Management of Mineral Resources

Creating Value in the Mining Business

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On the Cover: Chuquicamata Mine, Chile. Photo by David Tutton.

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Foreword

INTRODUCTION

In this book, management is defined as the process of generating plans and supervising their implementation. For a mineral resource, these plans relate to a strategy that determines how the resource is to be exploited. The process has two important aspects—one is the organizational setting within which it occurs, and the other is the set of techniques available for the analyses. Ideas in both areas have evolved rapidly in recent years and this book presents an authoritative review of the current state of the art.

The author, Juan Camus, is well qualified for this undertaking. He gained his practical experience in Chile when the country was achieving phenomenal economic growth and its copper mining industry was leading the world in expanding production and bringing new mines on stream. He worked first with Codelco, the Chilean national copper company and largest international producer, and then as the managing partner of a very successful private mining consultancy that participated in the planning of many of the Chilean operations during this period. Four years ago, Camus sold his interest in the partnership and set out to study and develop his ideas for a Ph.D. at Queen's University in Canada. This book is the result.

ORGANIZATION

Historically, mine planning has been viewed as an engineering function largely concerned with the design of a hole in the ground and the logistics of expanding it. The geological function supplied the data, the mineral processing function extracted any constituents of value, the sales function wrote the contracts, and the finance function arranged for the money. Although this demarcation followed the structure of the mining process, its rigidity inhibited the generation of well-integrated plans that required the cooperative participation of all the functions. All too often each function was concerned with defending or extending its own status within the organization, tending to pursue objectives not necessarily consistent with those of the organization as a whole. Throughputs, unit costs, recoveries, and longevity, rather than economic criteria, were considered of dominant importance.

For decades, this culture of rigid demarcation has been slowly yielding to international pressures and trends. Mining, as a global industry, is subject to forces similar to those faced by other major worldwide producers and manufacturers. With the decline of central executive authority, coordination has become increasingly important. To respond to these forces, an organizational pattern is evolving—one in which a strong central planning function is allied to delegated executive powers within a framework of targets and incentives. In his discussion of this subject, Camus recommends what he calls an "overlay structure," which is responsible for developing and modifying the strategic plan. By this he means a group that is not embedded in the routine structure, free from local vested interests, aware of the wider issues, and not necessarily full time or permanent. He cites Codelco as an example. Codelco's huge financial improvements can be attributed, at least partly, to its management policy of seeking consulting assistance to review its mine plans. The premise of this approach is that consultants form an overlay structure with no routine constraints. In addition, they have a powerful motivation because their fees and future assignments depend on their success. However, the relationship between Codelco and certain local consulting groups is a special one not easily reproduced elsewhere.

The efficacy of good incentives is another of the author's more important themes. Although incentives can transform organizational performance, the difficulty in practice lies in developing a metric that measures results against corporate objectives. Many general systems have been proposed, some of which have been widely promoted by commercial groups. However, they often involve complex administration and accounting, and may rely on artificial inputs that detract from their effectiveness. In addition, they are usually designed for businesses with many products and production units. They do not adapt well to mining that is conceptually very simple, with a single production line and often a single product.

Nonetheless, many examples can be cited where special bonuses have achieved remarkable results. The idea of quoted shareholdings and bonuses in the form of options is attractive in certain circumstances, such as a group with several subsidiaries. An informed market provides as good an assessment of company worth as any other method. It also has the virtue of independence. On the other hand, it is suitable only for top management executives and is likely to be dominated by mineral price movements that are beyond their control.

TECHNIQUES

A plethora of techniques has followed in the wake of the computer revolution. Contrary to a layperson's first impression, mining is a complex subject starting with the intricacies of grade variations in the deposit; continuing with questions about how, where, and when to excavate; and ending with the problems of controlling an often elaborate extraction process. The development of computer systems in all these areas has greatly simplified what were once onerous manual tasks. But these systems have not simplified decision making about managing the resource. Instead, they have complicated these decisions by making much more detailed analyses possible and extending the range of planning studies.

The development with the most profound influence in this area is the set of techniques that has come to be known as optimization techniques. These techniques have their roots in the acceptance, now nearly universal, of present value as the single overriding criterion of financial merit. The present value criterion was first applied to the screening of capital investments, with a positive net present value implying a return that exceeded the cost of capital to the firm. Later came the realization that the criterion was relevant as a guiding principle throughout the planning process and not just as a final measure of merit. Any variation in the plan that incremented the present value was advantageous, and increments were cumulative. This realization opened the door to a range of mathematical techniques concerned with maximization, a very common problem in many areas of physics and engineering. The term "optimization" was adopted to describe the maximization of present value in a planning context. Since the term was introduced in the mining industry, its use has become so widespread that the question, "Have these plans been optimized?" is now asked almost routinely.

The term has a particular significance in mineral resource management because every deposit is finite. There is always a trade-off between the present and the future. This compromise can be measured with a mathematical analysis. It takes the form of an additional time cost, or in economic parlance, an "opportunity cost," which must be included in breakeven studies. This result has not only aided optimum planning but also given insight into how many factors exert their influence.

These ideas were first applied on a large scale in the late 1960s to the Bougainville Copper project in Papua New Guinea. The final feasibility study was preceded by conceptual studies that compared different mine capacities, processing capacities, mining sequences, and cutoff grades in terms of their effects on the estimated net present value of the project. The final design was chosen on the basis of these studies. And the mine was one of the successes of the 1970s.

Subsequently the ideas percolated slowly through the industry until their significance was realized in Chile's expanding copper industry. Camus, as one of the earliest to grasp their potential, was one of the pioneers of their application in many new areas. Some of the results were spectacular, adding hundreds of millions of dollars to the value of existing resources by redesigning pushbacks, reevaluating sequences, and recalculating cutoff grades and recoveries.

CONCLUSION

This stimulating and informative book is also timely because, although a mass of published material already exists, it is widely scattered—much of it in technical papers—and not readily accessible. Here the author has selected, summarized, and presented the most relevant information in a form that preserves the perspective of relative importance.

What of the future? Although nobody doubts the importance of the organization, it is a subject with an excessive ratio of theory to practice. The mining industry, which suffered a crippling recession less than 20 years ago, now faces another. Case histories of enforced organizational changes and of the structures that proved most robust and adaptable would be most valuable.

Because computer developments will no doubt continue apace, plans will be routinely optimized. However, prices remain a vexing question. By calculating the opportunity cost associated with the assumed price changes and including it in the optimization studies, plans can be revised against any expected pattern of price variation. This kind of analysis was adopted as the basis for deciding on production cuts at many of the Chilean mines in reaction to the severely depressed copper market at the end of 2001. Such analysis is valuable as an aid to understanding the merits of different tactics in response to different assumptions. But this not the same as deciding how best to plan when confronted by price uncertainty, and there is room for more theoretical development in this area.

Perhaps these are subjects for the next book?

Kenneth F. Lane
Poole, England

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CHAPTER 1

Introduction

BACKGROUND

Mining is among the world's earliest industrial activities and its products continue to be fundamental to modern civilization. The growing demand for mineral resources was a prime incentive for the expansion of ancient empires and still motivates mining corporations to cross borders in search of wider opportunities.

In everyday life the significance of minerals is revealed in many different ways. Any potentially rewarding circumstance, for instance, is termed a "golden opportunity" or a "gold mine." Similarly, memorable dates, prizes, and gifts are often associated with precious metals or valuable gems. Consider, for example, silver and golden anniversaries and diamond jubilees.

Paradoxically, and despite a deep-rooted belief to the contrary, the industry that produces such minerals is not as lucrative as people tend to assume, at least in general. This contention not only relates to the last years of the twentieth century—one of the weakest periods in terms of metal prices—but to the distant past as well. In *The Wealth of Nations,* Adam Smith (1776:606) wrote:

> *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, together with the ordinary profits of the stock, commonly absorb both capital and profits.*

Despite the vast technical advances that have occurred in the intervening years, the mining industry's position has not improved. Instead, it seems to have deteriorated, which becomes evident when we look into mining and metal performance indices and compare them to more global indices. In this respect, Figure 1.1 illustrates the performance of three mining sectors and contrasts them with a global indicator called the World Index. Morgan Stanley Capital International (MSCI) supplied the figures, which relate to monthly price equity indices for the 21-year period from December 1979 to December 2000. The information is produced in a consistent way across all countries, encompassing 23 developed markets, 28 emerging markets, and almost 6,000 companies in all.

So far, the industry's strategy for coping with this problem has been focused mainly on controlling production costs. The preferred cost drivers have been the quest for new technology and the pursuit of growth.

In the first case, many mining companies have centered on the use of innovative technology, although generally without a thorough analysis of its ultimate benefit. Moreover, some mining firms also allocate considerable resources to the development of new technology whose underlying purpose is to reduce costs.

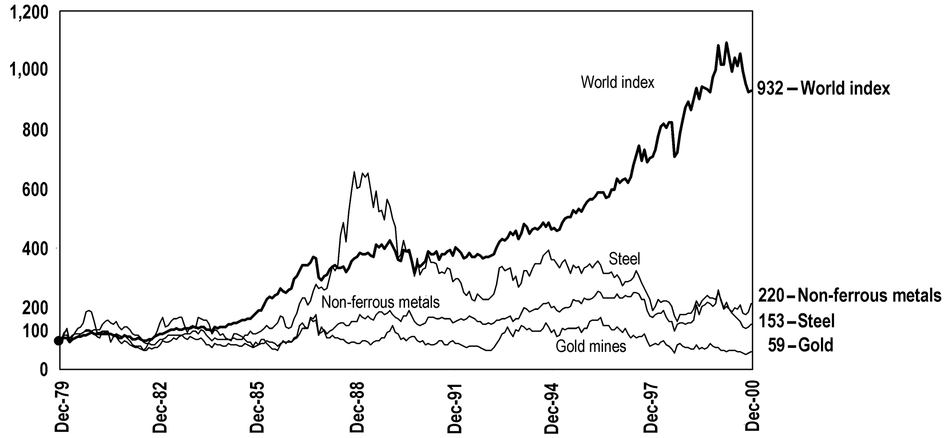

FIGURE 1.1 Mining and global price equity indices[1]

When growth is being pursued, the strategy is to gain a market share on the premise that, in mining, size matters. The "bigger is better" notion, which has been ingrained in business since the industrial revolution, has been integrated into mining as well. Big is viewed as desirable because of economies of scale, among other advantages. Total costs can thus be reduced by the expediency of distributing fixed costs over a larger output. The increase in market share, however, has been achieved not only through marginal investments in existing operations, but also through mergers and acquisitions.

Although both approaches have effectively reduced costs, they have not brought the industry higher returns. Instead, they have caused a downward trend in metal prices, which has hurt the sector's performance even more. In effect, in the quest for decreasing costs, mining companies have delivered their products at increasingly lower costs, which have been reflected in lower market prices for their commodities.

The cost strategy is based on the concept that single producers cannot influence prices in free markets, so the only way for them to compete is by continuously pushing production costs down. Indeed, it is becoming commonplace to see mining producers ranking themselves according to their relative cost position in the industry, with those who happen to be in the lower quartiles being highly rated. Worse yet, many firms pride themselves on being among the largest or lowest cost producers, relegating objectives such as shareholder value as a mere consequence of the previous conditions.

In pursuing such inadequate objectives, some mining companies even tie employee compensation to cost indexes or production targets. As a result, goals are frequently achieved, although many times through nonprofitable investments, such as dubious developments, untimely expansions, and even reckless mergers and acquisitions—put simply, at the expense of shareholders.

This curious behavior may be the result of the way companies account for these expenses. In mining, almost all these capital expenditures are not part of the income statement. For this reason, they do not increase but usually reduce operating costs.

1. Share prices in MSCI indices are properly adjusted for corporate actions such as stock dividends, rights offering, stock splits, spin-offs, and the like. As share prices are expressed in constant U.S. dollars, the series can be used as a nominal performance metric of $100 invested in these portfolios on December 31, 1979.

However, the productivity of that capital, which is what really matters, is not always satisfactory. There is room for these counterproductive actions because such investments are generally financed through equity or retained earnings, meaning that the cost of this money does not appear in the balance sheet. Under traditional performance measurements, then, people who make or influence decisions are perversely induced to make use of money as if it were actually free.

A similar behavior occurs when using the main asset of the mining firm—the mineral resource. As its true economic value does not commonly appear in the balance sheet either, the cash flow generated by mining rarely exceeds the opportunity cost that could be realized if the deposit were sold and the proceeds invested elsewhere, at the company's cost of capital.

All these problems, even the failure to notice the opportunity cost, appear to come from inadequate methods for managing the exploitation of mineral resources. In effect, mining is traditionally viewed as a mere cost-based activity whose fate is ultimately determined outwardly by market considerations.

In contrast to this traditional view, the approach presented here regards mining as a manageable business activity, with its performance largely determined by the managerial knowledge applied to its conduct.

OBJECTIVE AND SCOPE

As discussed, despite mechanization, automation, and other technical advances, the aggregate profitability of the mining industry still falls far short of that realized by most other industries. The factors that could explain this low financial performance can be conveniently classified as exogenous and endogenous. The former are beyond industry's control, such as inhibited international competition and the increasing substitution of mining products. The latter can be managed within the industry, such as global marketing to stimulate the demand for mineral products and the enhancement of management practices to improve production effectiveness.

This book is concerned only with the analysis of some endogenous factors that influence production effectiveness. In fact, the approach developed here comes to light on the conviction that mining performance can be substantially improved if more managerial knowledge were put into enacting the strategy to exploit a mineral resource. The objective of this work, then, is to formally devise a holistic method to optimally manage the exhaustion of a mineral deposit.

The methodology, which will be called the "management of mineral resources" from now on, brings together the existing knowledge in the fields of management and mining. In dealing with these two subjects, the main purpose here is not to present an exhaustive review of the literature or a compilation of the findings in either area. Instead, more emphasis is put on developing an integrated theory that makes sense of the very nature of the mining business and conceptualizes the challenges inherent in exploiting mineral resources. More precisely, the idea is to provide an analytical framework that traces the level of analysis, the variables to be taken into consideration, and the ways in which these variables can be accounted for in a systematic manner.

Management is seen as a discipline with historical roots in the need to enhance the profitability of business organizations. Therefore, the purpose of using management theory in mining is to learn how the existing knowledge in various disciplines can best be applied to improve results. On the other hand, mining is recognized as a cyclical business activity. Because of the finite character of mineral resources, unique economic principles should be applied to determine a complete optimal consumption policy. The goal here, therefore, is to combine these two fields and devise a mining strategy that will generate maximum profit from the consumption of the deposit. The entire life cycle of the mining business encompasses five successive stages—prospecting, exploration, development, production, and closure. To limit the scope of work described here, it will be assumed that the mineral deposit already exists and its exploitation seems attractive under the prevailing market conditions. The prospecting stage and the activities leading to discovery of the deposit are outside the scope of this work. The main question, therefore, is how to deplete a mineral deposit so that it delivers the maximum wealth to the owner.

Put another way, this study emphasized that it is one thing to discover a mineral deposit, but quite another to mine it and earn money exceeding that obtainable by selling the deposit and investing the proceeds in a similar-risk portfolio.

It is important to point out that after a mineral deposit is discovered, an exploratory stage follows, with the purpose of further delineating its geologic characteristics. This stage, here called "supplemental reconnaissance," results in a more reliable assessment of the deposit's real potential. If the supplemental reconnaissance is promising, a development stage follows. It consists of ongoing metallurgical tests along with engineering works that evolve from an initial scoping study to a final feasibility report. After firm approval, government authorizations, and financial arrangements, construction begins. Henceforth, on commissioning (the end of the construction phase), the operating stage begins and continues until eventually no additional resource can be extracted at a profit. This initiates the last stage, which is concerned with the closure and post-closure activities.

One way or another, the mineral deposit is present in all these stages so the objective of mineral resource management is to provide a framework for making the best possible decisions about how to exploit the mineral deposit.

Mineral resources management does not aim to solve the problem of distributing wealth among stakeholders. It intends only to ensure that the depletion is made in the best interest of the owners, which for this purpose is presumed to be pecuniary.

STRUCTURE OF THIS BOOK

The framework proposed here uses elements of management science to integrate the economics of mineral resource use and the theory of the firm. Following this introduction, Chapter 2 reviews the concept of management along with its practice and evolution in business organizations. This review is undertaken to clarify the definition of management and explain the context in which the term is employed here. At the end of the chapter, the amalgamation of mining and management is formally outlined. This includes the development of a conceptual model that gives shape to mineral resource management and sets the stage for subsequent chapters.

Chapter 3 examines the economics involved in the use of finite, nonrenewable resources such as mineral deposits. The goal is to use tools of economic theory to derive a set of principles for the optimum consumption. An important result of this analysis is the definition of an explicit metric to measure the true ongoing value that is created as the resource is extracted.

In Chapter 4, the optimality principles developed earlier are applied to determine certain critical variables of the mining business. Among these are the method of mining, the processing route, the scale of operation, the sequence of extraction, and the selective cutoffs that progressively separate the valuable fraction of a mineral resource. This work constitutes the basis of the mine planning process, which for this purpose is broken down into strategic mine planning and tactical mine planning. The most crucial of these, strategic mine planning, is then expanded to reveal how the critical variables within its scope should be managed to create value in extractive mining businesses.

Chapter 5 deals with the organizational factors that are essential to success when the preceding framework is implemented. In many respects, this is the most vital function of management, although this is often neither acknowledged or even appreciated in mining. The idea is to use organization theory to suggest ways in which mining organizations can be created or changed to incorporate the function of mineral resource management. The ultimate goal is to replace intuitive theories of organizations with ones that have been derived scientifically and systematically; that is, by looking at relationships with an eye to attributing causes and effects, and basing conclusions on scientific evidence.

Chapter 6 presents the main conclusions of this work and offers some insights aimed at enhancing policy formulation at corporate mining, government organizations, and institutions of higher education.

All costs in this volume are expressed in U.S. dollars and denoted by the symbol $, unless otherwise indicated.

CHAPTER 2

The Concept of Management

Concern with management in business organizations began with the advent of the industrial revolution that spanned the eighteenth and nineteenth centuries. Management theory arose as a tool to help administer the large and complex organizations that suddenly emerged as a result of the technological changes of that period. Now, effective management is considered the main resource of developed countries and probably the most needed resource of developing ones.

To be precise about the meaning of the term "management" and to circumscribe it within the scope of this study, this chapter first deals with its definition, as well as with some semantic problems. It then outlines the evolution of modern management, and finishes by addressing the structure of the proposed integration between management and mining.

DEFINITION OF MANAGEMENT

The word management is often used loosely and with a variety of meanings. It can denote a subject, a rank, or even activity, producing confusion. As a subject, management is defined as a cumulative body of knowledge that provides insights to make the available knowledge productive. Peter Drucker (1993) regards management as the act of "supplying knowledge to find out how existing knowledge can be best applied to produce results." However, "the management" is also used to designate those people who occupy positions of authority or manage organizations. As an activity, management is usually defined as "a process of getting things done by people who operate in organized groups" (Koontz 1962). Drucker's meaning will mainly be used in the course of this study. Nonetheless, an understanding of the various uses and definitions of the term should certainly help to eliminate miscommunication during management-related discussions.

When mining is related to management as a subject, it can be argued that today there is a great deal of knowledge about the economics of and techniques for exploiting mineral resources. However, this knowledge is not productive because it has failed to provide results. This leads to the conclusion that what the mining industry may need is not more technical knowledge about how to extract metals at lower costs, but just sound management that makes the existing knowledge productive.

THE EVOLUTION OF MODERN MANAGEMENT

Although it would be readily agreed that management problems have existed since the dawn of organized life, most would also agree that the first attempts to elaborate a formal body of theory took place at the turn of the twentieth century, with the pioneering works of Frederick W. Taylor (1911) in the United States and Henri Fayol (1916) in France. Both identified productivity problems and personnel management as keys to industrial success and applied rigorous analysis to solve the two problems.

Scientific Management and the Classical Approach

Taylor's definitive studies were made at the Bethlehem Steel Company in Pittsburgh, Pennsylvania. His primary goal was to increase worker efficiency by applying what he called the four essential elements of scientific management:

1. The replacement of rules of thumb with a scientific design of the job
2. The careful selection and subsequent training of the workforce
3. The integration of job design and people by a suitable reward scheme
4. The equal division of work and responsibility between workers and management.

Even though the methods of scientific management associated with Taylor were supposed to apply to all aspects of the organization, they worked primarily on the shop floor, from the bottom of the organization up.

