses too much attention on technicalities. It gives less consideration to the managerial aspects of the business. This means that to take advantage of mineral resource management, the mining industry will first have to produce the right professionals. This is going to take some time. So in the interim, mining firms should look for the most suitable individuals and tailor specific training programs according to their needs.

In this regard, it is advisable that nontechnical people in the mining company acquire a general knowledge concerning the technicalities of the business. Conversely, specialized mining professionals, working in technical areas, should enhance their skills in economics, finance and business management. This is because the understanding of the mining business is easier when an economic way of thinking has already been nurtured.

In any case, this educational process should begin at the highest level in the organization. This is because the first step to implementing mineral resource management is to develop a commitment to these ideas among the senior executives. This includes a thorough grounding in the theory and the practicalities underlying the subject.

**Case study**

The following case study illustrates how the concepts discussed have been applied to optimize the selective cutoffs in a large-scale project in Chile. The project is a US$1.36-billion venture, commissioned at the end of 1999. It consists of a porphyry-type copper deposit to be mined by openpit, coupled with a conventional mill concentrator.

The study began in mid-1998 when the project was already under construction. A mine plan had been developed during the feasibility stage (Table 1). The cutoff grade policy at the mine had been optimized with the same principles presented here. The metallurgical variables, though, had not been included in the optimization. It seems that they were determined by traditional methods — divorced from the definition of ore at the mine and aimed at recovering as much as possible. The scope of work, therefore, was to carry out a simultaneous optimization of the cutoff grade at the mine and the cutoff particle size at the mill, to maximize the present value.

This exercise was very preliminary, with gross assumptions and without a thorough analysis of the potential bottlenecks at the plant. This is because it was the first formal attempt to apply these concepts to a real case. The primary objective was to show to the company’s management the impact of this optimization on the overall economics. After obtaining these order-of-magnitude results, the firm commissioned a more formal study that led to some changes in the design criteria.

Initially, the project planned an openpit mine extracting about 190 kt/d (209,000 stpd) for the first five years. Throughout this period, a cutoff grade of 0.7% copper would classify 85 kt/d (93,400 stpd) as ore, which was the mill’s design capacity.

The grinding circuit consisted of two parallel lines each having a semiautogenous grinding (SAG) mill coupled with two ball mills. The primary grind size estimated at feasibility was 55% passing -75 μm (-200 mesh), equivalent to a P_{90} of around 137 μm (about 100 mesh). According to pilot tests and certain design criteria, this particle size would allow an overall copper recovery of around 92.5% and concentrate grades of about 36% copper.

The bulk of the metallurgical tests supporting the feasibility study had been performed at a grind particle
The behavior of the ore above that range was unknown. Luckily, some favorable comments included in laboratory reports and the experience gained at an earlier small-scale operation provided useful indications regarding the continuing good recoveries at coarser grind sizes. Using this information, the relationship displayed in Fig. 7 was projected.

To make the comparisons easy, the economic data used in the study were similar to the ones employed in the feasibility study. The most relevant were:

- **Mining costs** — US$69 cents/t (US$63 cents/st) of material.
- **Processing costs** — US$2.73/t (US$2.47/st) of ore.
- **Annual fixed costs** — US$31.4 million/year.
- **Annual discount rate** — 10%.
- **Net copper price** — US$73 cents/lb.

Using these values plus the molybdenum content (not shown), the present value of the base case mine plan was calculated in US$2.46 billion, before taxes. This plan was broken down in years and the total material in these intermediate pits was tabulated in terms of tons of ore and average grade for different cutoff grades. Thus, the aim of the optimization was to find the optimum time to mine each of what was originally tabulated as 12-month fractions. The selectivity problem inherent in this openpit-mill configuration is shown in Fig. 8.

The time-quality problem in Fig. 8 arises when a fraction of the resource has to be mined. In openpit mining, all of the material in this fraction is extracted. But during the process, a cutoff grade defines the fraction of ore, which is classified as ore. The higher the cutoff, the lower the tonnage of ore and the higher the grade of that ore. Hence, the lower the tonnage of ore, the lower the time to process that ore. In the absence of operational constraints, upstream and downstream of the grinding circuit, a higher cutoff grade at the mine leads to a faster exhaustion of the deposit and a more rapid realization of the remaining present value $W$.