Unlike Taylor, Fayol focused on the high level of the organization's hierarchy and worked down throughout its whole structure. His insights are very useful for the purpose of this study, as he was educated as a mining engineer and nurtured his ideas about management during an outstanding career in the mining industry. It started in France, in 1860, when he was appointed junior engineer of Commentry pits, a coal operation owned by one of Europe's largest but totally disorganized firms—the Commentry-Fourchambault Company. Six years later, he became manager and in 1872, general manager. After that, in 1888, when the whole enterprise was on the verge of bankruptcy, he took the helm of the parent company and succeeded in turning it around to reach a solid financial position by the time he retired in 1918. He remained a director of the company until his death in 1925.

Fayol postulated that all industrial undertakings give rise to activities that can be split into technical, commercial, financial, security, accounting, and managerial. He conceived of management as a special activity concerned with forecasting and drawing up the business plan, assembling personnel, and coordinating and harmonizing the firm's resources to achieve this plan. This definition is the basis for Fayol's functions of management—planning, organizing, commanding, coordinating, and controlling. These functions are still considered a worthwhile division under which to study, analyze, and implement the whole management process. Over the years, this classical approach to management has been expanded, modified, and criticized by subsequent schools of thought. However, it is almost always possible to identify Fayol's ideas in these other management theories that have tried to build up a discipline of administration based on this tradition.

The main criticism of the classical school of management, particularly of the scientific management approach, has been that the human variable in the organization was not adequately integrated into the theory. In effect, in Taylor's scientific approach, analysis focused on the individual worker, seen as an isolated unit whose activities must be rationalized in the interest of maximum productivity. Moreover, in the "Taylorian" spirit, the individual is viewed as a mere instrument of production that can be handled as easily as any other production factor.

Human Relations and Decision-Making Schools

With the introduction of the behavioral sciences into the industrial scene, the managerial line of thought moved away from its previous formalism and took a more empirical and sociopsychological approach. The human relations movement, led by Elton Mayo (1933) and Abraham Maslow (1943), and the decision-making approach to organizations, pioneered by Herbert Simon (1976), Richard M. Cyert, and James G. March (1992), focused their attention on the impact of the organization's structure on various aspects of individual behavior.

From the perspective of the human relations school, the individual is seen as an agent with feelings and self-interested goals that often conflict with organizational goals. The worker is no longer perceived as an isolated psychological being but as a group member whose behavior is greatly controlled by group norms and values. Despite the humanistic flavor of this approach, its main concern is the study of how people behave in organizations, and its objective is their productivity. In this context, insights about working conditions and the informal aspects of the organizational structure are often seen as additional factors to consider when shaping managerial policies.

The same can be said about decision-making theory. The goal of this theory can be seen as an attempt to fill the gap between the rational elements of economists and management theorists and the nonrational aspects brought to light by the human relations approach. Eventually, the theory reemphasizes the rational aspects of the organization and furnishes a general framework that can account for both rational and nonrational aspects of behavior. In addition, this framework can achieve an integration of the human relations approach and the classical school, albeit at an individual level. The framework assumes that, when one looks at the organization as a whole, what holds true for the individual decision maker remains true for all decision makers.

Both these developments emphasize the social psychology of organizational behavior and focus on the individual level, consequently neglecting the whole organization and its environment. With this still-narrow perspective, the problems of social power and conflict, which arise when the organization is viewed from a broader perspective as a social system, are overlooked.

The Systems School

The systems theory of management, then, is an attempt to explain and predict the behavior of the organization—its people, structure, environment, and technology—not just by a single aspect of it (as in the previous movements), but as a collection of interacting parts that must be viewed as a whole.

The major contributor to this way of thinking is probably Talcott Parsons (1956), who described the organization as a social system, composed of various subsystems such as divisions and departments, embedded in a wider social system like a community or the society itself.

Parsons identified four basic requirements for survival of this system: adaptation, goal achievement, integration, and latency. Adaptation refers to procuring all the resources necessary to achieve organizational goals, resources that then, in turn, must be mobilized to reach goal achievement. Integration deals with the relationships among subsystems, and latency refers to the inner conditions within subsystems and their relevance to the larger system.

In this integrative view of the organization, Parsons viewed the dilemma of power as the problem of resource mobilization and the difficulty in making decisions for goal attainment.

In contrast, Melville Dalton (1959), a more radical proponent of the system approach, saw the organization itself in terms of power and conflict among the groups or subgroups. Based on his experience as a participant–observer in six firms, he painted a revealing portrait of the organizational structure in terms of conflicting cliques and their endless struggles to gain more power and ensure a greater share of organizational rewards. His study brought the daily political activity of the organization to the surface. This activity is completely hidden from the outsider or even from naïve theorists who base their findings only on interviews and questionnaires. This analysis shows, in a striking way, to what extent organizational members and groups may be primarily interested in the rational pursuit of their narrow interests and the consolidation of their own power positions, even at the expense of wider organizational interests. It also shows how this intense political activity is scrupulously and skillfully camouflaged so that the resulting policies appear to harmonize with the official ideology and the organizational code book (Mouzelis 1968).

Thirty years later, Robert Jackall (1989) confirmed this particular view of the organization in another reflective study intended to grasp the ethical behavior in several U.S. corporations. In a vivid and somewhat shocking manner, Jackall's analysis revealed the hidden part of corporate America and capitalism, and conducted a clinical autopsy on the crude practice of management.

In conclusion, it can be said that the systems approach has contributed to the development of management thinking in three major ways. First, it has shown that management must consider all the variables in the organization as a cohesive whole and not as separate items. Second, it has drawn attention to the importance of planning, as it has shown that formal organizations need a purpose, making it vital for managers to plan. And third, it has demonstrated that achieving the plan depends on monitoring actual results against planned results to correct any deviations.

The Contingency Approach

The contingency approach to management further illuminates the complex nature of the organization already emphasized by the systems approach, although in a more conditional context. Using this perspective, the study of organizations shifts from the search for the one ideal organization to the one that fits the task. By following this concept, the management style and organizational structure should reflect and evolve as the circumstances and environment of the organization change. Put another way, managers should use whatever method is best for the organization according to the circumstances at that particular time.

Advocates of this line of thinking are Henry Mintzberg and colleagues (1995), who reject the rationalistic approach to management because, in their view, it tries to explain how organizations *should* work rather than to understand how they *actually* work. Mintzberg contends that there is no one best way in management and that no prescription works for all organizations. He points out that "even when a prescription seems effective in some context, it requires a sophisticated understanding of exactly what that context is and how it functions." In other words, one cannot decide reliably what should be done in a system as complicated as a contemporary organization without a genuine understanding of how that organization really works.

On the other hand, Mintzberg criticizes the assumption that a strategy is first formulated and then executed, with organizational structures and control systems following obediently behind strategy. He believes that formulation and implementation are intertwined as complex interactive processes in which politics, values, organizational culture, and management styles determine or constrain particular strategic decisions. In fact, he compares strategists to potters, in the sense that managers are craftsmen and strategy is their clay.

Unlike the prescriptive or normative models, which stress that a coherent strategy requires everything to be thought through in advance, Mintzberg asserts that people may act and get ideas from their actions. Like potters when displaying a retrospective of their work, they sit between a past (of corporate capabilities) and a future (of market opportunities).

Some Contemporary Management Tools

Today, strategists and management practitioners have interpreted the corporate world in rather different ways. As a result, many management tools have emerged, the most popular being "total quality management," initiated by William Deming (1952); "management by objectives," introduced by Drucker, Smiddy, and Greenwood (1981); "benchmarking," linked to Robert Camp (1989); and "reengineering," connected with Michael Hammer and James Champy (1993).

The financial management tool known as economic value added (EVA) deserves some attention because of its resemblance to the framework proposed in this study. It emerged from the Modigliani-Miller propositions (1958) and agency theory developed by Michael Jensen and William Meckling (1976), and has been nurtured at the US management consulting firm Stern Stewart. Many people simply dismiss the idea and view it as another management fad. Other people, however, see it as a powerful tool aimed at helping companies navigate safely on the slippery slope of profitability.

The approach introduces a performance metric based on economic grounds rather than on accounting procedures. This special metric provides a common language for employees across the organization and allows management decisions to be modeled, monitored, communicated, and compensated in a single way. The performance measurement is based on the proposition that the firm's value is independent of its capital structure and ultimately depends on the value of the underlying productive capital. The market value of the firm is found by capitalizing its expected earnings by the appropriate cost of capital. Because this value is a stock measure, it does not solve the problem of grading ongoing performance. This obstacle is overcome with the EVA metric, which measures the continuous economic profit added to the business. Thus, for a certain period, the *EVA* is defined as the net cash flow produced in that period (C), minus the cost of capital (k) times the dollar value of the assets employed in the business (V) (Stern, Stewart, and Chew 1999):

$$EVA = C - k \cdot V \qquad \text{(EQ 2.1)}$$

It is worth mentioning that in most mining companies the main asset is the deposit itself, but this fact is rarely considered at the time of measuring the real economic value that is added as a result of the exploitation.

To generally address the compensation and incentive issues, the EVA framework makes use of the agency theory, which holds that managers will not act to maximize shareholder returns unless appropriate governance structure and incentives are implemented. Agency theory specifies incentive schemes to reduce agency losses coming from unaligned interests and thus safeguard the interest of the shareholders. Such schemes typically tie executive compensation and levels of benefits to shareholder returns, deferring part of the compensation to the future to reward long-term value maximization and deter short-term executive action that might harm corporate value.

It seems, then, that EVA fully approaches the two main concerns about the firm's performance determinants. On one hand, it places the value-creation notion as the compass of the business and defines a metric to gauge the ongoing true value generated by the firm. On the other, it addresses the incentive issue with innovative schemes, which mitigate the agency problems that occur when the interests of the employees (agents) and the interests of the shareholders (principals) are not aligned.

Nevertheless, as Jensen and Meckling (1999) also pointed out, "EVA is not a panacea." Like all single-period or flow measures, it fails to solve the capital value problem. This problem arises for projects where EVA in the early years is negative, but the future annual EVA of a project is sufficiently large to justify the investment on a net present value (NPV) basis. Managers evaluated solely on the basis of the current year's EVA are not likely to take on such projects. In these cases, the NPV is the appropriate value to maximize.

On the other hand, EVA, like all divisional performance measures, will likely fail to reflect shared costs and benefits (synergies) among different business units, despite the most ingenious transfer pricing system.

In natural resource projects and particularly in mining, however, there is another more important consideration to justify caution with the use of the single-period EVA metric. It has to do with the finite character of the resource and the fact that the exploitation eventually ceases. This feature has a key implication on the derivation of the optimum extraction policy and ultimately on the present value of the resource. A multiperiod optimization, performed over the whole mine life, is then required to maximize both the yearly value added and the NPV of the whole resource. This is the objective of Chapter 3.

CONCLUSIONS ABOUT MANAGEMENT THEORY

Contributions to the theory of management have come from many different sides—most importantly, business administration, organization, economics, psychology, sociology, and political science. Despite the variety of angles from which this discipline is analyzed and regardless of the point of view selected, management can always be seen as a process that is about planning (both for the short term and the long term) and about organizing all the available resources to achieve these plans. In addition, management is about leading, coordinating, and motivating people. And last but not least, it is about controlling all the processes in the organization to meet the firm's stated goals.

It is important to emphasize that business performance is the ultimate acid test of management. A company can only justify its continued existence and contribution to society by the systematic making of profits. As Milton Friedman (1963) once put it, "there is one and only one social responsibility of business—to use its resources and engage in activities designed to increase its profit so long as it stays within the rules of the game, which is to say, engages in open and free competition without deception or fraud."

Other results of management, such as a happy and contented workforce and efficient communication, are worthwhile in themselves, but if they are not utilized to produce economic results as well, management has been unsuccessful.

MANAGING MINERAL RESOURCE ASSETS

As briefly discussed in the previous section, management theory has been dominated by a concern for the management of people within organizations. In effect, the question of how to make workers more productive has stood as the basis for management practice since the advent of the classical approach. Yet such emphasis overlooks factors of production that can be managed. Although managing people within the mining company is essential, managing its mineral resources is often as critical to the firm's success.

In this respect, Koontz's (1961) ideas about integrating management with other disciplines are fundamental. He said that "management should be regarded as a specific discipline and other disciplines should be looked upon as important bases of the field. Under these circumstances, the allied and underlying disciplines would be welcomed by the business and public administration schools, as well as by practitioners, as loyal and helpful associates." He later stated that in approaching the clarification of management theory—which he saw as being in a state of mental entanglement—the theory should deal with an area of knowledge and inquiry that is manageable. It can be thought of as adding a surname to the practice of management—for instance, the management of mineral resources.

To advance in this line of thinking and develop a structure to link mining with management, this section begins with a brief discussion about the nature of the mining firm. Next, some ideas about the tasks and organization to be considered when performing this managerial function in mining are delineated.

The Nature of the Mining Business

The existence of a mining firm rests on the possession of property rights to exploit one or several mineral deposits. These rights, usually divisible and transferable, give the firm the privilege of the exclusive use of the resources. When a mining company has the property rights to mine a certain mineral deposit, the main question for the company is whether to exploit, sell, or hold the deposit for future use. Making this decision requires a thorough economic analysis of these three scenarios. Mineral resource management, then, can be seen as the discipline that deals with the required activities to support and make this decision.

A good way to look into the core concept of mineral resource management might be by analyzing the foundation on which previous decisions are made. Whether the deposit is a company discovery or an acquisition, the first task is to estimate its economic value. This means looking ahead, realistically assessing the future, and having the imagination to develop a mining strategy. If the resulting estimate is greater than the "market value," the option to sell is rejected, leaving mining or holding it for future use as the only two options.

It must be acknowledged that the market value is not an easy figure to obtain. In fact, it is almost impossible to arrive at a reliable estimate unless a bidding process is always open. This is perhaps one of the most serious drawbacks in the mining business because profitability has to be measured through estimates that may not represent the true value of the underlying asset. Keeping this difficulty in mind, the decision to mine or to continue operating a deposit suggests that there is no economic benefit to selling or preserving it for future use. In other words, the cash flow resulting from the exploitation plus the future cash flows surpass both the profit that can be obtained if the market value of the deposit were invested elsewhere, and the capital gain that could be realized if the deposit were kept on standby (appreciation).

This statement is fundamental, because to date the profitability of mining has usually been measured against the book value of physical installations, which has nothing to do with the market value of the asset that produces the rent. Worse yet, in many cases the comparison is made with no alternative at all; that is, by assuming a null value for the mineral deposit. Regardless of the condition of the deposit, whether in operation or on standby, these kinds of decisions must be analyzed continually as the deposit is mined, as the knowledge of it evolves, and as market conditions change. This ever-changing setting reinforces the dynamic character of this managerial function, which should begin as soon as a mineral deposit is discovered.

The Task and Organization in Mining

To clearly envision the scope of mineral resource management, it may be useful to draw attention to the profit drivers of what could be a totally externalized mining company. This mining concern's unit operations, such as mining, transportation, processing, and the like, would be executed by contractors. If these third parties operate in a competitive environment, which means that their costs fairly reflect the best market prices and thus the best business practices, the only controllable variables that could affect the company's earnings are those related to the strategy, known as the mine plan, to mine out and process the ore of the deposit. This dual job, the formulation and execution of the mine plan, is the ultimate goal of mineral resource management and an important instrument for creating value in mining enterprises. To succeed, the plan has to be formulated and implemented not in the traditional way prescribed by conventional management, but in the way described by Mintzberg (1987)—as a continuous process that cycles between action and thinking. Additionally, this process must involve people from other areas of the organization; strategy, in this case, is rarely formulated by an elite strategist but by the contributions of the many minds participating in the organization.

For the purpose of this analysis, the organization needed to accomplish this task should provide timely and efficient information so that the contractors can execute the mine plan. The organization will demand interaction with a variety of other disciplines: geology to characterize and update the knowledge of the deposit; mining engineering to devise the best exploitation method and designs; metallurgy to define the processing route and ensuing metallurgical parameters; finance to account for the firm's financial position (and ultimately the discount rate to be used in decision making); and marketing and sales to furnish the market input such as expected volumes and prices. This group will also have to work with representatives of other specific disciplines to obtain advice on legal, environmental, and political issues, among others. These advisers may either be part of the staff or hired externally. It is important to stress that choosing the design for this part of the organization is a crucial decision. It may directly determine what sort of problems shall be emphasized, how and by whom they will be considered, and so on. In doing so, it is useful to bear in mind the so-called "Gresham's law of planning," which stipulates that routine chases away nonroutine activities in organizations.[2]

If systematic considerations of strategic plans are considered vital for a firm's success, the organization should be designed to counteract this harmful effect. For example, a special planning unit devoted to nonroutine or strategic activities, which operates within an overlay structure above the traditional structure, could be created. This peculiar structure may take the form of a standing committee and function as a highly adaptive entity. This is common in consulting firms where technically proficient and trained professionals interact with few formal rules and little supervision.

This unit can be overseen by a permanent committee, chaired by the top executive, that integrates the leaders of each of the functions mentioned earlier. In fact, this part of the organization should be similar to the one required for preparing a feasibility study. The main concerns under this framework are the emphasis given to its integration and its cohesiveness, along with the way of rewarding its actions.

The previous framework—strategy formulation and strategy implementation—is not a new idea. In fact, Frederick Taylor (1911) got to the heart of the matter when he said, at the turn of the twentieth century, that productivity could be substantially improved if management would only show workers how to do the job better and then share the returns with them. He suggested that these joint aspects, the task and the bonus, "constitute two of the most important elements of the mechanism of scientific management."

The same two concerns can be placed into contemporary business parlance: How to create value and how to structure and reward the organization for success. Both continue to be the essential challenge of modern management. The following section elaborates on these two ideas and presents a holistic model that may serve as a conceptual framework for managing mineral resources.

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2. This is likely a variant of the original Gresham's law, which honors Sir Thomas Gresham, who founded the English Royal Exchange in the mid-1500s. He proclaimed: "Bad money drives out good" to assert that when two or more currencies are in circulation, people will hoard the one with the higher intrinsic value, thus driving it out of circulation.

A BUSINESS MANAGEMENT MODEL FOR MINING

The preceding discussion reveals that any attempt to model the function of mineral resource management inevitably leads to the measurement of business performance. For the moment, it is difficult to provide a precise definition for business performance, let alone determine how to measure it. At this point, it suffices to say that business performance is related to organizational effectiveness, which in turn can be defined as the degree to which an organization realizes its goals (Etzioni 1964). Hidden in this definition, however, are many ambiguities that severely curtail both research on the subject and the ability of management to grasp and use the concept. Nonetheless, with this succinct definition and no matter what goals, it is possible to advance in the job of identifying the elements that make mineral resource management an effective function.

The Elements of Effective Management

For years, researchers and practitioners in administrative sciences have studied and debated the key features of an effective organization and how they relate to organizational effectiveness. Today there is good agreement on these key features, although the way of assembling and pulling them together to achieve organizational goals continues to be a matter of discussion.

Strategy and structure has been the mainstay of strategic thought for decades. In fact, much of the earlier discussion about organizational effectiveness was focused on the following dilemma: should strategy follow structure or should structure follow strategy? After studying nearly 100 of America's largest business firms, Chandler (1962) concluded that changes in business strategy precede and lead to changes in an organization's structure. The acceptance of goals and strategy as determinants of an organization's structure was founded on the following assumptions, which are inherent in classical economic theory:

- The organization has a goal or goals toward which it drives
- It moves toward its goals in a rational manner
- The organization exists to transform economic inputs to outputs
- The environment within which the organization operates is given.

If these are valid assumptions, an organization's structure can be interpreted as the outcome of a rational process. "Structure is a means for attaining the objectives and goals of an organization. Any work on structure must, therefore, start with goals and strategy" (Drucker 1974). Structure is seen as a rational means by which inputs are translated into outputs. Thus, after having designed, formally planned, or analyzed the best strategy to use, the strategist's responsibility is to use the tools of structure and systems to carry it out.

In the intervening years, with the introduction of behavioral sciences into business practices and the advent of the contingent approach to management, these assumptions were questioned, and the approaches begin to take a different direction. Both management movements assert that different kinds of structures will lead to different kinds of strategy processes. The kind of process one might find in a small entrepreneurial company, for instance, may be quite different from what one would see in a large bureaucracy. Mintzberg (1987) stresses that strategy walks on two feet, deliberate and emergent. Strategy and structure are like two feet walking—one foot always precedes (and follows) the other. In other words, sometimes structure does follow strategy—if, for example, the organization can realize its strategy deliberately. At other times, strategy follows structure, as when an innovative organization shows an inclination to form emergent strategies. And sometimes an organization can change over time from one type of structure to another, creating a different strategy process along the way.

During the same period, other researchers and practitioners begin to identify a number of other variables as determinants of effective management. Strategy and structure were only two of these variables.