At the mill, a cutoff particle size at grinding determines the degree of liberation of the valuable minerals. The finer the particle size, the higher the liberation and the better the recovery thereafter. This occurs, though, at the expense of additional time and specific energy. And this, in turn, leads to a lower throughput and, accordingly, a longer mine life. At flotation, the separation of valuable minerals from the gangue is also controlled by time. The higher the flotation time, the higher the recovery. But this happens at the expense of a lower throughput and sometimes more diluted concentrates. In this exercise, however, there was no evidence of this problem so this effect was not considered.

Each fraction should be analyzed in terms of value added for each pair of cutoffs (a cutoff grade at the mine and cutoff particle size at the mill). The attainable value added is computed for the given capacities and the maximum value is picked. Table 2 shows an intermediate iteration for the first fraction of the deposit (year one in the base case), when the present value of the operation was yet being increased to about US$3 billion, before taxes.

This first fraction corresponds to about 62.5 Mt (68.9 million st) of material that produced a value added of only US$26.9 million at feasibility, when it was cut at 0.7% copper at the mine and 137 µm (about 100 mesh) at the grinding circuit in the mill (92.5% recovery).

In contrast, when the cutoff grade at the mine and the primary grind size P80 at the mill are set at 0.6% copper and 300 µm (50 mesh) (85.1% recovery), respectively, the value added rises to US$107.7 million. In this case, though, the time $t$ decreases from 1 to 0.71 years and mill throughput increases from 85 kt/d (93,700 stpd (31 Mt/a or 34 million stpy)) to 131 kt/d (144,400 stpd (47.8 Mt/a or 52.7 million stpy)).

The same procedure should be repeated for the following fractions until the mine is exhausted. Iterations cease when the present value stabilizes. In this case, it

### Table 3

<table>
<thead>
<tr>
<th>Year</th>
<th>Cut-off Grade (%Cu)</th>
<th>Mill Recovery (%)</th>
<th>Ore to concentrator Tonnage (t/d)</th>
<th>Concentrate Grade (%Cu)</th>
<th>Mining Rate (t/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP</td>
<td>0.70</td>
<td>91.7</td>
<td>8,000</td>
<td>1.04</td>
<td>160,000</td>
</tr>
<tr>
<td>1</td>
<td>0.60</td>
<td>85.1</td>
<td>131,000</td>
<td>0.96</td>
<td>263,000</td>
</tr>
<tr>
<td>2</td>
<td>0.60</td>
<td>85.1</td>
<td>131,000</td>
<td>1.03</td>
<td>314,000</td>
</tr>
<tr>
<td>3</td>
<td>0.60</td>
<td>85.1</td>
<td>131,000</td>
<td>0.90</td>
<td>248,000</td>
</tr>
<tr>
<td>4</td>
<td>0.60</td>
<td>85.1</td>
<td>131,000</td>
<td>0.88</td>
<td>240,000</td>
</tr>
<tr>
<td>5</td>
<td>0.58</td>
<td>85.1</td>
<td>131,000</td>
<td>0.84</td>
<td>221,000</td>
</tr>
<tr>
<td>6-7</td>
<td>0.54</td>
<td>85.1</td>
<td>131,000</td>
<td>0.75</td>
<td>228,000</td>
</tr>
<tr>
<td>8-10</td>
<td>0.51</td>
<td>86.3</td>
<td>131,000</td>
<td>0.72</td>
<td>230,000</td>
</tr>
<tr>
<td>11-15</td>
<td>0.43</td>
<td>85.1</td>
<td>131,000</td>
<td>0.67</td>
<td>192,000</td>
</tr>
<tr>
<td>16-20</td>
<td>0.34</td>
<td>85.6</td>
<td>128,000</td>
<td>0.67</td>
<td>186,000</td>
</tr>
<tr>
<td>21-30</td>
<td>0.25</td>
<td>92.9</td>
<td>82,000</td>
<td>0.62</td>
<td>133,000</td>
</tr>
<tr>
<td>31-51</td>
<td>0.25</td>
<td>93.6</td>
<td>81,000</td>
<td>0.62</td>
<td>131,000</td>
</tr>
</tbody>
</table>