For instance, Peters and Waterman (1982) proposed "The 7-S framework," which includes systems, style, skills, staff, and shared values in addition to strategy and structure. Systems encompass all the procedures, formal and informal, that make the organization function. Style refers to the patterns of actions followed by managers, which are essentially manageable. Skills make up a firm's distinctive competency. Staff captures the fact that having and developing good people is critical to an organization's effectiveness. The final element of the framework is the shared values, which are the superordinate goals or the "culture" of the firm. This set of values and aspirations, often unwritten, goes beyond the conventional formal statement of corporate objectives.

In a similar way, Galbraith (1995) proposes another tool to put what he considers the critical elements of an organization in order. It is known as the "Star Model" because it has a pentagonal shape with a five-pointed star inside (see Figure 2.1). Each point of the star represents the features of an organization: strategy, structure, rewards, process, and people.

A finer examination of the earlier variables somehow resembles Fayol's functions of management, which are planning, organizing, commanding, coordinating, and controlling. These new models, however, have modified the language, the arguments, and the emphasis given to these variables to accommodate them to contemporary usage and prevailing circumstances.

A Proposed Model

The business model proposed to capture the essence of mineral resource management is a combination of the preceding ideas, though tailored to account for the particular fact of dealing with a mineral deposit. Figure 2.2 shows this model, where the dependent variable is the business performance. It is explained by the actions resulting from two core variables that are under the firm's control: the business strategy and the organizational design. These variables, in turn, depend on the business environment, which is beyond

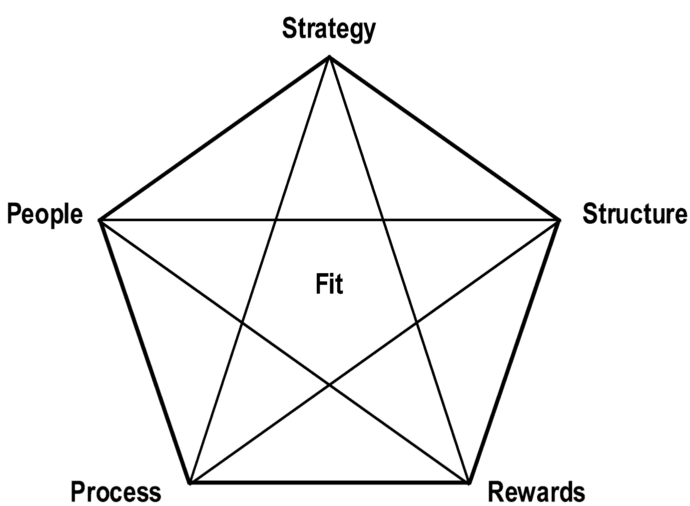

FIGURE 2.1 The Star Model

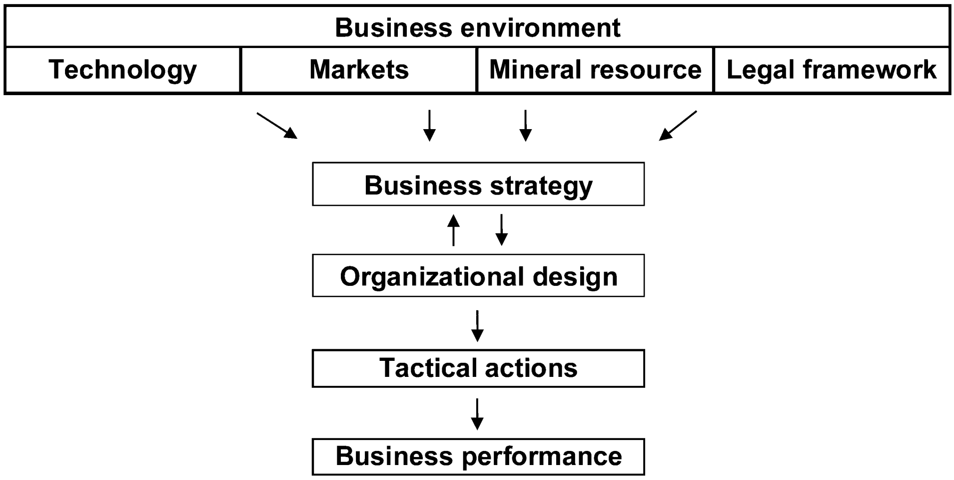

FIGURE 2.2 A proposed model for mineral resource management

the firm's control and includes the technology, the markets, the mineral resource, and the legal framework of the host country where the deposit lies.

The business strategy is the first cornerstone component of the model. It is, or ought to be, an organization's way of saying: "here is how we will create value." In doing so, the business strategy needs to define the kind of organizational goals that are required, the competencies that are needed, and the intended responses of the firm to its business environment.

The organizational design, on the other hand, addresses questions such as how the mining firm is structured; how people are compensated; how performance is measured; and how individuals are recruited, 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 if the firm is to accomplish its goals. Indeed, the misalignment of these variables is seen as a major cause of the dysfunctional practices observed in many mining operations.

It is essential to bear in mind that the analysis focuses here on the business level; that is, on the exploitation of a certain mineral deposit. The business strategy, therefore, applies to a mining firm whose only purpose is exploiting a mineral resource. It is the deposit and the mandate for exploitation that gives meaning to the organization. Simply put, without the mineral deposit, there would be no organization.

This clarification is vital because strategy at the corporate level may require a rather different approach. The question that corporate strategists must address is not "what must we do to exploit this deposit and compete successfully in this industry?" but a much broader question, such as "in which businesses should we compete?" For mining companies that operate only one mine, the business and corporate levels are the same.

The preceding model also sets the stage for subsequent chapters that examine in some detail each variable that, as indicated by the model, influences the company's performance. The remainder of this chapter discusses the first aspect of the business strategy, the organizational goals.

Organizational Goals

By definition, a business organization is created deliberately to achieve one or more specified goals. Despite this formal definition and the accent on goals that differentiates business enterprises from other types of spontaneous social units, there has been considerable difficulty in trying to agree on a single business goal and the corresponding performance measure. Yet there is consensus that this is the central theme in management theory. In fact, it is difficult to conceive of a sound theory of management that does not include the concept of business performance.

So far, the purpose of the business organization that has been emphasized is simply financial. For the mining firm that owns a single deposit, the objective already defined is simply to maximize both the ongoing economic value and the long-term economic returns coming from the actions taken on the deposit. As already argued, these actions could be selling the deposit, exploiting it, or adopting a wait-and-see stance. The tacit assumption behind this goal achievement is that it must be done at least in compliance with the rules and laws of the host country. However, when attempting to specify the exact meaning of the expression “ongoing economic value and long-term economic returns,” some complications arise.

The first consideration is risk. In business–and mining is no exception–it is common to observe that higher risks are usually associated with higher economic returns. In an open pit mine, for instance, a steep slope angle can be easily achieved to increase returns. However, this usually results in higher risk in terms of wall instability.

A second problem is related to the nonrenewable and finite character of mineral resources. Although this issue will be properly addressed in the following chapter, for the moment it suffices to say that long-term economic profit in mining is usually the product of a unique and deliberate strategy that goes beyond a single-period or short-term optimization.

Even if the previous concerns are addressed in some way, the work is not over. If an organization is to achieve its goals, those goals must first be communicated and then accepted by the whole organization as common goals. Moreover, the mechanisms or driving forces for achieving those goals must also be understood by the organization, particularly by those people who make decisions and take actions in these respects. Decision makers, however, are human beings with human frailties. They recognize only a limited number of options. Their choice of criteria and the weight they give to each will naturally reflect the self-interests of the decision maker.

It is worth mentioning that self-interest here in no way means that people are selfish, or materialistic, or irresponsible, or interested exclusively in money. None of these is implied by the assumption that individuals make choices based on expected benefits and costs to themselves. Everything depends on what, in fact, people find to be in their own interest. It is quite evident that some people derive enormous satisfaction from helping others; some find their keenest pleasure in the sight of roses blooming; others would far rather speculate on mining stocks. Modern behavioral theories, with surprisingly few exceptions, are simple extensions of the assumption that individuals take whatever actions they think will yield them the largest net advantage.

According to Herbert Simon (1976), a Nobel Prize winner in economics, the result is that a decision maker’s selection of the best solution is not an optimum choice but one that “satisfies.” The final choice is both satisfactory and sufficient. Decision making, therefore, is not a comprehensive process of searching for an optimum solution but an incremental process, during which the decision maker assesses choices until finding one that meets the minimum acceptable level. Once this level is attained, the

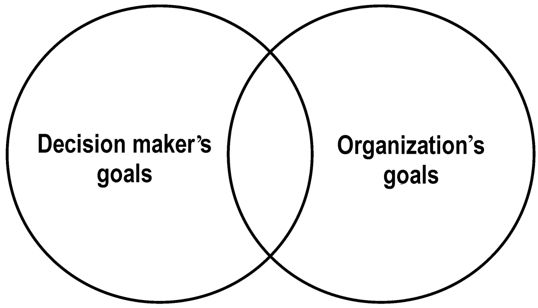

FIGURE 2.3 Decision maker and organization's goals

search stops and the decision is made. The final solution, then, is satisfying rather than optimizing.[3]

Although the traditional decision-making process assumes that decisions are made in the best interests of the organization, the reality is that the interests of decision makers and those of the organization are rarely the same. This important fact, illustrated in Figure 2.3, must be carefully considered when the mining organization is being designed. Although aligning the two circles perfectly would be desirable in terms of organizational effectiveness, this is far more likely to be the exception rather than the rule.

Because decision makers act in their self-interests, their choices will reflect only the criteria and preferences compatible within their circle. At no time would a decision maker be likely to sublimate his or her own interest to those of the organization. Moreover, if confronted with a set of choices, all of which met the "good enough" criterion, the decision maker would obviously choose the one most beneficial, personally. Thus in Figure 2.3, the overlapping area of the circles represents the region in which the decision maker acts consistently with the organizational effectiveness criteria. The area outside the overlap and within the decision maker's boundary represents situations not compatible with the best interests of the organization but beneficial to the decision maker.

In addition to human limitations, the organization itself imposes constraints. For instance, the organization's evaluation or appraisal system and its reward structure influence decision makers by suggesting to them what choices are preferable in terms of their payoff. For this reason, the decision makers can be expected to be constantly "looking over their shoulder" to assess the consequences of their actions. These organizational constraints, coupled with the human constraints mentioned earlier, imply that decision makers can be expected to make choices consistent with their self-interests. Moreover, they will always look for ways to expand their influence to control those decisions that could affect their self-interests.

One way or another, the previous analysis subtly leads to the informal but not less important aspect of survival, which is the goal that most researchers and practitioners agree as a necessary condition for an organization's success (Kimberly 1979). For some

3. Simon's assertion is especially valid in practical mining where, by its very nature, the flow of information for decision making is a continuous, never-ending process.

organizations, and favorite targets include government agencies and large corporations, organizational death practically never occurs. Yet in mining, survival is key because the exploitation of a mineral deposit eventually ceases, which almost always implies the organization's dissolution. As will be examined in detail in subsequent chapters, all major decision-making variables that influence the exploitation strategy somehow also affect the life of the mine. Thus, if survival is a relevant issue for decision makers—to accommodate their retirement, for example—pecuniary organizational goals such as long-term economic profit might be in direct conflict.

Besides the human and organizational constraints that are imposed on organizational goals, an effective organization must also satisfy the demands of those constituencies in the environment from which it requires support for its continued existence (Pfeffer and Salancik 1978). For this reason, actual goals do not always reflect official goals. Worse yet, official goals tend to be masked by standards of social desirability with statements such as "to produce quality products at competitive costs," or "to be a responsible member of the community," or "to ensure that our operations do nothing to damage the environment." These vague official statements may sound good, but they rarely make any contribution to understanding what the organization is actually trying to accomplish.

Given the fact that an organization faces multiple goals and diverse interests, consensus may not be possible unless goals are stated in such ambiguous and vague terms as to allow the varying interest groups to interpret them in a way favorable to their self-interest. This fact may explain why most official goals in large mining organizations are traditionally broad and intangible. They are likely intended to placate the many different interest groups within and without the organization rather than to communicate a tangible message.

The use of multiple criteria ranging from general factors such as quality and morale to more specific measures such as profit, accident rates, and absenteeism, certainly leads to the conclusion that organizational effectiveness means different things for different people. Because a business organization can be effective or ineffective in a number of different facets that may be relatively independent of one another, some researchers contend that organizational effectiveness has no operational definition (Campbell 1977). However, as the central issue in the management of mineral resources, the meaning and measurement of organizational effectiveness must be confronted and certain basic rules adopted. To advance in that direction, the statement that organizational effectiveness can be defined as the degree to which an organization realizes its goals seems adequate, although the term "goal" does require some precision to make it operative.

The fundamental aspect in this respect is that an organization's effectiveness must be appraised in terms of the whole system; that is, the accomplishment of ends and the use of means. It is not only the bottom line that counts but also the resources employed to generate that outcome. In fact, organizational effectiveness comprises the ability to acquire inputs, process these inputs, channel the outputs, and maintain stability and balance in the system. In other words, the approach proposed here focuses not only on specific ends but also on the means needed to achieve those ends.

Under this approach, the traditional goal attainment criteria used in many mining organizations—such as maximizing earnings, earnings per share, market share, and the like—do not satisfy because they do not account for the means. On the other hand, common accounting yardsticks such as return on investment, return on assets, and return on equity, do not satisfy either because they do not take the market value of the mineral resource into account. Even if this value is considered, it is usually referred to as the acquisition or discovery costs. Although this may be required for complying with generally accepted accounting principles (GAAP), it has nothing to do with the prevailing market price of the mineral deposit.

In conclusion, the ultimate goals of business organizations must focus not only on specific ends but also on the means needed to achieve those ends. These goals must be clearly defined and communicated so that they can be understood and agreed to within the organization. They must also be few enough to be manageable. And the progress toward these goals must be measurable.

The next chapter addresses these problems, assuming that the broad declared goal of the mining firm is pecuniary—to maximize the economic value of its mineral resource. As will be seen, in mining this occurs only when both the ongoing economic profit and the long-term value are maximized simultaneously.

CHAPTER 3

The Economics of Mining

The exploitation of natural resources has always been an area of concern in the field of economics. The subject became a sensitive topic toward the end of the nineteenth century when the industrial era began, causing skyrocketing demand for these types of resources. With the emergence of conservationist and environmentalist movements in the second half of the twentieth century, the topic became even more controversial. In any case, it must be acknowledged that the uniqueness of natural resource assets, and the ways of using them, calls for a particular economic analysis if the goal is to maximize long-term economic returns.

Parts of these natural resources are mineral deposits, which are usually called finite, nonrenewable resources. This means that for a particular deposit, there is a limited amount of the resource in the ground, which cannot be replaced once removed. Developing the optimum exploitation strategy, therefore, requires dynamic allocation. The main concern in the economic analysis is the way in which and the pace at which the deposit is mined; in other words, how the deposit is consumed, what the flow of production is over time, and when the deposit will be exhausted. 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 depleted.

Before approaching these fundamental concerns, some basic economic concepts must first be introduced. The idea here is to nurture an economic way of thinking that is essential to understanding the foundation of the subsequent theory. This outline of managerial economics is then followed by a critical examination of the current developments in the field of mineral resource economics. Thereafter, a tractable theoretical framework for coping with the dynamic allocation problem is presented. At the beginning, the model is very simple because the idea is to trace the main economic implications of dealing with finite, nonrenewable resources. As assumptions are gradually relaxed, the model is expanded to cope with increasingly complex, and thus more realistic, market situations.

BASIC ECONOMIC CONCEPTS

Economic theory is based on the assumptions that human wants are unlimited and that society has limited productive resources. These two assumptions give rise to the fundamental economic problem of scarcity, which, in turn, necessitates choice. In effect, all social phenomena emerge from the choices individuals make in response to expected benefits and costs to themselves.

Scarcity means that society, in one way or another, must also choose what goods to produce—producing more of one item means having to produce less of something else. The act of choosing, therefore, involves costs. Interestingly, and in opposition to what common sense teaches, the previous statement asserts that goods do not have costs by themselves—only actions can have costs. A great deal of fruitless dispute about the true costs of objects stems from a failure to recognize that only actions have costs, and that actions can entail different costs depending on people and their circumstances. A glass of water, for instance, may have no cost for a person living in a modern Canadian city, but may be priceless if the same person is lost in the desert. In both cases, it is not the glass of water itself that has cost but how much time, effort, or other economic good, the person is willing to offer in exchange. That decision determines the value of that economic product, at that particular time, to that unique individual. The cost of any action is thus the value of the opportunity foregone by taking that action. Although fundamental to fully understanding the scope of mineral resource management, this is recognized as a very abstract concept.

In open societies, competitive markets clear up the scarcity problem by allowing individuals to freely express their wants and desires. In this respect, the market represents the place of encounter in which consumers and producers interchange their unlimited wants and limited resources. This process is facilitated by the introduction of money, which is nothing more than a medium of exchange that lubricates the trades among the many available goods and services. The money price of goods is then the result of interaction of buyers and sellers. The mechanism to set the price within this process, which is at the core of economic theory, is known as the *law of supply and demand.* The law of demand asserts that people will want to buy more of any item at lower prices and less at higher prices. Likewise, the law of supply holds that people will be able to produce more of any product at higher prices and less at lower prices. Genuine exceptions, if they exist at all, are rare, and alleged ones are usually based on misinterpretation of the evidence. For instance, if the price of some product rises and people buy more of it, it may not be an exception to the law of demand, but an anticipation of further price increases; that is, a change in expectations. In effect, the expectation of higher prices in the future, created by the initial price raises, increases the current demand for the item.

Coordinating this whole process is becoming increasingly complex in modern societies, giving rise to numerous institutions and organizational forms designed to reduce transaction costs (the costs of arranging contracts or transaction agreements between buyers and sellers). “Globalization” is all about this process.

Marginal Values and Economic Decisions

Economic analysis is basically marginal analysis. Marginal means on or at the edge, rather than small, as many people tend to believe. A marginal benefit or a marginal cost is, therefore, an additional or incremental benefit or cost. Economic theory is a form of marginal analysis because it assumes that people make decisions by weighing additional benefits against additional costs, all measured from the spot on which the decision maker currently stands. Nothing matters in economic decision making except marginal benefits and marginal costs.

Cost Analysis for Decision Making

The economic analysis of costs is especially treacherous because costs often have an ethical and political as well as an economic dimension. Nonetheless, for the purpose of decision-making analysis, the economic dimension is the most important. Moreover, as economic decisions are always made in the present with an eye to the future, they indeed entail some degree of uncertainty. This means that historical costs are useful only in the event that they resemble current or future costs. All this makes cost analysis difficult, especially when figuring in unforeseen inflation, unpredictable changes in technology, and the dynamic nature of markets. The proper way of estimating costs, then, is not to look back to the past, but forward to the future.

The fundamental principle in decision-making analysis is that there are different costs for different decisions. In this respect, costs can be conveniently regarded as "evitable" and "inevitable." Evitable costs are those that can be avoided if no decision is made; as such, they are relevant for decision making. Inevitable costs are those costs that must be incurred regardless of the decision—because they are unavoidable, they are irrelevant to whichever economic decision is made. For instance, the asking price for a certain mineral deposit is an evitable cost for the decision of whether to buy the property. Yet such a cost is inevitable for deciding if the deposit should be mined by open pit or underground methods, even if this last concern is being analyzed before the property is bought.

Economists usually refer to inevitable costs as "sunk costs." This term, though, is sometimes misleading because it is mainly associated with money already spent, which is clearly not relevant to any decision. The pertinent point is whether a particular future expenditure is relevant for a certain decision to be made now (for example, when planning). Development costs in underground mining are a good example. These costs are necessary for accessing certain areas of the deposit, so they are relevant (evitable) to determining whether to mine a particular area, but they are not relevant (inevitable) to deciding which fraction of that area will be processed. In effect, when deciding what is going to be ore and what is going to be waste, these development costs are effectively sunk costs and, therefore, inevitable for that decision. The relevant costs to determine what is ore are those marginal or extra costs incurred in actually extracting the ore once accessed—the cost of transporting the ore to the surface, for example.

Production Level and Costs

When a firm decides how much to produce, it uses the economic principle of supplying the amount that maximizes the firm's net benefit. Simply put, this means that the firm will continue to increase the rate of production as long as doing so adds more to its expected revenues than it does to its expected costs. The firm tries to maximize its net revenues, commonly known as profits.

The term "expected" is important because firms do not know today how much they will be able to sell tomorrow, let alone next month or even next year. Nor do they know precisely what their costs will be for any particular rate of production. Firms, however, give careful thought to these questions before and during the formulation of their business plans. These uncertainties mean that, for firms to make decisions, they must guess, estimate, calculate, and consider contingencies. This process includes estimating cost functions or cost-output relations for both the short and the long term. To estimate these functions, production costs must be classified as either fixed or variable.

Fixed costs, which do not vary with output, typically include interest expenses, charges on leased plants and equipment, and salaries for employees retained on staff during periods of reduced activity. If the assets employed in the business are company-owned items, an additional charge for using them must be considered. This theoretical cost can be estimated as the proceeds obtainable if the market value of the assets were invested elsewhere, at the firm's discount rate. It is a kind of depreciation charge, although not in the traditional way (as an accounting allowance) but in a strictly economic sense.

This last concept deserves more attention because it is a main point in this study—the payment for the use of the firm's assets. The assets owned by the firm almost always have an alternative use whose value is ultimately determined by the market. Sometimes, however, the market value of certain assets is close to nothing if detached from the core business. Many mining facilities, whose value is intrinsically associated with the mineral deposit, find themselves in this situation. In this case the value of the asset can be estimated as the price to be paid to replace it and continue operating. This point is clearly illustrated in one of the most basic businesses: a self-employed taxi driver who owns the cab vehicle. This entrepreneur should periodically compare the net income of the business with the interest obtainable by investing the car money elsewhere. The economic profit generated by the business is the difference, which should also cover the driver's alternative salary.

Variable costs, on the other hand, fluctuate with output and are related to raw materials, consumables, and some labor associated with production. In the short run, both variable and fixed costs are often incurred; in the long run, all costs are variable. A sharp distinction between fixed and variable costs is not always possible or realistic. For example, staff salaries may be largely fixed, but during severe downturns even chief executives may take a pay cut. Similarly, salaries for line managers and supervisors are usually fixed, but only within certain output ranges. Below a lower limit, supervisors and managers would be laid off; above an upper limit, additional supervisors and managers would be hired.

In mine planning, however, when decisions are focused on the mineral resource, the classification of costs is better made in terms of time and resources. In this context, time costs are those expenditures related to the passage of time as opposed to resource costs, which are attached to the consumption of the resource. In a mining operation, for example, staff compensation is a time cost usually expressed in money per unit of time (i.e., dollars per year); drilling and blasting, conversely, are resource costs normally expressed in money per some unit associated with the resource (i.e., dollars per tonne of material).

It is important to emphasize that much of the analysis of a firm's decision making is carried out on a per-unit basis. The unit must be related to the decision, which is usually output, though not necessarily a single unit of output. It could also be referred to a batch of output, or the entire process if the decision is whether or not to build. Decisions are often made in this discrete way.

Short-Run Cost Curves

In the short run, operating decisions are typically constrained by prior capital expenditures. For example, an underground mine that operates with a main shaft as the only access has indeed some capacity restrictions in hoisting ore to the surface. An additional shaft or some structural changes to the current shaft might alleviate the problem; however, either solution may take some time to complete, incurring production losses.

Thus, for a certain infrastructure and for certain operating conditions, there will be a cost-output relation. This function reflects the optimal or least-cost mixture of input for production under fixed circumstances such as wage rates, interest rates, plant configuration, and all other operating conditions. Any change in the operating environment leads to a shift in the function. Such a change must not be confused with movements along the short-run cost curve caused by a change in production levels.

Total cost (TC) at each output level is the sum of total fixed costs (TFC) and total variable costs (TVC). Using the previous abbreviations and Q for denoting the amount of output, two important unit costs can be derived. These are the average cost (AC) and the marginal cost (MC), whose formulae are presented in Equations 3.1 and 3.2:

$$\mathrm{AC} = \frac{\mathrm{TC}}{Q} \qquad \text{(EQ 3.1)}$$

$$\mathrm{MC} = \frac{\partial \mathrm{TC}}{\partial Q} \qquad \text{(EQ 3.2)}$$

Marginal cost is the change in cost associated with a one-unit change in output; i.e., the cost of the last unit produced. Figure 3.1 depicts these cost categories. The upper part of

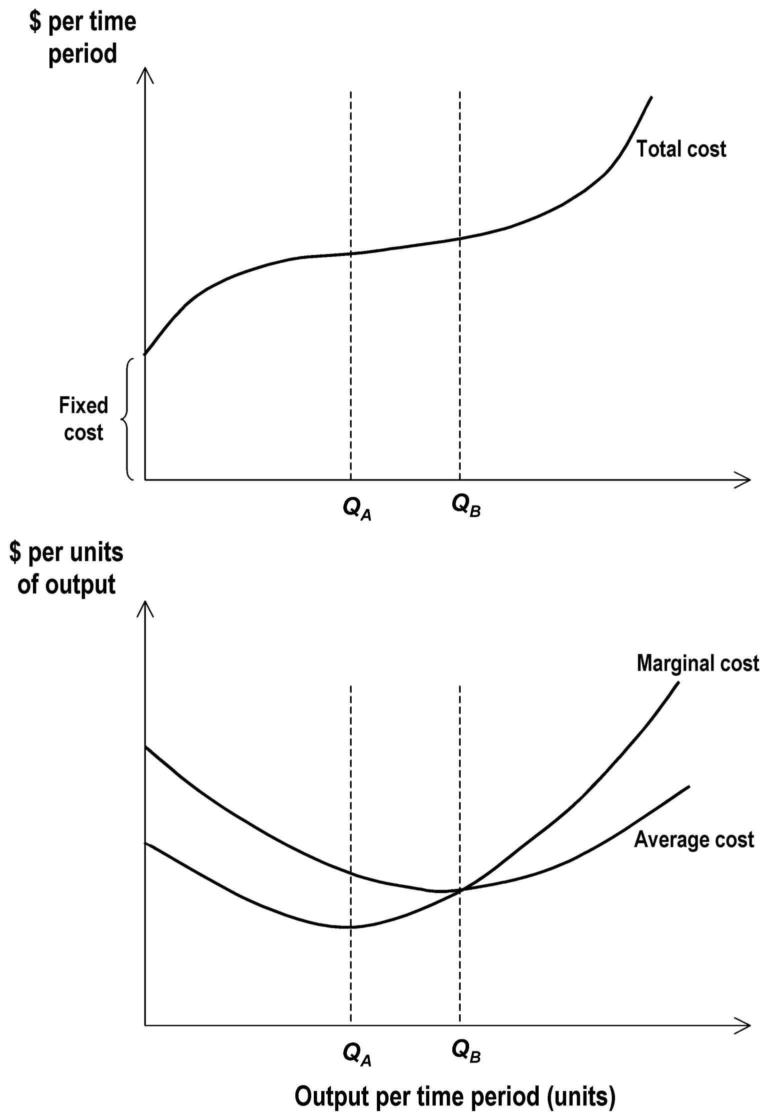

FIGURE 3.1 Short-run cost curves

the figure illustrates the total cost curve and the lower part shows the average cost curve and the marginal cost curve.

The shape of the curves in Figure 3.1 can be explained with an illustrative example. Consider an open pit mine in which total production is a function of the number of trucks running in the pit. Initially, the introduction of each additional truck increases the marginal productivity of the system and the total cost increases at a decreasing rate up to output Q_A. At that point, the system begins saturating and each truck added diminishes the marginal productivity of the system. Consequently, the total cost begins growing at an increasing rate. This phenomenon is known as the "law of diminishing marginal productivity" or as the "law of diminishing marginal returns." Both laws hold that using more and more of some input without changing any of the other inputs will eventually start adding less and less to the total output.

On the other hand, marginal cost decreases as each additional truck improves the marginal productivity of the system and starts rising when the marginal productivity of the system begins falling (beyond Q_A). As long as marginal cost is below average cost, the average cost curve is downward because each additional unit of output is cheaper. Conversely, when marginal cost is above average cost, the average cost curve turns upward because each additional unit of output is now more expensive. The marginal cost curve must then intercept the average cost curve at its minimum point (at Q_B).

Optimum Level of Production

To calculate the optimum production level, the revenues associated with each level of production must be estimated. Generally, three scenarios are possible: first, the firm is a "price taker," which means that it does not affect price at any level of output; second, the firm effectively affects the market price so as output increases, the market price of the product decreases, obeying the law of supply and demand; and third, the firm is a monopoly, which means that there is no other player in that business, allowing the firm to set the price. In each case, the shape of the total revenue curve is what makes the difference. For instance, if the firm is a price taker, total revenue is directly proportional to the level of output and the total revenue curve is a straight line with a slope that corresponds to the unit price (which, in this case, coincides with the marginal revenue).

Figure 3.2 depicts the problem of setting the optimum level of production. The maximum net revenue or greatest difference between total revenue and total cost is met at the output level Q_C, which corresponds to the output at which marginal cost equals marginal revenue. Mining professionals, who repeatedly advocate lower average costs, usually overlook this fundamental principle in the theory of the firm. As the previous analysis shows, once the cost curves are known—which is a matter of a certain technology process and the cost of the many inputs—the average cost is a mere consequence of equating marginal cost and marginal revenue.

Any attempt to reduce costs, therefore, should not be based on movement over the average cost curve but on getting a better price for the input or improving the process; that is, by pushing down the cost curves. If investments are required for such improvements, these expenditures must be weighed with the cost savings over the whole mine life.

The previous analysis is based on the assumption that production factors are always available. In mining, however, this assumption does not apply because mineral deposits are exhaustible. This makes conducting the proper analysis much more complicated. The next section, then, is intended to extend the previous economic framework to cope with mining's unique characteristic—the finite character of its main asset.

DEVELOPMENT OF MINING ECONOMICS

Lewis Gray (1914) and Harold Hotelling (1931) pioneered the modeling of the economics involved in exploiting mineral resources. Hotelling developed the fundamental principle of the economics of exhaustible resource use, which is known as "Hotelling's r-percent rule." It states that the resource should be depleted in such a way that the rate of growth of value of the extracted resource should equal the discount rate r (k in this study). The previous statement underlies an important feature of the economics of mineral resource use. It treats in situ resources as capital assets, so by leaving them in the ground (preserving them) the owner may expect a capital gain if, for example, the value of the in situ resource rises over time at a higher rate than the discount rate. This gives an

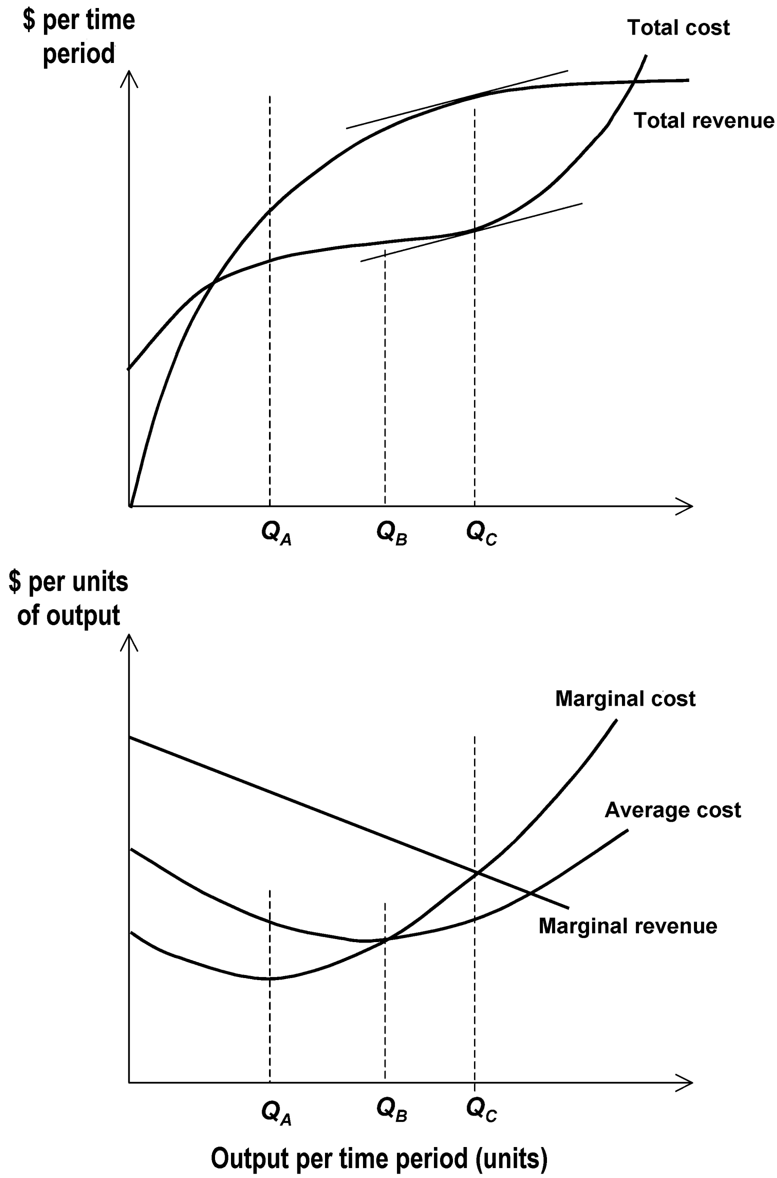

FIGURE 3.2 Optimum level of production

economic meaning to the word "deposit," which is commonly used in mining parlance to indicate where minerals are found.

In analyzing the economics of exhaustible resources, Hotelling's main concern was the rate of mining. According to Donald Carlisle (1954), however, at least half the problem is neglected when only the "rate of recovery" (rate of mining) is considered in the analysis. He introduced an additional concept called the "level of recovery," which deals with the variability of grades within the resource and the effect it has on the amount of resource. This measurement may change according to the quantity of ore effectively recovered as different cutoff grades are applied to the resource. Later, Kenneth Lane (1964) reformulated these seminal works and strongly emphasized not only the economics of the mineral resource but also to the whole mining process, including the size of the installations. Lane also introduced some practicalities to make the elaborate theory more applicable.

Later, Mike Blackwell (1971) successfully employed these ideas in the planning and development of a large-scale project in Bougainville, Papua New Guinea. Subsequently, Lane (1997) developed a complete formulation to relate finite resources and present value, focusing attention on the economic definition of ore and the cutoff grade determination at the mine.

Beyond mine cutoffs, the approach presented here holds that the many cutoffs inherent in mining may be determined concurrently and applied to the whole selective process that takes place before the final product is delivered. This feature, which is rarely considered in practical mining, will be one of the main topics of the next chapter. For now, so as to concentrate on the economic principles of mining, this selectivity aspect will be omitted.

LIFE-OF-MINE MODELING

One of the concerns for dealing with a finite, nonrenewable resource is the time horizon in which the planning process takes place. In effect, because the resource can be exhausted, the life of the deposit is a decision variable that depends mainly on the rate of extraction. Sometimes, when the deposit allows a form of selectivity, the definition of successive economic cutoffs throughout the extraction process may also affect the size and the life of the deposit. To some extent, this is the case with many metal deposits whose physical properties and spatial dissemination of valuable minerals permit an ongoing concentration to obtain a final salable product (e.g., mining, processing, smelting, and refining).

Because of this characteristic, the economic mine life of a mineral resource is a decision variable and the derivation of an optimum strategy to deplete the deposit should encompass the entire resource. Only in this way will it be possible to account for the different lives associated with each strategy. Using the present value of cash flows generated by the entire exploitation of the resource, the ultimate merit of each option can then be assessed. Figure 3.3 illustrates this problem.

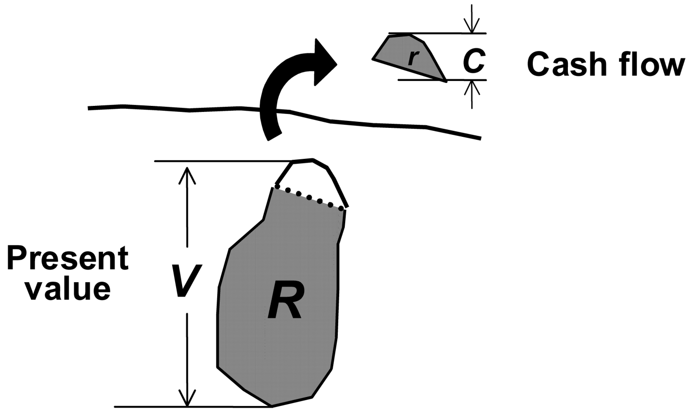

FIGURE 3.3 Mineral resource and present value

Let C represent the cash flow that arises from the extraction of the fraction r of the resource R. For a given cost structure, this cash flow depends on the adopted strategy. In this case, the word strategy is used to represent the setting of the many variables that affect the life of the mine, such as the rate of extraction, for example. As previously pointed out, the level of selectivity that is applicable at different stages in the operation may also affect the life of the mine, with the selectivity level becoming a key decision variable as well. As will be seen later, the setting of these variables affects not only cash flow C but also the timing of receiving future cash flows that will result from exploiting the remaining reserves. Because of this time dependency, cash flow C cannot be optimized in isolation from the rest of the deposit.

It is important to emphasize that cash flow C and present value V both depend on the strategy adopted for exploiting fraction r of the resource. Let us assume for a moment that the strategy is related only to the rate of extraction, such as that shown in Figure 3.4. Thus, if the extraction rate is set at the minimum average cost, cash flow C will not be maximized, although the total undiscounted cash flow for the whole resource will effectively be maximized. However, in this case, the time to extract the fraction r will tend to be longer, which will then postpone the realization of the remaining cash flows.

Conversely, if the rate of extraction is set at the point where the marginal cost equals price, cash flow C will be maximized and the extraction time will be reduced. This benefit, in turn, will be at the expense of increasing the average cost, which will reduce the total undiscounted cash flow for the whole resource. This is the typical problem of dealing with finite resources where the rule of matching marginal cost and marginal income (price) to set the optimum rate of production is no longer valid in its traditional form. In this case, to set the optimum rate, the timing of the forward cash flows arising from the operation must be taken into account.

Therefore, for a positive discount rate, there will be a compromise between a maximum cash flow C that increases the average cost and reduces the life of the deposit, and a minimum average cost that extends the life of the operation but reduces the annual cash flows.

The following example illustrates the preceding reasoning. Let us assume that the cost structure of Figure 3.4 corresponds to certain installations for exploiting a coal deposit. The horizontal axis (strategy) represents the rate of extraction, in millions of

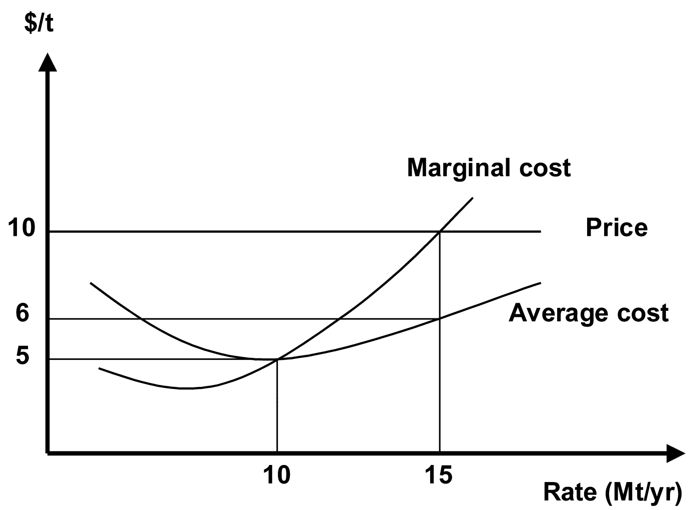

FIGURE 3.4 Cost structure for a coal mining operation

tonnes of coal per year (Mt/yr) and the vertical axis, the unit value in dollars per tonne of coal ($/t). The forecasted long-term price for this type of coal is estimated at $10/t of coal for the entire horizon life; the minimum average cost of $5/t is found at 10 Mt/yr; likewise, the marginal cost equals the price at 15 Mt/yr and the average cost at that point is $6/t. Figure 3.4 depicts these numbers and shows the shape of the marginal and average cost curves.

At 10 Mt/yr, the margin is $5/t and the annual profit is $50 million. At 15 Mt/yr the margin is reduced to $4/t, although the annual profit rises to $60 million. For a perpetual flow, the latter option maximizes the total value for any positive discount rate. However, if the size of the deposit is fixed to, say, 90 Mt of coal, the life of the deposit and the total value for a null discount rate are 9 years and $450 million, respectively, for the lower rate, and 6 years and $360 million for the higher rate.

When introducing a positive discount rate, the optimum rate of extraction will be contingent on this variable and lie somewhere between these two extremes. This effect and the preceding calculations can be seen in Table 3.1, which displays the present value *V* in million dollars (M$) for discrete increments in the rate of extraction and various discount rates. For the sake of simplicity, the marginal cost function in Figure 3.4 has been assumed linear with a slope of 1 in the range of interest (10 to 15 Mt/yr). This means that the average cost increases accordingly, resulting in a decreasing margin.