### Table 4

<table>
<thead>
<tr>
<th></th>
<th>Investment (MUS$)</th>
<th>Present Value (MUS$)</th>
<th>Net Present Value (MUS$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base Case</strong></td>
<td>1,360</td>
<td>2,460</td>
<td>1,100</td>
</tr>
<tr>
<td><strong>Optimized</strong></td>
<td>1,460</td>
<td>3,170</td>
<td>1,710</td>
</tr>
<tr>
<td><strong>Difference</strong></td>
<td>100</td>
<td>710</td>
<td>610</td>
</tr>
</tbody>
</table>
occurred at US$3.17 billion, before taxes. The final iteration gives rise to the optimum cutoff policy for the grades at the mine and the grinding size or overall recovery at the mill. Table 3 presents the optimized mine plan.4

As can be seen from the optimized mine plan, the cutoff grade policy at the mine is slightly lower compared to one in the base case. The declining policy honors the fact that the present value decreases as the deposit is mined and so does the opportunity cost. The same premise is valid for the primary grind size, which in the optimized mine plan varies from 300 µm (50 mesh) in the first years to around 100 µm (about 140 mesh) toward the end of the mine life. This allows mill recoveries ranging from 85.1% to 93.6% and mill throughputs from 131 to 81 kt/d (144,400 to 89,300 stpd) for the same period. The production rate at the mine had to be adjusted to support the higher mill rates. This was done by keeping unchanged the preproduction period (the same at feasibility) and liberating the mine restriction thereafter.

The added investments required to the mine-mill configuration as designed at feasibility were estimated at US$100 million. And the gain in net present value due to the optimization was estimated to be about US$610 million, before taxes. A summary of these economic results is presented in Table 4.

These results shed light on several studies that were developed in parallel with the construction. Among these are metallurgical tests carried out in Chile and in Canada, an analysis of the main bottlenecks in the concentrator, a study on cost classification and studies on market forecasts.

The approach presented here enabled the company’s management to improve the mine plan and create substantial shareholder value. Throughout 2000, the company progressively increased the treatment of ore, reaching 106.2 kt/d (117,000 stpd) during the last quarter. The metallurgical recovery for the same quarter was 92.2%, much higher than anticipated. For 2001, the throughput is planned to be around 105 kt/d (115,700 stpd). And after some minor investments in the plant (US$24 million) a rate of 114 kt/d (125,600 stpd) is being considered.

With hindsight, it now can be argued that this way of managing the deposit could be partly responsible for the outstanding equity performance of the controlling corporation. The price of its shares (listed on the London Stock Exchange) was trading at a consistent level during the course of these studies. After these preliminary results were released and as construction progressed, the price began to climb. It reached a record that almost tripled this initial level toward the end of 1999 when the operation started. As of October 2001, the shares continued to trade at about three times this initial level.

Conclusions

This article has been aimed at making mining a more challenging and profitable activity. The approach described here seems appropriate for this purpose because it could serve as a tool to reveal the value that is inherent in mining, but which is unseen under the current paradigms.

Perhaps the most significant fact that unfolds in this article is the proper definition of profit in mining. As shown, profit or value added is not the value attributable to an in situ mineral resource, which the owner can realize even without mining. Rather, it is the value that miners add to the in situ resource value by the use of their ingenuity and intelligence. To succeed in this task, mining leaders must realize that mining is a peculiar business that requires an extra managerial function — the management of the mineral resources. The market will reward those companies that not only work harder but above all, mine smarter.

References

Camus, J.P., Management of Mineral Resources: Creating Value in the Mining Business, to be published by the Society for Mining, Metallurgy, and Exploration, Littleton, CO.


MINING ENGINEERING    JANUARY 2002    25