TABLE 3.1 Present value (*V*), rate of extraction, and discount rate

Rate (Mt/yr)	Margin ($/t)	Cash Flow (M$/yr)	Mine Life (years)	*V* at 20% (M$)	*V* at 10% (M$)	*V* at 0% (M$)
10	5.00	50.0	9.00	201.5	288.0	450.0
11	4.91	54.0	8.18	209.2	292.4	441.7
12	4.75	57.0	7.50	212.4	291.1	427.5
13	4.54	59.0	6.92	211.5	284.9	408.3
14	4.29	60.0	6.43	207.1	274.9	385.8
15	4.00	60.0	6.00	199.5	261.3	360.0

For a 20% discount rate, the optimum rate of extraction is 12 Mt/yr. If this rate could vary over time, it would be possible to find a declining policy that would increase even further the present value for any positive discount rate. The development of this rationale is presented in the following model.

A Basic Intertemporal Model

The problem depicted in Figure 3.3 is twofold: (1) devising a strategy to exploit the whole resource *R* to maximize the present value *V;* and (2) concurrently finding the optimum trajectory to reach that maximum. Put another way, maximizing *V* requires that, at any stage, the economic contribution of each consecutive fraction *r* of resource *R* be maximized as well.

The problem can be likened to climbing a hill with topography that is contingent on three aspects: first, the geological features of the deposit such as size and quality; second, the market conditions in terms of prices and costs; and third, the scale of operation or size of the mine and mill infrastructure. Thus, if the hill elevation represents “money” that can be invested during the hike, the problem is to reach the top with the maximum amount of money (maximum present value). The solution can be found by selecting the shortest way; that is, by reaching the top through the steepest slope at each point of the hillside. By following that trajectory, each upward step will maximize its contribution to the economics and the top will be reached with the largest quantity of money. By choosing an alternative path, the top can also be reached but the interest accrued through the journey will be lower, decreasing the corresponding wealth at the top.

At this point, it is important to mention that the shape of the hill is also a function of the strategy to exploit the deposit, which is related to certain technical variables like the sequence in which the deposit is mined, for instance. This aspect of the analysis is developed in the next chapter.

To explore the influence of the exploitation in the economics of mining, it is necessary to relate cash flow *C* to overall present value *V*. Let *W* be the remaining present value once the fraction *r* has been extracted. Then the present value for the whole operation can be expressed as

$$V = \frac{C + W}{(1 + k)^t} \quad \text{(EQ 3.3)}$$

where:

k = weighted average cost of capital (equity plus debt)
t = required time to exploit fraction r

Figure 3.5 displays the stream of cash flows (C_i) that arises from the whole life of the mine and the relationship of those cash flows with present value *V* and remaining present value *W*.

For a small *t,* say about a year, it is possible to make the following approximation:

$$(1 + k)^t \approx 1 + k \cdot t \quad \text{(EQ 3.4)}$$

Thus, replacing Equation 3.4 in 3.3:

$$V(1 + k \cdot t) = C + W \quad \text{(EQ 3.5)}$$

By rearranging Equation 3.5:

$$v = V - W = C - k \cdot V \cdot t \quad \text{(EQ 3.6)}$$

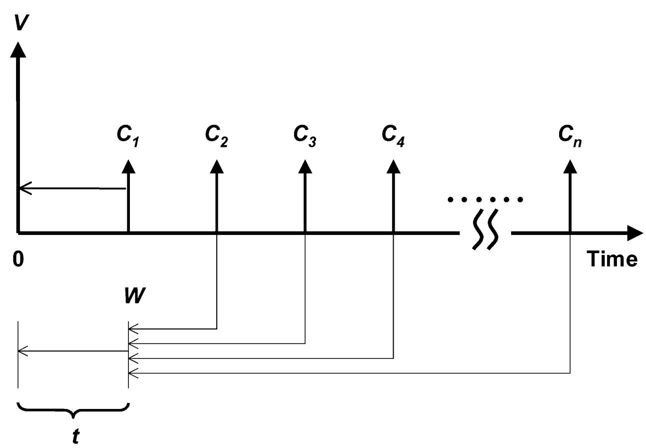

FIGURE 3.5 Timing of cash flows and present values

In Equation 3.6, v represents the increment in present value resulting from the exploitation of fraction r of resource R. It can also be called the economic profit or value added associated with the exploitation of that fraction. The right-hand side includes cash flow C and factor $k \cdot V \cdot t$, which, for the moment, can be regarded as an additional time or fixed cost to be borne by the operation. Some observations on this equation are important:

- The optimum present value V is unknown until the best strategy is determined. In practical applications, this problem is usually overcome by estimating it from a preliminary evaluation. However, if the policy is so sensitive, it is possible to iterate with an initial arbitrary value that can be refined in due course, until a stable optimum value is reached.
- The formula is identical to the EVA equation (Equation 2.1) previously defined, but in this case the capital employed to generate cash flow C is the value of the deposit itself, including installations. However, it is estimated here not by using accounting rules but the present value of future cash flows. In other words, the economic profit defined in Equation 3.6 is, in essence, a measure of the true economic surplus that is created as the deposit is mined. As such, it is the proper ongoing metric to optimize when dealing with the extraction of a deposit or any other asset of finite life.

When applying the recursive Equation 3.6 to the coal mine example, the following steps are required to determine an optimum extraction policy.

For the first iteration, let us assume that the annual discount rate k is 20% and the present value V for that discount rate is taken from Table 3.1 (V = \$212.4 million). This is, in fact, the best present value for that discount rate, which is associated with a fixed rate of extraction of 12 Mt/yr. Let us also assume that the first fraction to be extracted is set at 15 Mt. Table 3.2 shows the value added for each extraction rate, assuming that there is now an explicit opportunity cost to take into account.

The maximum value added is now reached at 13 Mt/yr and this is set as the rate of exploitation for the first year of operation. The cash flow in that particular year is \$59 million (13 Mt with a margin of \$4.54/t) and the reserves shrink from 90 to 77 Mt.

Following this, the next fraction can be extracted, and for practical purposes, it is assumed that the amount is defined again as 15 Mt. The remaining present value can be estimated by rearranging Equation 3.5 and assuming that time $t = 1$:

$$W = V(1 + k) - C \qquad \text{(EQ 3.5a)}$$

By replacing values, W is estimated at \$195.88 million $(212.4 \cdot (1 + 0.2) - 59)$. Table 3.3 shows the value added for each rate of extraction, but now the values relate to the second fraction, which corresponds to 15 Mt of the remaining 77 Mt.

In year two, the production rate is set again at 13 Mt/yr and yearly cash flow C remains at \$59 million. The reserves in this case are reduced from 77 to 64 Mt. For the next fraction, the remaining present value W is estimated at \$176.06 million and the rate of extraction and the corresponding cash flow remain the same for the third year of operation.

The successive calculation for the following fractions continues until the exhaustion of the entire deposit. Table 3.4 shows the complete long-term strategy obtained with two iterations.

As the deposit is consumed, the rate of extraction declines until it eventually reaches the rate that matches the lowest average cost. The resulting present value is \$214.2 million, which is slightly higher than the initial seed of \$212.4 million and almost identical

TABLE 3.2 Value added for each extraction rate (first increment)

Rate (Mt/yr)	Margin ($/t)	Time, *t* (years)	Cash Flow, *C* (M$)	Value Added, *v* (M$)
10	5.00	1.50	75.00	11.28
11	4.91	1.36	73.65	15.88
12	4.75	1.25	71.25	18.15
13	4.54	1.15	68.10	19.25
14	4.29	1.07	64.35	18.90
15	4.00	1.00	60.00	17.52

TABLE 3.3 Value added for each extraction rate (second increment)

Rate (Mt/yr)	Margin ($/t)	Time, *t* (years)	Cash Flow, *C* (M$)	Value Added, *v* (M$)
10	5.00	1.50	75.00	16.24
11	4.91	1.36	73.65	20.37
12	4.75	1.25	71.25	22.28
13	4.54	1.15	68.10	23.05
14	4.29	1.07	64.35	22.43
15	4.00	1.00	60.00	20.82

TABLE 3.4 Long-term policy

Year	Reserves (Mt)	Rate (Mt/yr)	Profit (M$)	Value Added, *v* (M$)	Remaining Percent Value, *V* (M$)
1	90	13	59	16.16	214.20
2	77	13	59	19.39	198.04
3	64	13	59	23.27	178.65
4	51	12	57	25.92	155.38
5	39	12	57	31.11	129.45
6	27	11	54	34.33	98.34
7	16	11	54	41.20	64.01
8*	5	10	25	22.72	22.72
				Σ **214.20**	

*6 months.

to the one used at the beginning of the last (second) iteration. If they were much different, another iteration might be required. The rate of growth of the resulting value-added stream fairly matches the discount rate of 20%, which honors Hotelling's r-percent rule.[4]

Effect of Price Changes in the Model

The derivation of the previous model is valid only if present value *V* depends on the size and quality of the deposit and not on the time. This is equivalent to assuming that both price and time costs remain constant. Time costs are those that may change as time

4. Because the analysis was done with discrete, rounded rates of production for simplicity, the Hotelling rule could not be exactly met in the 2 years where the mine plan changes from one rate to a lower one.

elapses but that do not depend on the resource (e.g., energy, exchange rate, and labor). However, in reality, market conditions change over time and the same deposit can have different values, depending on the time at which the evaluation is performed.

Under this condition, the hill of the preceding analogy is actually in continuous movement so reaching the top and maximizing the present value becomes a much more complicated task. At any place on the hill and regardless of the route already covered, each upward step should be carefully evaluated—what could have been the highest slope at a certain time might have moved because of changes in market variables.

This consideration is of the utmost importance in the management of mineral resources because expectations may also affect today's decisions. In fact, the change in value of the in situ resource might lead to strategies that can even include a temporary closure of the operation. In many academic and corporate circles, this feature is usually known as the managerial or operating flexibility inherent in resource projects (Guzman 1991).

Both price and time-cost fluctuations may induce changes in extraction policies and resulting project values. This possibility to respond to variations in either economic or technical conditions adds value to investment projects. Although wise managers rarely ignore this hidden value—strategic factors dressed in nonfinancial clothes—it is not explicitly considered in the standard decision-making process, as traditional discounted cash flow methods are not intended to measure these opportunities.

Modern stochastic methods to deal with the cyclical nature of resource projects are based on option theory. The "real options approach" is the specific tool used to value the strategic and timing opportunities held by resource firms (Mardones 1991 and Trigeorgis 1996). Nonetheless, the traditional present value framework may also be applied to value these opportunities (flexibility) if it is assumed that future scenarios could be described in a deterministic way (i.e., by projecting time costs and prices).

Lane (1997) presented a general solution for this deterministic problem, and the reasoning behind this idea is developed in the extended model that follows.

Present value V of a resource business at any particular time T can be expressed as

$$V = V(T, R, \Omega) \qquad \text{(EQ 3.7)}$$

where:

R = available resource at time T

Ω = whole strategy that defines the setting of the variables affecting V

There is an optimum strategy Ω^* for which V is maximized. This optimum present value can be denoted as $V^*(T, R)$ and it is no longer a function of the strategy Ω:

$$Max_{\Omega} V(T, R, \Omega) = V^{*}(T, R) \qquad \text{(EQ 3.8)}$$

For a small decrement r in resource R (increment if viewed as extraction), consider ω as the strategy to extract that decrement, with t being the required time to mine r and c, the cash flow per unit of resource ($C = r \cdot c$).

Both time t and cash flow c are a function of fraction r of resource R as well as of the adopted strategy ω for that decrement. After extracting fraction r, the remaining resource will be $R - r$, the new time will be $T + t$, and the present value will be $V = V(T + t, R - r, \Omega')$, where Ω' is the adopted strategy from that time onward. The present value at the beginning of time T can be conveniently expressed as cash flow $C = r \cdot c$, plus the remaining present value.

$$V(T, R, \Omega) - r \cdot c + \frac{V(T + t, R - r, \Omega')}{(1 + k)^t} \qquad \text{(EQ 3.9)}$$

Maximizing both sides of Equation (3.9) with respect to strategy ω and using Equation 3.8:

$$V^*(T,R) = Max_{\omega}\left\{ r \cdot c + \frac{V^*(T+t, R-r)}{(1+k)^t} \right\} \tag{EQ 3.10}$$

Assuming r and t are small and using the binomial theorem, the last term of the right side of Equation 3.10 can be expanded as follows:

$$\frac{V^*(T+t, R-r)}{(1+k)^t} = \left[V^*(T,R) + t \cdot \frac{dV^*}{dT} - r \cdot \frac{dV^*}{dR} \right](1 - k \cdot t) \tag{EQ 3.11}$$

By accepting an approximation of first order:

$$\frac{V^*(T+t, R-r)}{(1+k)^t} = V^*(T,R) - k \cdot t \cdot V^*(T,R) + t \cdot \frac{dV^*}{dT} - r \cdot \frac{dV^*}{dR} \tag{EQ 3.12}$$

Replacing (3.12) in (3.10) and dropping (T, R) dependence to simplify the notation:

$$V^* = Max_{\omega}\left\{ r \cdot c + V^* - k \cdot t \cdot V^* + t \cdot \frac{dV^*}{dT} - r \cdot \frac{dV^*}{dR} \right\} \tag{EQ 3.13}$$

However, both V^* and $r \cdot dV^*/dR$ are independent of the strategy ω because V^* is already at optimum. For this reason, both terms can be removed from the maximization expression, canceling V^*:

$$r \cdot \frac{dV^*}{dR} = Max_{\omega}\left\{ r \cdot c - \left(k \cdot V^* + \frac{dV^*}{dT}\right) \cdot t \right\} \tag{EQ 3.14}$$

The previous equation can be accommodated to explicitly show how optimum present value V^* changes as resource R is consumed. This change in present value is actually the economic profit that is generated as the resource is consumed.

By dropping the asterisks and rearranging Equation 3.14, then, the following general formula can be obtained:

$$v = \frac{dV}{dR} = Max_{\omega}(c + F \cdot \tau) \tag{EQ 3.15}$$

where:

v = economic value added when mining and processing a unit of resource

F = fixed cost to be borne by the operation $(k \cdot V - dV/dT)$

τ = time taken to mine and process a unit of the resource (t/r)

In conclusion, the optimum exploitation strategy to maximize the present value of an operation based on a finite resource could be determined, at any stage, by maximizing Equation 3.15 with respect to the strategy ω. In this expression, the only variables that are affected by the strategy are c and τ, because factor F is independent of the adopted strategy (V is already at optimum).

Equation 3.15 is similar to Equation 3.6, although the former includes two time costs instead of one. Both costs depend on the present value and they can be called an opportunity cost, which measures the penalty of doing nothing.

The first component of this opportunity cost, $k \cdot V$, represents the capital gain in the event that the deposit were to be sold at present value V and the money invested elsewhere, at the same cost of capital. In other words, if the operation were to cease for a period, the time at which future cash flows would be realized would be delayed and, in that circumstance, the new present value would decline because of the effect of discounting.

The second component, dV/dT, is related to variations in present value because of changes in economic conditions such as prices and time costs. If no resource were consumed, the rate of change would be dV/dT, which measures the penalty per unit of time of changes in economic circumstances if nothing is done. It can be estimated as the present value at the end of time t minus the present value at the beginning of the same period. This has to be done with the same quantity of resource and the difference, ΔV, could be positive or negative depending on the nature of the change. For instance, if price increases over time but the rest of the variables remain constant, the difference will be positive and the net result will be a bonus rather than a penalty.

In conclusion, the revenue that comes from exploiting any fraction of the resource should cover not only the operating and fixed costs of the operation but also the foregone opportunity cost of being in operation. To put it another way, the owner of the business always has the option of selling the operation at any time and investing the proceeds at the company's discount rate. Therefore, if the owner is to make a profit, the operation has to first cover all of the operating expenses, including this opportunity cost.

The effect of a change in market conditions, specifically the price of the commodity, may be illustrated in the previous coal mine example by assuming a sudden increase in the coal price from the estimated figure of \$10/t to \$12/t. If this change is judged to be transitory, with the price recovering to its forecast level within a year, the extra revenue for the policy of Table 3.4 is \$26 million (\$2 extra per each of the 13 Mt extracted in the first year). The present value of the long-term plan exhibited in Table 3.4 is then increased by \$21.67 million, from \$214.20 to \$235.87 million.

This change in present value necessitates the determination of a new exploitation policy. Assuming that the first fraction of the deposit is again set at 15 Mt, the value added for each rate can be reestimated. However, this time, both components of the opportunity cost must be considered.

This effect can be viewed by pretending that instead of extracting that fraction of the deposit, nothing is done in the first year. In that case, opportunity cost F comes from the postponement of the present value over that period ($k \cdot V$) minus the change in present value resulting from the passage of time (ΔV). This gives a total unit value of \$68.88 million/yr, which corresponds to the algebraic sum of $k \cdot V = 47.18$ (0.2·235.9) and $\Delta V =$ 21.70 (214.2 – 235.9).

For each rate of extraction, the time period in which the fraction is depleted is different, as is the cash flow and opportunity cost. For instance, if the rate of extraction is 10 Mt/yr, the time is 1.5 year. It means that the first 10 Mt yield a net cash flow of \$70 million and the remaining 5 Mt only yield \$25 million (because at that time, the price and margin is \$10/t and \$5/t of coal, respectively). The total cash flow for this amount of resource at this extraction rate is \$95 million. When taking away the opportunity cost of \$103.32 million ($1.5 \cdot 68.88$) to this cash flow, a value added of \$–8.32 million is obtained. Table 3.5 displays the margin for both prices p as well as a summary of the results and the value added for each rate.

The maximum value added is reached at 15 Mt/yr, which indicates that in response to a temporary price rise, the rate of extraction should be increased a bit to maximize the

TABLE 3.5 Optimum rate for the first increment

Rate (Mt/yr)	Margin ($/t) p = 10 $/t	p = 12 $/t	Time, t (years)	Cash Flow, C (M$)	Value Added, v (M$)
10	5.00	7.00	1.50	95.00	–8.32
11	4.91	6.91	1.36	95.65	1.97
12	4.75	6.75	1.25	95.25	9.15
13	4.54	6.54	1.15	94.10	14.89
14	4.29	6.29	1.07	92.35	18.65
15	4.00	6.00	1.00	90.00	21.12
16	3.25	5.69	0.94	85.35	20.60

TABLE 3.6 Long-term policy for an increased price

Year	Reserves (Mt)	Rate (Mt/yr)	Profit (M$)	Value Added, v (M$)	Remaining Present Value, w (M$)
1	90	15	90	42.48*	237.61
2	77	13	59	19.97	195.13
3	64	13	59	23.97	175.14
4	51	12	57	26.77	151.15
5	39	12	57	32.12	124.38
6	27	11	54	35.55	92.26
7	16	11	54	42.66	56.70
8†	3	10	15	14.10	13.51
				Σ 237.61	

* The total value added of $42.48 can be split in two: (1) $23.41 ($237.61– $214.20), which corresponds to the pure effect of the price increase; and (2) the remaining $19.07, which is the value added in absence of that escalation.
† 4 months.

value added. This result is consistent with market forces, in the sense that a price increase is nothing more than a call for more production. A stable policy is reached after two iterations and the remaining years seem almost identical to the previous policy of Table 3.4. The new policy is shown in Table 3.6.

The present value for this new policy is $237.6 million, $1.7 million above the alternative of doing nothing (policy of Table 3.4 valued with the increased price in Year 1).

In summary, an optimum way of depleting a finite, nonrenewable resource has been discussed. The fundamental finding is that the finite character of mineral deposits modifies the common maximization condition as traditionally applied in economic theory. Time, in this case, plays an essential role in the analysis. It calls for a multiperiod optimization, which in turn demands a special metric to gauge the economic profit that results from the resource exploitation. Under this approach, ore is defined as any material that when mined and processed adds economic value to the business.

These optimality principles are general and could be applied to any business based on a finite life asset. If they are to be employed in the management of mineral resources, an in-depth discussion about the special characteristics of mineral deposits is required. This is indeed the objective of the next chapter.

CHAPTER 4

The Mining Strategy

Chapter 3 outlined the basis for optimally exploiting what was supposedly an ore deposit with fixed boundaries and constant characteristics. The analysis was aimed at tracing the economic principles to be applied to the depletion of a mineral resource and at devising an appropriate metric to gauge the ongoing economic profit resulting from the exploitation. In reality, however, mineral deposits are more complex, and so are the mining and processing techniques that separate their valuable content.

The objective of this chapter, therefore, is to characterize mineral resources in a more realistic way and then examine the effect of the characterization on the development of a complete mining strategy. These activities are commonly called mine planning, although the term is used here in a wider context that comprises the planning of the entire productive chain—from the ongoing reconnaissance of the material in the ground to the delivery of the final product.

Fortunately, as will become evident as the analysis progresses, the principles and the metric derived in Chapter 3 can still be used when considering the special features of mineral resources.

MINERAL RESOURCE CHARACTERISTICS

Mineral resources form as a result of continuous natural forces acting over vast periods of time. Although the genesis of these geologic phenomena can be grouped according to some common patterns, specific conditions in the host setting and the environment make all formations distinct. This means that the characteristics of mineral occurrences are unique and depend on the location and circumstances in which the formation process took place and later developed.

An adequate knowledge of the mineral deposit is critical in mining, for all the economic analyses and decision making about the deposit's fate must be made based on conjecture about the true characteristics of the deposit and its behavior during mining. When the deposit's life cycle begins, information about its characteristics is scarce and usually limited to sparse sample data. This fact permits only a vague representation of the true intrinsic geological properties of the mineral deposit, with geologic intuition and sound judgment being crucial in the modeling and interpretation of its features.

These unique characteristics make mineral investments somewhat different from other types of investment opportunities. In addition to these particular features, mineral deposits can be mined only where the minerals are found, so options for locating an operating site are likely to be more limited than with other types of industrial developments (Torries 1998).

Mining professionals often depict mineral deposits by contouring their boundaries in a rather sharp way so that they can be easily visualized. This oversimplification can be misleading because it may result in an erroneous notion about the homogeneity of the mineral deposits within these confines. Although some deposits, such as strata-bound and vein-type deposits, can be reasonably represented in this way, mineralization and almost all geological properties are essentially erratic (although they may also follow some structural patterns). In fact, grades and other geologic attributes are generally distributed in a way that makes determining exact boundaries difficult.

In addition, geologic modeling and interpretation is often complicated by a variety of natural phenomena that continually occur in the earth's crust, such as erosion, tectonic movements, and volcanic eruptions. All these activities may radically change the original state of the deposit. Figure 4.1 shows how a mineral deposit is typically depicted in a cross section. In this case, the various patterns represent the grades of what could be a disseminated-type copper deposit, intersected by six 50-m-spaced vertical drill holes.

As these intersections illustrate, the grade within the confines of what could be the region of interest is essentially variable, although a certain trend is also evident. Any attempt to extrapolate this information calls for imagination about how the anomaly occurred and how it came to be in its current state.

Geologic and Block Models

For descriptive purposes, a mineral deposit is normally represented with a geologic model, which is essentially a three-dimensional array of attributes that attempts to describe the spatial characteristics of the deposit. These attributes come from different types of samples and include the presence of various minerals and metal contents (grades, including impurities), as well as other measurements, such as rock types, density, hardness, and even metallurgical parameters. The model may take the form of plans and sections or a computerized three-dimensional database, as is now the norm. The geologic model serves as the basis for establishing a geologic block model, which is the first attempt to represent the deposit in terms of selective mining units. The shapes and sizes of these units are associated with the method of exploitation and the characteristics of the deposit.

In the case of a small open pit mine, blocks could be small parallelepipeds, say cubes of 5 × 5 × 5 m. For larger open pit mines, the block size can be bigger, say 20 × 20 × 15 m for a 15-m bench-height mine. The block size is a function of the grade variability, the geometry of the deposit, the bucket size of the loading equipment, and the bench height, among the most relevant. Although the selectivity process in an open pit mine is not really carried out in terms of blocks, mine planning becomes much more manageable with a block model, especially when available computer tools are used. In fact, the day-to-day selectivity carried out in an open pit mine—or more precisely, the operational

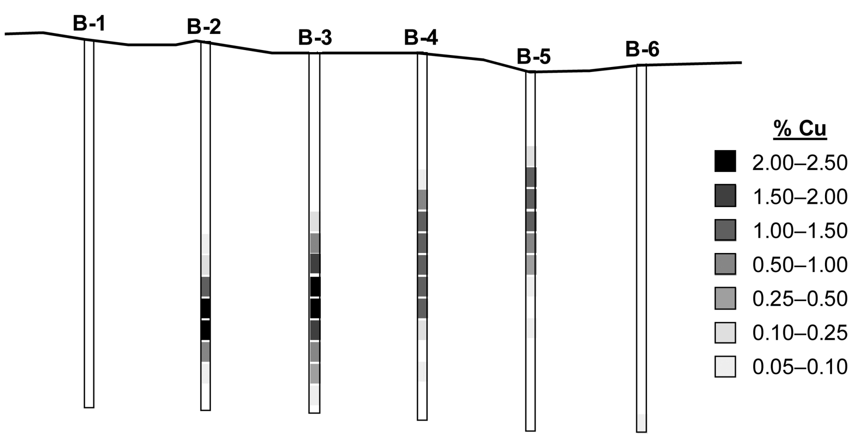

FIGURE 4.1 Drill-hole intersections for a mineral deposit

separation of ore and waste—is usually done in irregular zones made up from isograde or dig lines demarcated over the blast pile. These lines or boundaries, which define the destination of materials coming from the pit, are estimated from the grade samples yielded by blast-hole assays and certain specific cutoff criteria. If the block model is created properly using good geologic information and sound estimation procedures, the selectivity process simulated by means of blocks in open pit mine planning seems to be a good approximation of what the operation can achieve.

The same types of blocks can be used to design selective mining units in underground methods. In underground mining, however, the selectivity process and block size are closely tied to the exploitation technique. In stoping methods, for instance, the computerized stope design is facilitated with a small block, say 2 × 2 × 2 m, which can adequately contour the distribution of mineralized zones in the periphery. Then the contents of blocks within the stope, appropriately adjusted by a dilution factor, can function as a good estimator for the tonnage and grade of the stope.

In caving methods, such as block caving or panel caving, larger blocks, say 30 × 30 × 15 m, can be used to make up the columns from the base up. If the grade of these blocks is properly diluted, the column height can be established by applying a certain cutoff condition. As in open pit mining, the day-to-day selection in underground mining is not made through blocks, but by means of sampling and grade control at drawpoints or loading faces, together with a cutoff condition. Therefore, the predictions of tonnage and grades in underground mining deal not only with in situ block grade estimation, but also with dilution criteria.

The geologic block model is also a three-dimensional data inventory, although in this case the geologic information is associated with blocks. Each block is ascribed the corresponding geologic properties of the surrounding sector. These properties are estimated from nearby sample data by interpolation, which is usually done in conjunction with the geologic model. In this way, the estimation process is controlled. As previously discussed, to acknowledge operational factors, a mining block model is usually necessary for mine planning. The purpose is to incorporate certain aspects of the operation, such as mining dilution and metallurgical recoveries, into the geologic block model. In practice, this is done by correcting the in situ estimations of blocks, which are affected in some way by the mining operation. These adjustments improve the forecast of tonnage and grades, the quality of mine planning, and eventually, the economics of the business. This ongoing process requires, at the beginning, preliminary estimates that are refined in due course as the mining operation becomes stable.

Figure 4.2 depicts a two-dimensional view of what could be a block model for the drill-hole intersections of Figure 4.1. In this case, the size of the blocks is 10 × 10 m. Grade blocks were interpolated using the inverse distance square method, samples were regularized at 2.5 m, and a search radius of 30 horizontal meters and 15 vertical meters was defined. The purpose here is not to advocate any particular method of grade estimation but to show how the general procedures advance from the geologic information to the establishment of a mining block model. In fact, grade estimation in mining is a special subject deserving special attention that is beyond the scope of this study.

In summary, establishing a geologic model that conceptualizes the mineral deposit is a preliminary task for any mine planning activity. This geologic model is the foundation for creating a geologic block model and then a mining block model. These block models, in turn, serve as the basis for the mine planning process.

The quality of all these estimates affects the reliability of all subsequent analyses. For this reason, in the development and operation of mines, much effort and money is usually expended on ongoing exploration, sampling, testing, and estimation techniques. As mining proceeds, more information is added to the geologic model. This constant flow of information coming from the exploitation, coupled with the information originated from successive infill drilling campaigns, creates a continuous process that

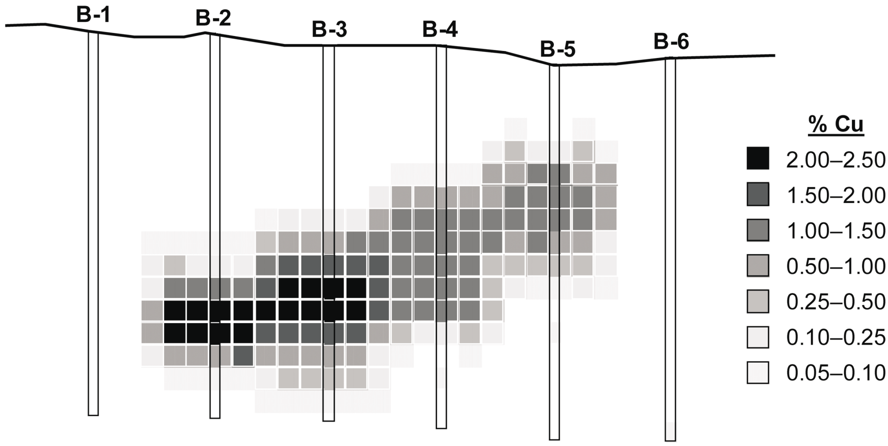

FIGURE 4.2 Block model for a mineral deposit

progressively increases the knowledge and understanding of the mineral deposit. This process begins when the deposit is discovered and continues until it is eventually exhausted or abandoned.

Level of Reconnaissance

One of the fundamental aspects in assessing the economic value of a mineral deposit is the quality of the estimates, particularly of tonnage and grades. This quality is intrinsically associated with the amount of geologic information and the procedures employed for gathering and analyzing samples. Interestingly, the amount of information collected from a mineral deposit is negotiable, in the sense that additional information and thus better-quality estimates can be always achieved by expending more time and money in the reconnaissance of the resource.

The level of reconnaissance of a mineral deposit does not necessarily have to be the same for the entire resource. Because of the time value of money, only the sectors to be mined in the early years require detailed information. In fact, the economic contribution of sectors that will likely be extracted after Year 20 in a mining project is almost negligible for assessing that deposit's value. The importance of a mining schedule then becomes significant at the time of designing an infill drilling campaign—even at the development stage. As mining goes on, forward sectors of the deposit must be progressively equalized in terms of reconnaissance, which calls for ongoing reconnaissance programs at most mines.

The opportunity cost concept developed earlier should first be put into operation in the early stages of the deposit's life cycle. In effect, dealing with a less than well-defined deposit always raises the question of whether further reconnaissance is necessary. It should be done only if it adds value; that is, if the current value of the deposit is less than the value achievable if additional reconnaissance works were executed. The economic value added by an infill drilling campaign would then be the difference between the value of the deposit with and without the additional information. If the campaign were planned for execution before the production stage, it would delay the project's start-up. In such a case, an opportunity cost should be considered in the cost-benefit analysis. The opportunity cost is related to the delayed cash flow resulting from postponing the venture for the period devoted to the campaign's execution. Therefore, if the campaign is to add economic value, its economic contribution must also cover this opportunity cost.

This assessment is fundamental because planning an infill drilling campaign during the development stage implies a considerable amount of money and time, and the opportunity cost is contingent on this time interval and the value of the deposit at that time. To increase the economic value added as a result of the campaign, careful management is crucial.

It is worth mentioning that an additional benefit associated with an infill drilling campaign is the improvement in resource classification. According to the amount of supportive data (samples), geologic resources are usually categorized as measured, indicated, and inferred. In the case of minable reserves, meaning the fraction of the resource that is actually reported in the mine plan, the categories are proven and probable. Despite the effort of mining organizations and linked institutions in trying to standardize the use of these definitions, it has been difficult to produce a set of precise norms because this aspect of the mining business is neither easy to quantify or simple to value. In any case, in terms of reliability of estimates, it is always desirable to draw on a large number of samples, but this must be balanced with the economics of the business. In short, to be justified, additional information must add economic value.

Distribution of Minerals

From the mining point of view, the distinctive and most important feature of a mineral deposit has to do with the variability and distribution of minerals within the deposit. This characteristic is important for both the valuable minerals and the impurities. Volumes and concentrations typically vary across the resource. If mining is to be profitable, these anomalies require not only a certain minimum concentration of valuable minerals but also sufficient tonnage. Thus, the whole mining process can be viewed as the art of separating these valuable contents in the most effective and efficient way. In general, two fundamental aspects must be managed:

1. The way and sequence in which the ore deposit is mined
2. The progressive separation of the valuable minerals from the ore.

The mining sequence and selective process are often intertwined, because to improve the performance of the downstream plants, many mining operations have to blend the materials extracted from the mine. This aspect is critical when exploiting mineral deposits that contain undesirable elements or impurities. For example, consider phosphorous and sulfur in iron ores where a high-grade iron sector containing these impurities above a certain limit cannot be classified as ore unless it can be blended with another sector that allows the limit to be achieved. Because this is what mine planning is all about, the next section deals first with planning in general and then with the planning of mines in some detail.

THE PLANNING PROCESS

Planning is a vital function in any business undertaking. In general, planning can be described as the process of determining how an organization can get where it wants to go. Objectives are identified and plans for achieving them are progressively generated. These ongoing plans are or should be increasingly valuable according to some evaluation criteria. In mining, however, they can also be the result of changing market conditions or increasing knowledge of the mineral resource. This process, which is at the core of all planning activities, is one of repeated refinement, revision, and reevaluation. Within this process, plans are usually generated in three stages. At the outset, a general strategic plan is typically envisaged, providing a framework for more specific plans, each contributing to the general strategy. Additional detailed plans are then developed for evaluation and, finally, implementation. Figure 4.3 depicts this distinctive process.

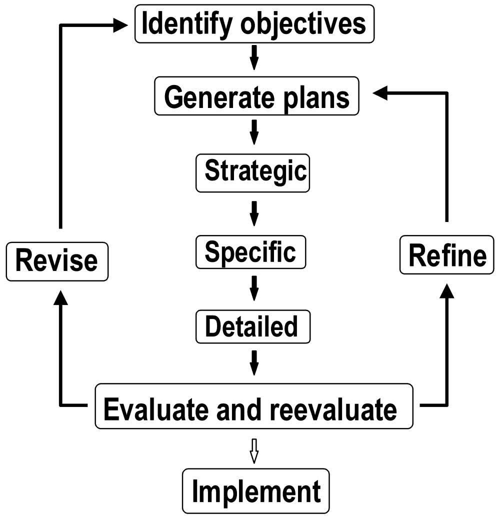

FIGURE 4.3 The planning process

Mine Planning

Although mine planning is essentially the same as planning conducted by other businesses, it has certain unique characteristics that result from its dependence on a mineral resource. As already discussed, this is a complex and finite asset with attributes that are determined progressively as time and money are invested. After a mining operation begins, the knowledge of the deposit is gradually enriched as more information is revealed by the ongoing reconnaissance and the exploitation itself.

The final product of the mine planning process is a business plan for exploiting the deposit. The business plan includes a mine plan, which is the production schedule that indicates the origin and destination of tonnage and grades to be extracted from the deposit. As a business plan it also specifies the human and material resources required for implementation—personnel, equipment, and consumable goods being the most important.

Formulating the mine plan is critical to the success of the mining business because, for certain market conditions, this plan largely determines the economics of the exploitation and ultimately the value of the mineral resource. In effect, the mine plan establishes the revenues, capital investments, and operating costs for the whole mine life, all of which account for the cash flow stream of the business. Unlike in most other industries, alternative plans cannot be compared directly within certain periods. Mining in any period affects the extent and state of the remaining resource. Evaluation, therefore, must extend over the life of the deposit and take into account variations in mine life as well as variation in schedules during the mine life.

Mine Planning Stages

Traditionally, the mine planning process is divided in stages according to either the level of detail of the analysis or the time scope to which the planning decisions apply.

When the level of detail is sufficient, a typical conceptual planning stage is developed. It establishes a basis for the main variables of the project. If the project looks promising, a feasibility planning stage, which is required to obtain the capital to bring the mine into production, follows. If successful, this is followed by the operational planning stage, which is aimed at specifying the details about how the overall plan will be implemented. This division is useful when dealing with progressive decisions such as those occurring at the outset of the business cycle, before operation begins. It is also appropriate for appraising mining properties and studying expansion schemes in existing operations.

When a time frame is imposed on the analysis, the planning process is broken down into long-, medium-, and short-term planning. The idea is to group activities according to the degrees of freedom in which decisions are made. In long-term planning, almost all decision variables are free and are therefore subject to specification; in short-term planning, certain variables are already set so the planning becomes more restricted. It is common to use this categorization in the planning activities of operating mines, using time as the parameter to characterize the scope of the business period. Long term is thus usually defined as a period of time extending 5 or more years into the future; short term is associated with activities within the next year.

Instead of classifying the mine planning process in either way, the proposition here is to divide its activities according to their degree of breadth. In this respect, two types of mine planning may be defined—strategic mine planning and tactical mine planning.

This classification is introduced for two reasons. The first is to highlight the importance of two systematic types of mine planning throughout the entire life cycle of the mining business. The second is for organizational purposes, although this issue will be covered in the next chapter. An explanation of these two types of planning, along with an outline of how they should be used in mining, follows.

Strategic mine planning deals with the factors of the operation and the decisions that largely determine the value of the mining business. The main concern is the development of the plan to mine out the whole mineral resource. Among the typical aspects to specify within its scope are the method of mining, the processing route, the scale of operation, the mining sequence, and the definition of the various operational cutoffs that progressively separate the valuable fraction of the resource. Even though all these variables are set at the beginning of the business cycle, they must be reviewed periodically as the internal and external conditions of the business change. In operating mines, the scope of strategic mine planning is related to the continuous revisions of long- and medium-term plans, which is essential for maintaining an up-to-date basis that defines the future of the operation. This plan is necessary for consistent direction but also serves as a base against which to assess new plans and, ultimately, new projects.

Tactical mine planning, on the other hand, encompasses the routine planning activities required for commissioning the operation and ramping it up. In operating mines, the scope includes the continuous reworking of short-term production plans with the aim of incorporating the new information gathered from the operation into the actual plan. Tactical mine planning also deals with the preparation of budgets; equipment deployment and production scheduling, on a monthly, weekly, and daily basis; grade and quality control; and various other routine activities. Figure 4.4 portrays both types of planning and shows their relative importance during the life cycle of a mineral deposit.

This particular way of looking at mine planning reinforces the timeless character of strategic mine planning. Strategic considerations are not restricted to the earlier stages of the life cycle of the mining business but are important through all the stages within the scope of this study. Traditional mining practices, on the contrary, employ conceptual planning only at the beginning of the business cycle, then switch to operational planning right after development.

In summary, strategic mine planning is concerned with those decisions that largely determine the value of the business, and tactical mine planning is concerned with the tasks required to actually achieve that value. Both types of planning are necessary; they can be looked at separately, even discussed separately, but they cannot be separated in

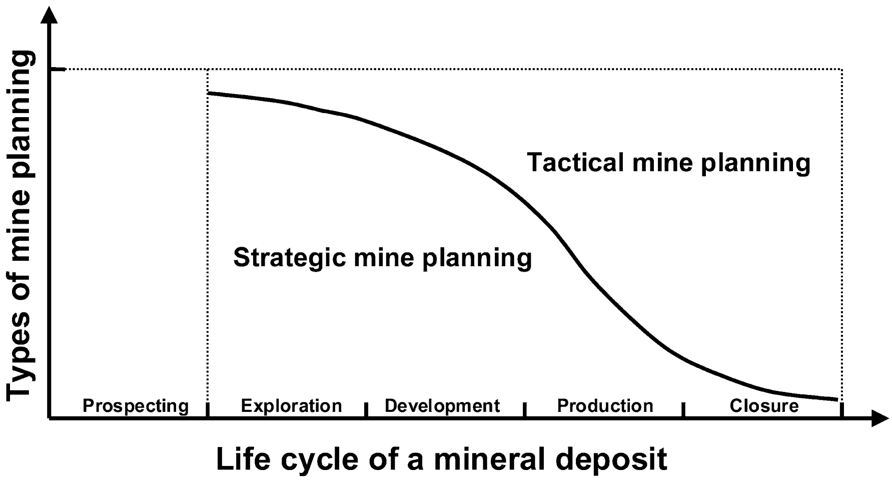

FIGURE 4.4 Types of mine planning and the life cycle of mining

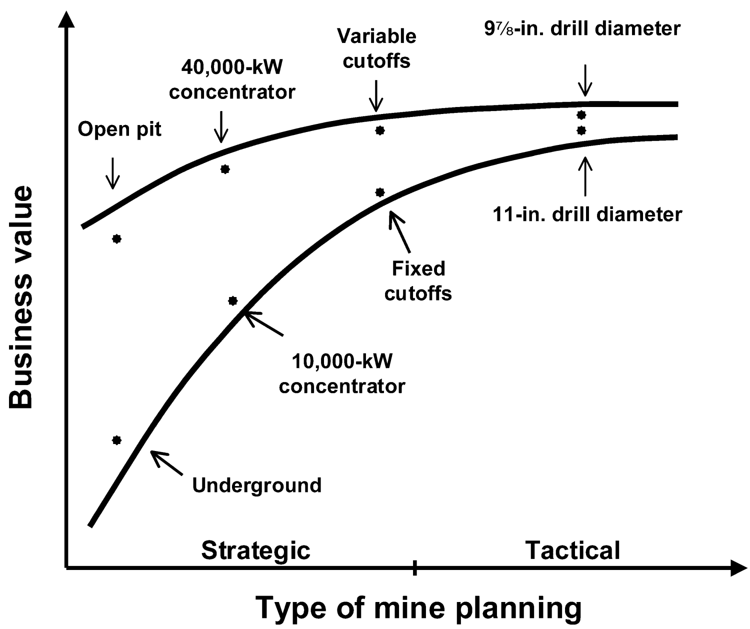

FIGURE 4.5 Profitability and decision making in mine planning

practice. Figure 4.5 illustrates the impact of both types of planning decisions on the profitability of the business.

As depicted in Figure 4.5, variables within the scope of strategic mine planning are key to establishing the value of the mineral resource and, ultimately, the value of the mining firm. Their proper determination is an important step toward achieving economic value. The following sections, therefore, go deeper into the major issues involved in strategic mine planning. First, a conceptual framework is developed to link these variables and then each variable is examined in some detail.

MAJOR ISSUES IN STRATEGIC MINE PLANNING

Strategic mine planning is a powerful tool for enhancing the economics of the extractive mining business. It is crucial during exploration and development, although it may also become key to creating value at the production stage (during the day-to-day operation). All the variables involved in strategic mine planning are related to the mineral deposit, so the ongoing reconnaissance described here must continue throughout the entire life cycle of the mineral deposit. Then, having conceptualized the geologic model, the main technical decisions that follow, in a logical but not necessarily a time sequence, are

- The method of mining
- The processing route
- The scale of operation
- The mining sequence
- The selective cutoffs

These variables are intertwined in the sense that none of them can be determined in isolation from the others. The scale of operation, for instance, has to be assessed once the mining and processing methods, the mining sequence, and the selective cutoffs have been thought through. Likewise, defining the mining sequence requires that the rest of the variables have been previously set as well. This is the well-known "chicken-and-egg" dilemma that pervades all strategic mine planning activities. It has to be solved recursively, through gross initial assumptions that are refined as iterations proceed and the problem becomes clearer. In practice, the key aspects of a mining operation are formally conceived during the development stage where these strategic variables are initially set. Thereafter, however, the same variables, especially those that have certain flexibility (such as the mining sequence and the selective cutoffs) must be reviewed regularly during the production stage.

During the development stage or even in major revisions of plans for actual mines, this circular analysis eventually delivers a mine plan that satisfies the firm's expectation and serves, among other purposes, as a reference for further detailed planning. Through this analysis, feedback about important aspects of the deposit is received from the market and from other technical models (the geologic, metallurgical, geotechnical, and environmental models). If sociopolitical issues are also relevant, they must be considered as well. In any case, for the purpose of this conceptual framework, all these aspects can be considered collateral models.

Although the scope of the geologic model has already been discussed, it is important to mention here that once a mine plan has been delivered, it serves as a guide for identifying the sectors that might require additional reconnaissance. Because of the effect of the time value of money, the earlier years of the mine plan should always be the best-known sectors. The mine plan also serves as a guide for updating the metallurgical model, which is intended to predict the metallurgical response of the composites indicated in the mine plan. In general, the metallurgical behavior of individual ore types varies if they are combined in different proportions. As the mine plan outlines the origin of tonnage and grades to be extracted from the deposit, this information becomes key to preparing pilot tests and thus determining in advance the metallurgical response of the plan's composites.

The mine plan also furnishes useful information to the geotechnical and environmental models. In the geotechnical model, the evolution of the excavations, which is indicated in the mine plan, allows the rock mechanic specialists to specifically predict the stress patterns in the various mine sectors. This information is useful for assessing design criteria and determining operational parameters, such as slope angles, excavation and pillar dimensions, and the like. Then again, the environmental model, which is intended to assess the impact of mining on the environment, is highly dependent on the mine plan.

For instance, smelting operations are usually monitored to verify that they comply with certain maximum amounts of emissions. This often means that the sources of emissions or impurities from the mine must be controlled, which in turn may call for special blends.

Figure 4.6 illustrates this conceptual framework by comparing the development of the mine plan to the creation and delivery of life. This analogy is deliberate because the idea is to highlight the importance of the gestation period, which is fundamental for a sound delivery. As in nature, the plan's development should not be done prematurely or carelessly. Once a mine plan is conceived and implemented, there is a point of no return—although the plan can later be enhanced and even ceased, it can never be retrieved. The opportunity to develop a deposit from its original state occurs only once.

In the model, the market supplies the nutrients and the collateral models yield the technical input that will allow the strategic mine planning process to nurture and eventually deliver a mine plan. This plan then serves as feedback to these outer models and occasionally even to the market, if the deposit were big enough to justify a large operation. In effect, a large project might affect not only the price of the commodities it produces but also the input costs—which may even include a higher discount rate resulting from a firm's greater exposure to risk.

Before going deeper into each topic of strategic mine planning, it is important to emphasize that the intent here is not to discuss the technicalities of mining, which are well-covered in the literature available in the field. Instead, the focus is on examining the economic implications of these decisions and suggesting how they can be managed to enhance the performance of the mining business.

Selecting the Mining Method

Selecting the most appropriate method of mining is the first and most basic attempt to separate the ore from the ground. To return the greatest profit, the chosen method must best match the unique characteristics of the mineral deposit, as well as the limits imposed by safety, technology, and economics (Hartman 1987). The choice between

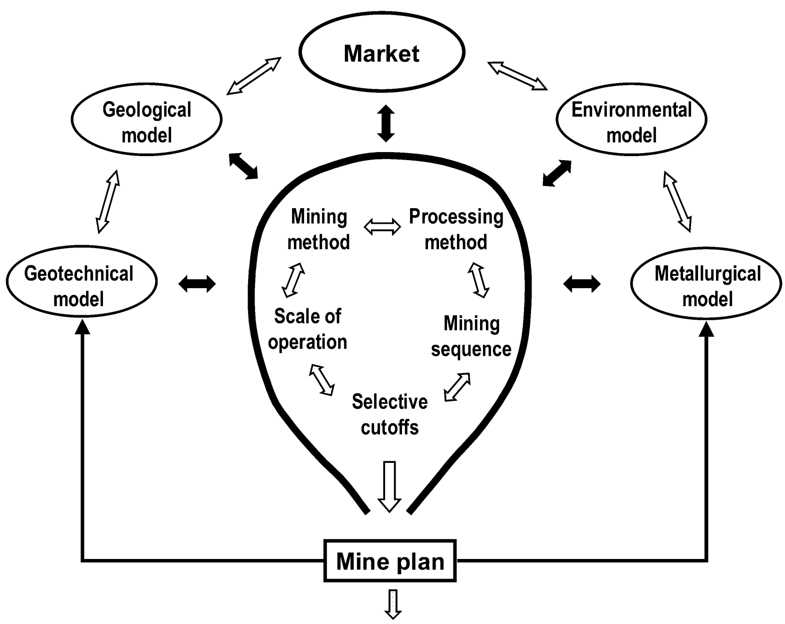

FIGURE 4.6 Strategic mine planning model

surface and underground mining is often clear from a rough evaluation of the deposit's spatial characteristics. To choose between the two methods, the analysis must sometimes be continued through the detail of a feasibility study. In some cases, an optimal solution combines two or more methods, and perhaps the various methods can be applied either simultaneously or consecutively. Consider, for example, mining operations that start with surface mining and then switch to underground mining when the economics become advantageous.

Under certain market conditions, the most important determinants for selecting the mining method are the spatial characteristics of the deposit—size, shape, depth, dip, and grade distribution, for example—as well as the geologic properties of the rock mass that comprises the deposit and adjacent host rock. All in all, however, economics ultimately govern the choice.

Because the opportunity cost concept developed earlier is subtly embedded in this decision, a proper analysis requires an awareness of that factor. For example, when the shape of a deposit suggests an open pit mine followed by underground works, the analysis to determine when the methods should be switched must take into account the various existing possibilities—a stand-alone underground mine, a stand-alone open pit mine, and the many combinations of both. If the bulk of the higher grades are at the bottom of the deposit, dismissing the open pit may be beneficial even if the level of deposit recovery is reduced. This strategy may bring forward the profit associated with the higher grades, outweighing the costs of sacrificing the upper part of the resource. In the same way, the opportunity cost of delaying a future underground exploitation must always be considered when the optimum open pit underground frontier is being defined. Accordingly, the ore from the last pushback in the open pit should cover not only its stripping cost but also the cost of delaying the value of the underground project.

On the other hand, if scattered lenses of high-grade ore are susceptible to extraction with underground methods along with a small plant, a larger plant combined with a more productive open pit operation might be a more profitable mix. In this case, the higher productivity and rate of development of the open pit method may outweigh the positive features of other underground methods that could be applied.

It is important to emphasize that there are no definitive rules for finding the best mining method. The best method is selected using a combination of dexterity, creativity, and above all, business perceptiveness. The process is also time-consuming because it calls for many alternatives, all of which must be conceived and developed over the whole resource, to be developed.

The formation of the team to carry out this activity is fundamental. Although this organizational problem will be analyzed in more detail in the next chapter, it is mentioned here because the selection of the mining method strongly influences the overall selectivity process and the strategy for developing the deposit. In effect, as technical experience plays a major role in the decision, the backgrounds of the people involved usually channel the selection toward preconceived ideas that act as a sort of paradigm. This can be explained by the old adage that when someone holds a hammer, everything looks like a nail. To reinforce this point, it is important to mention that the underlying goals of many technical people in the traditional mining organization are often aimed at improving operational parameters such as productivity, selectivity, dilution, life of mine, and even production costs. Although all these pseudo-objectives may sound desirable, none of them account explicitly for the NPV of the business or consider the opportunity cost that may be embedded in the decisions.

Selecting the Processing Route

The objective of further processing the run-of-mine (ROM) ore is to extract the valuable substances contained in the host rock. From an economics viewpoint, two critical aspects deserve special attention. First are the marginal costs associated with the processing of ore, which may include an opportunity cost tied to the time interval at which the extraction takes place. Second is the process efficiency, which is often measured in terms of the percentage of recovery and the product quality. These features, costs and efficiency, are headed in opposite directions in the sense that efficiency usually increases only at the expense of extra time and costs. In this case, time means money too, although not just in terms of that spent in additional reagents, labor, and the like, but also as the opportunity cost of delaying the treatment of remaining ore.

It is worth mentioning that most of the industry's research and technical literature is oriented toward efficiency and cost-related subjects. Not much attention is paid to all the consequences of time-related subjects in the overall performance. Depending on the circumstances, time may have a considerable effect on the economics because the period at which the separation occurs to a large extent determines throughput, which in turn defines the rate of extraction of the deposit and, eventually, the life of the mine. The analysis that follows, therefore, is aimed at describing the main methods for detaching ore minerals from the gangue and at examining the trade-off between efficiency and time in some detail. Both aspects are essential not only for choosing the processing route but also for properly designing and using the plant installations.

Basically, two fundamental operations take place in mineral processing. One is the release or *liberation* of the valuable minerals from their waste gangue, and the other is the *separation* of these values from the gangue (Wills 1992). Liberation mainly encompasses size reduction or comminution; separation deals with grade enrichment or concentration. Depending on the ore properties and ultimately on the economics, separation can be performed by physical or chemical methods. In physical methods the separation occurs without altering the intrinsic structure of the ore minerals; in chemical methods detachment takes place by induced changes in the chemical properties of the ore. Figure 4.7 illustrates these operations.

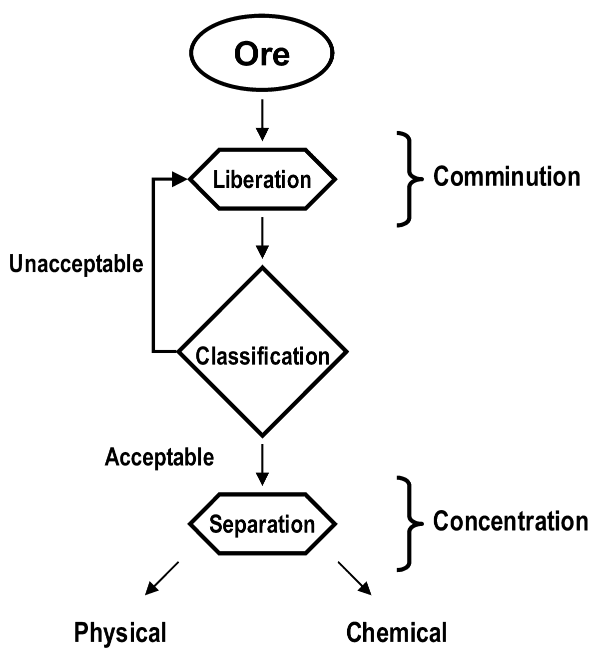

FIGURE 4.7 Basic processing operations

To separate the valuable content, physical and chemical methods exploit certain properties of the ore. Flotation, for example, makes use of surface properties, gravity methods of density, magnetic concentration of magnetic properties, sorting and manual selection of optical properties, leaching of solubility, and solvent extraction of extractability, among others. Physical methods of separation are all grouped under a discipline generally called mineral processing or mineral dressing. Although they may use external reagents to condition and enhance the process, this treatment rarely changes the composition of the ore. Chemical methods, on the other hand, use external elements to alter the mineralogical composition of the ore and produce the separation. Examples are the action of heat in pyrometallurgy, solvents in hydrometallurgy, or electricity in electrometallurgy. Choosing a particular route depends on the characteristics and properties of the ore minerals and gangues, although mixing or sequentially combining various methods is also common.

Mineral processing is usually carried out at the mine site in facilities known as the mill or concentrator. In this case, the enrichment process is aimed at increasing the contained value of the ore to allow more economic transportation. Liberation is accomplished by comminution, which includes crushing (and grinding if necessary), to such degree that the product is a mixture of relatively clean particles of mineral and gangue. The major objective of comminution is the release of the valuable minerals from the associated gangue minerals at the coarsest possible particle size. Grinding is often the most capital-intensive and the greatest energy-consuming unit operation, accounting for up to 50% of a concentrator's energy consumption. To improve efficiency, it is necessary to grind the ore fine enough to liberate the associated metals. Fine grinding, however, takes more time, increases energy costs, and eventually reduces throughput. Sometimes, it can also produce very fine slime particles, which may be lost into the tailings. Grinding, therefore, becomes a compromise between the degree of liberation of the ore minerals, their subsequent recovery, and the rate of treatment of the ROM ore.

Separation in mineral processing often takes place once the ore minerals and the gangue have been liberated. Regardless of the method, separation is always aimed at recovering the maximum amount of valuable minerals, in the smallest total amount of material, in the minimum amount of time. The objective is to separate the various minerals into two or more products—the concentrates containing the valuable components and the tailings containing the gangue. As in liberation, during separation compromises must be made among the recovery of the valuable minerals, the quality of the product, and the rate of treatment. These compromises are necessary because better recoveries are usually achieved at the expense of further dilution and more time. The dilution may be caused by incomplete liberation (especially of those small particles locked within worthless rock) or by inadvertent recovery of liberated gangue minerals (which may result from process conditions of poor selectivity). Whatever the mechanism of dilution might be, it always leads to lower grades in concentrates.

Unlike many physical methods, hydrometallurgical processes such as vat, heap, or dump leaching require only that the liberation stage partially expose the valuable minerals so that the chemical reagent can percolate through and dissolve them. These processes are coming into wider use for base metal, precious metal, and even uranium ores. In recent years, they have been used in combination with solvent extraction and electrowinning (SX-EW) techniques, particularly in copper and gold ores. In porphyry copper deposits, this route is an alternative not only for the oxidized ore often located in the upper part, but also for the enriched or supergene ore that is usually found under the oxidized ore and above the primary or sulfide ore. The key feature of the SX-EW methods in copper is the use of special synthetic organic liquids that can extract copper so that it can be deposited later by electrolysis. This relatively low-cost method makes the economic processing of very low-grade ores possible. As air emissions and waste products are generally minimal, the method is doubly attractive.

Time-related parameters are essential for design purposes in hydrometallurgical processes. Metal recovery, for instance, usually increases as leaching solution circulates longer through the broken ore in the pile. The rate at which recovery increases, however, gradually diminishes beyond a certain time, which poses a key question about the best time at which to cease the leaching extraction (LX). The optimal time must be based on economic grounds, although the plant layout plays an important role in the economic analysis. In effect, if the piles are permanent and there is no downstream constraint, the marginal revenue should be compared to the marginal cost, which in this case is related only to the extra supplies required to keep the pile alive. However, if the piles are temporary or downstream restrictions exist, the time cost of postponing the treatment of fresh ore must be taken into account. In this last case, the productive life of the pile ultimately affects total production and consequently the pace at which the deposit is exhausted. This fact, often overlooked, constitutes an important input for selecting the size and fine-tuning of the downstream SX-EW facilities. Specifying the size of the final facilities for the SX-EW process, along with the quality of the final product, requires the production per period of time for delivery to the market to be set. The optimization problem is therefore reduced to producing such a quantity at the lowest possible cost. If leaching is expensive compared to mining, the rate of mining should be stressed and vice versa.

These trade-offs, as well as their impact on the whole mine plan and ultimately on the economics of the business, should be carefully studied during the method selection. In practice, laboratory-, pilot-, and even industrial-scale testwork helps a great deal in setting these variables and determining the best method. This testing process must be conducted consistently with the current mine plan, because the characteristics of the ore and the blending at the mine usually change as mining proceeds. This means that the composites for metallurgical testing should be based on minable ore, similar to the mixture contained in the mine plan.

Scale of Operation

The scale of operation refers to the size of the installations required to mine and process the ore minerals from the deposit. It is directly related to the initial investment and also strongly related to the amount of final product delivered to the market. The greater the scale of operation, the higher the production level.

It is common to associate the scale of operation with the treatment capacity of the processing facilities because they usually represent the major investment. In this context, an 80,000 tonnes/day (t/d) operation means a mine-mill operation in which the nominal capacity of the mill is around that figure. From the viewpoint of mineral resource management, however, it is more convenient to gauge capacity from some fixed physical units rather than from a measure that is actually a decision variable. A more appropriate reference for the preceding example could be the description of the grinding equipment, say 2 semiautogenous grinding (SAG) mills of 11×5.2 m and 4 ball mills of 6.4×10 m; or even the total power available at the mill, say 55,000 kilowatts (kW). Then, whether to treat 70,000 or 100,000 t/d in those installations becomes a decision that is contingent on the specific circumstances of the operation.

Likewise, in the case of a mine, the scale of the operation should be referred to the component that supposedly limits the rate at which the material is mined. It could be the main shaft in an underground mine or the loading and haulage system in an open pit mine. Instead of considering a 210,000 t/d open pit mine, for example, it could be better to express the size of the operation in terms of the shovel-truck fleet (such as three 44-m^3 shovels and eighteen 240-Mt trucks). In this way, the economic circumstances of the business determine the best mine output. This feature is fundamental because when estimating the maximum capacity of a mining operation, mining professionals tend to assume that the equipment and installations should work at the most efficient rate, a rate that in turn is usually associated with their lowest operating costs. In the previous example, the average loading rate of each 44-m^3 shovel is 70,000 t/d, but adding a similar shovel and some trucks could improve the economics even though it lessens the overall productivity of the system (an increase to 240,000 t/d in total could reduce shovel productivity to an average of 60,000 t/d, for example).

From the standpoint of a mining project, the scale of operation is always a dominant consideration because it is the main determinant of capital investments and mine life. As such, there is a compromise between the scale of the operation and the project's NPV. In effect, the larger the scale of operation, the higher the revenues and the lower the operating costs, but this usually occurs at the expense of higher investments and a shorter mine life, among other factors. An optimum NPV is therefore a compromise. A clear understanding of this fact is fundamental for the success of the business because for big deposits, it is almost always attractive to push up the scale of operation. However, a large project also poses serious concerns at the time of getting the funds, especially if the deposit is located in a place with political or social instability, because the risk exposure of the firm increases accordingly with the project size.

Mining Sequence

The mining sequence defines the way in which mining progresses through the ore body. The sequence addresses the problem of where to start the exploitation and how to expand it from there. It is important to emphasize that the mining sequence is an issue only because of the time value of money. Thus, instead of developing the deposit once and for all, it is phased so that revenues can be brought forward and investments spread out over the mine life. Under this premise, the mining sequence is obviously an economic problem that depends on the method of mining. It is also strongly influenced by the mineral distribution within the deposit. In this regard, it is economically advantageous to encounter the higher grades in the earlier years, but it is also common to encounter certain restrictions, such as the amount of development, the presence of impurities, and geotechnical constraints.

All these considerations are somehow internalized in the traditional way of dealing with the sequence problem. However, what is more difficult to notice is the relationship of the sequence variable with economic factors, such as the discount rate, opportunity cost, and commodity prices. These effects are illustrated in an example that corresponds to a real situation, which has been introduced to draw attention to the problem under analysis. It involves an iron ore complex that comprises an open pit mine along with the installations to preconcentrate the iron ore at the mine site and produce iron pellets in a facility located 100 kilometers (km) away from the mine site—close to the port of embarkation. Because the current deposit is close to exhaustion, the company is studying the opening of a new deposit located at about the same distance from the pellet plant, although at quite a distance from the current mine. The sequence problem, in this case, consists of establishing the time at which the new mine should enter into production and displace the old mine. The problem is depicted in Figure 4.8, which displays the layout and the calculation of the economic profit of what might look like the last push-back of the current open pit mine.

Both mines require the services of the pellet plant to treat and deliver their final product, so the proper evaluation of whether to continue operating the current open pit mine should take into account the opportunity costs of postponing the new mine, whose value is estimated at $120 million. The example of Figure 4.8 assumes that mining the push-back displayed in the cross section (denoted as the area from A to A′ in the figure) takes 1 year and redeems a net value of $10 million once finished. The $90 million in direct costs include the rehabilitation expenditures required to close the current operation. Considering an annual discount rate of 10%, the opportunity cost of postponing the

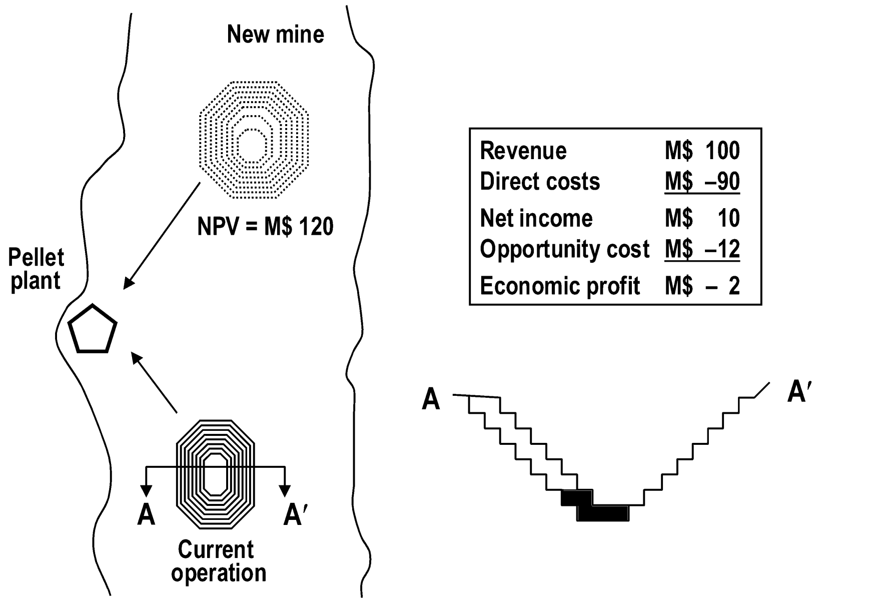

FIGURE 4.8 The sequence problem

new mine for 1 year is $12 million. This means that the push-back undergoing analysis is no longer profitable, at least at the time of analysis.

The new mine in the previous example could also be an underground mine, beneath the open pit operation, conceived to recover the deeper part of the deposit more economically. It could also be an independent push-back within the same open pit mine. In these cases, or in any other sequential problem, the measurement to assess the merit and order in which these independent units should be mined is again the same value-added metric derived in Chapter 3 (see Equation 3.15).

Despite efforts to develop computer tools to make handling this problem automatic, these efforts have not been very successful to date because a complete understanding of the problem itself does not exist, at least from the perspective of the approach presented here. Worse yet, when the selectivity feature and other operational constraints are added, the entire problem becomes even more complicated. This is the case when the sequence problem deals with the adding or movement of mining installations, such as in-pit crushing. A sensible solution, therefore, must always be found through a trial-and-error approach, in which the NPV of the whole operation is gradually increased as different sequences are tested.

Selective Cutoffs

A mining undertaking is typically composed of consecutive unit operations designed to progressively increase the value of the extracted material. It can be an open pit mine along with a concentrator to produce only concentrates; or an underground mine coupled with LX, SX, and EW processes to produce a certain metal; or even a stand-alone mine that extracts ore for direct selling. In all these cases, the valuable content of the deposit is progressively detached from its waste material by means of a selectivity process, which depends on the particular mining and processing methods.

At the mine, selectivity defines what will be ore and consequently, what will be waste. Depending on the mining method, this process generally establishes the ultimate mining boundary first and makes the selection inside that boundary second. The former is an investment decision in that the boundary determines the limit beyond which the potential ore no longer repays the cost of development. The latter is a cutoff decision that depends on production capacities and economics. In an open pit operation, for instance, the final limit is determined by analyzing successive push-backs incrementally. Within each push-back, however, normally mineralized material that is susceptible to being selected is found. In a block caving mine, on the other hand, the final boundary depends on whether a certain periphery block is profitable to develop. Thus, once the production level is set, the extent to which a particular block is extracted (column height) is usually a matter of selectivity. This is in the sense that a higher percentage of extraction is often accompanied by higher dilution. In this case, waste is the broken material that is discarded and left in the column when the extraction or drawpoints are shut down.

At the processing facilities, the selectivity process is again dependent on the metallurgical route. Regardless of the method, the objective of further ore processing is actually to separate the valuable minerals from the gangue until a commercial product is eventually achieved. Because this process can take one or more stages, the final product can be an intermediate product such as concentrates or a fine metal. Figure 4.9 displays the selectivity process described earlier using the same hypothetical deposit employed in the coal mine example from Chapter 3, but now with the selectivity feature added.

As in the other mine planning problems, the selective cutoffs over the whole mine life can also be optimized by using the value-added metric derived in Chapter 3. The procedure is similar to the one employed in that chapter's coal mine example, but in this case there are more independent variables. For a certain physical configuration, which gives the cost structures for the mine and each of the downstream processes, the independent variables are the rate of extraction at the mine and the throughput at each processing unit. Throughput at each unit, in turn, is defined by a selective cutoff, which decides which fraction of the input is rejected and which will continue being separated until the final product is delivered.

Optimizing all these variables simultaneously could be intricate if they are all set to be free. This is not just a consequence of the number of variables but also of the

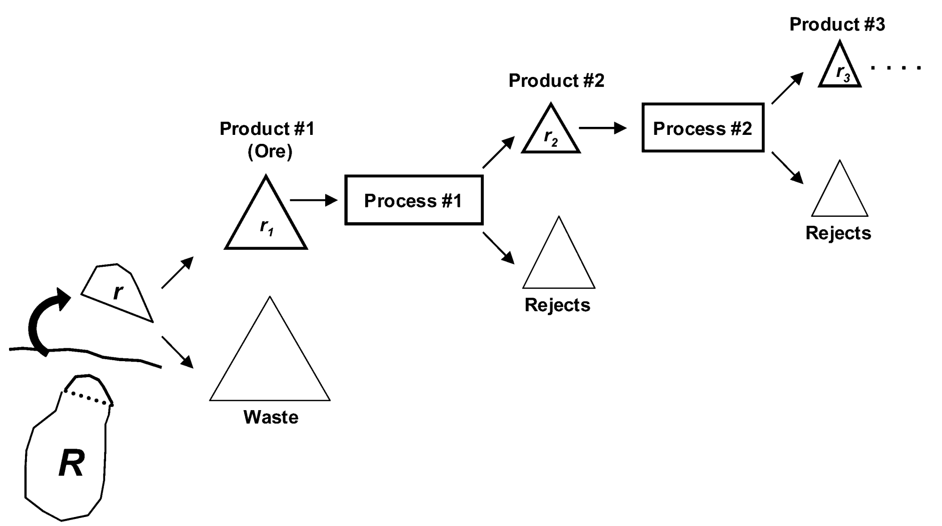

FIGURE 4.9 Selectivity in a general mine-plant configuration

bottlenecks that might appear during the operation because of changes in the grade distribution within the deposit. Those grade distribution changes must be coupled with fixed capacities in each processing unit, including the mine. In fact the simplest situation occurs when the intermediate products are freely tradable in open markets. In this case, each processing unit could be optimized independently because a product that cannot be processed further—as a result of a bottleneck in the system—could be sold in the market. Likewise, purchasing such a product in the market could easily fill any eventual spare capacity at one unit. This is more or less the case of a mining complex that comprises a mine-concentrator unit along with a smelting and a refining facility. The costs to be used in the optimization process, though, should be the costs of acquiring these intermediate products in the market.

If the intermediate products were not marketable—which is usually the case of ROM ore or leaching solutions—the number of dependent variables would be tied to the number of processes beyond the mine. In any case or configuration, an economic model must be tailored specifically to account for the effects of changes in the selective cutoffs on throughputs and ultimately on the cash flow resulting from the exploitation. Equation 4.1 shows a generic model for establishing the cash flow resulting from the mining of fraction r of the resource along with $n - 1$ processes in Figure 4.9:

$$C = p \cdot r_n - \ldots\ldots - h_2 \cdot r_2 - h_1 \cdot r_1 - m \cdot r - f \cdot t \qquad \text{(EQ 4.1)}$$

where:

C = cash flow arising from the mining and processing of fraction r
p = net market price per unit of output
h_i = variable average processing costs per unit of input at processing unit i
m = variable average mining costs per unit of extracted material
f = fixed costs per unit of time or time costs
t = time to either mine r or process r_i (the greater)

For certain physical installations, the unit that imposes a limit on the rate at which the material flows defines time t. That unit could be the mine if the rate of development of ore is too low, or it could be any of the downstream processing units. Sometimes, it could be more than one unit or even all of them if they all perfectly fit each other. As the mineral distribution within the deposit may vary over time, so may the bottlenecks. This is a good reason for breaking the mine plan in periods of about a year to see the changes in tonnage and grades as mining goes on.

The cash flow formula given in Equation (4.1) can conveniently be substituted in Equation (3.15) to give rise to a general expression to be maximized when the selectivity feature is incorporated:

$$v = p \cdot r_n - \ldots\ldots - h_2 \cdot r_2 - h_1 \cdot r_1 - m \cdot r - (f + F) \cdot t \qquad \text{(EQ 4.2)}$$

Once fraction r is defined and once the cost functions for the mine and downstream units are established, value added v of that fraction depends on time t and on the amount of output achievable. In this case, time t depends not only on the rate of extraction at the mine—as in the coal mine example—but also on selectivity at the mine and each downstream process. It is the selectivity process, along with capacities, that ultimately determines the amount of output and its quality.

As already pointed out, simultaneously optimizing all the variables inherent in Equation 4.2 may become convoluted for certain mining configurations. Practical applications, therefore, should be solved iteratively; that is, by first fixing certain variables to leave only one or two decision variables free. A sensible final solution can then be obtained by comparing results for various scenarios (by changing values in each of the variables initially defined as fixed).

In conclusion, it is important to highlight that properly understanding the economics that govern the whole selectivity process is fundamental to the success of the mining business. These unique economic principles have important repercussions in the definition of ore, in the design and operation of the whole mining facility, and ultimately in the overall economics of the business.

CASE STUDY

The following example illustrates how the selectivity principles were first applied to a large-scale copper mine located on the Chilean copperbelt in the Andes cordillera. The project was commissioned in the fourth quarter of 1999 at a total cost of $1.36 billion, including interest. It basically consists of a porphyry-type copper deposit to be mined by open pit, coupled with a conventional mill concentrator. Among other facilities, the project includes a tailings dam and a 120-km pipeline to transport the concentrates to the port of embarkation, which is also part of the venture.

During the course of the study, around the second quarter of 1998, the project was under construction, so a mine plan had already been developed at feasibility. The cutoff grade policy had been optimized with the same principles presented here. The metallurgical variables, however, had not been included in the optimization. Apparently, they were determined with conventional methods, which are usually divorced from the definition of ore at the mine and aimed at recovering as much as possible of the valuable minerals. The scope of work, therefore, was to carry out a simultaneous optimization of both the cutoff grade at the mine and the cutoff particle size at the mill.

It is worth emphasizing that this first application was very preliminary, utilizing gross assumptions and lacking a thorough analysis of the potential bottlenecks at the plant. This was the first formal attempt to apply these concepts in a real case and the objective was to show to the company's management the potential of this optimization process in 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 and, consequently, identified key operational variables.

Initially, the project considered an open pit mine with a daily extraction of around 190,000 t/d during the first 5 years. Throughout this period, a cutoff grade of 0.7% copper (Cu) would classify 85,000 t/d to the concentrator whose design capacity had been established in that range. The grinding circuit consists of two grinding lines each composed of one SAG mill and two ball mills, with a total combined power of about 53,700 kW. The fineness of the primary grind size stipulated at feasibility was estimated at 55% passing 200 mesh, equivalent to a P_{80} (80% passing size in circuit product) of around 137 μm (microns). According to metallurgical tests and design criteria, this particle size would allow an overall recovery of around 92.5% Cu and concentrate grades of about 36% Cu. The mine plan developed at feasibility, called the "base case" from now on, is presented in Table 4.1.

At the beginning, it became evident that most of the metallurgical tests supporting the feasibility study had been performed at a grind particle size ranging from 100 to 180 mm, so the behavior of the ore above that range was unknown. Luckily, some favorable comments included in lab reports and the experience gained at a small-scale operation that preceded this project provided useful indications about the good recoveries obtained at coarser grind sizes. Using all the information available and taking the small operation as an optimistic case, the relationship shown in Figure 4.10 was projected.

To facilitate the comparisons, the economic data used in the study were similar to the ones employed in the feasibility study. The most relevant are shown in Table 4.2.

TABLE 4.1 Mine plan at feasibility (base case)

Year	Cutoff Grade (% Cu)	Mill Recovery (%)	Ore to Concentrator (t/d)	(% Cu)	Mining Rate (t/d)
PP*	0.70	91.7	8,000	1.04	160,000
1	0.70	92.5	85,000	0.99	170,000
2	0.70	92.5	85,000	0.96	204,000
3	0.70	92.5	85,000	1.09	203,000
4	0.70	92.5	85,000	0.91	186,000
5	0.70	92.5	85,000	1.00	175,000
6–7	0.60	92.5	85,000	0.82	141,000
8–10	0.53	92.5	85,000	0.75	141,000
11–15	0.50	92.5	85,000	0.72	143,000
16–20	0.50	92.5	85,000	0.67	144,000
21–30	0.41	92.5	85,000	0.70	109,000
31–56	0.40	92.5	85,000	0.66	155,000

*Preproduction period.

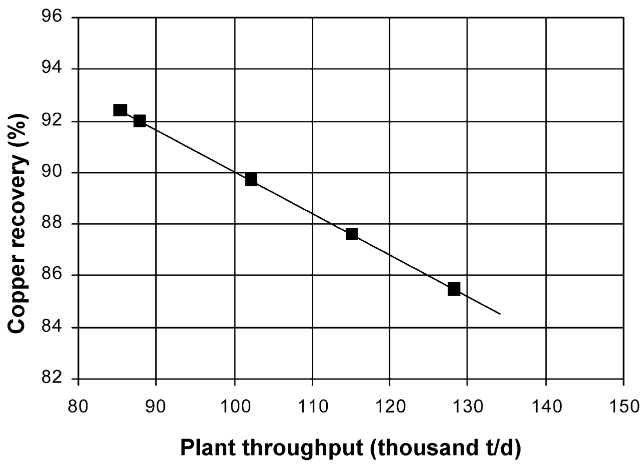

FIGURE 4.10 Overall copper recovery and plant throughput

TABLE 4.2 Economic parameters

Item	Value
Mine variable costs	$0.69/t of material
Processing variable costs	$2.73/t of ore
Annual fixed costs	$31.4 million/year
Annual discount rate	10%
Net copper price	$0.73/lb Cu

Considering these parameters, and the molybdenum content that is not displayed in the mine plans, the present value of the base case is estimated in \$2.46 billion (before taxes). Each year of the mine plan was analyzed in terms of tonnes of ore and average grade for different cutoff grades. Thus, the purpose of the optimization was to define the optimum time extent for each fraction of the base case (year). As already stressed, each 12-month fraction in the base case can now last more or less time depending on the specific cutoffs applied at both the mine and the mill. This problem is shown in Figure 4.11, which illustrates the selectivity problem for an open pit mine and a mill concentrator.

In Figure 4.11, the fundamental aspect of selectivity is a time-quality dilemma that arises when fraction r of the resource is set to be extracted from the open pit mine. In this type of mining, all the material within fraction r is mined but during this process a cutoff grade can define fraction r_1 that will be classified as ore. The higher the cutoff grade, 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, both upstream and downstream of the grinding circuit, a higher cutoff grade for fraction r leads to a faster exhaustion of the deposit and, consequently, a more rapid realization of remaining present value W.

At the mill, specifically at the grinding stage, a cutoff particle size can establish the degree of liberation of valuable minerals. The finer the particle size, the higher the liberation of valuable minerals and thereafter the better the recovery of them. This occurs, however, at the expense of additional time and specific energy, which 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 of valuable minerals. However, this happens at the expense of a lower throughput and sometimes more diluted concentrates (of lower grade). In this case, however, because no evidence of changes in the grade of concentrates was seen, this effect was not considered in the optimization.

Generally, the main constraint in a concentrator is not flotation but grinding. The grinding activities are less flexible, relatively more expensive, and more capital-intensive.

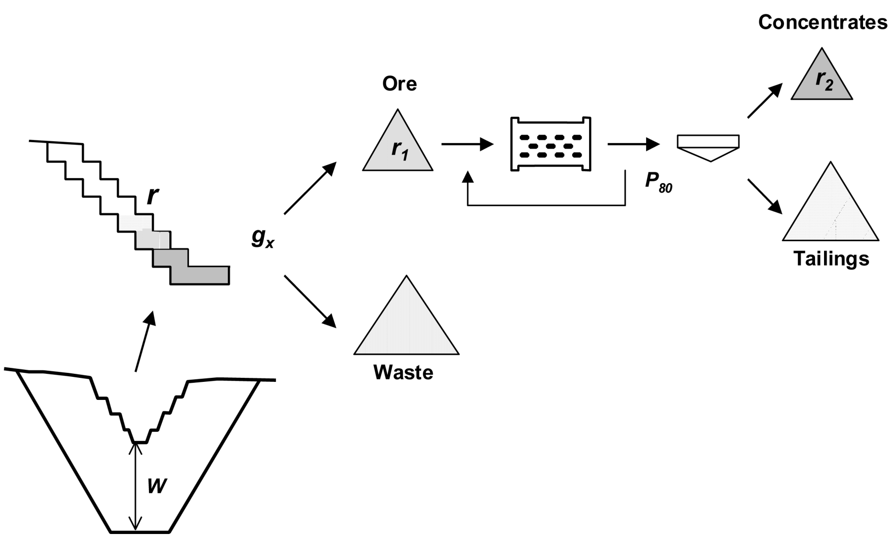

FIGURE 4.11 Selectivity in an open pit mine and a mill concentrator

In the mine-mill configuration presented earlier, the economic model used to estimate the value added resulting from the mining of fraction *r* could be rewritten as follows:

$$v = p \cdot r_2 - h \cdot r_1 - m \cdot r - (f + F) \cdot t \qquad \text{(EQ 4.3)}$$

Once fraction *r* is defined in terms of amount, and once the cost functions for the mine and the mill are established, value added *v* of that fraction depends on time *t* and the amount of output achieved. Time *t* is determined here by either the rate of extraction at the mine or the mill throughput. Sometimes, however, it is the mine and the mill together that determine time *t*. This occurs when both entities are operating at full capacity. Mill throughput is in turn a function of the ratio $r_1{:}r_2$ that results from the cutoff grade at the mine and the cutoff particle size at the mill, respectively. These last two variables also determine the metallurgical recovery and the amount of output that is finally obtained from fraction *r* – (in this case, concentrate).

If the mine imposes a limit on the rate at which material is mined, $t = r/Q_m$, where Q_m is the maximum mine capacity that matches variable average cost *m* in the mine cost function. This capacity is expressed in unit of resource per unit of time; such as tonnes of material per year. In this case, Equation 4.3 can be rewritten as

$$v_m = p \cdot r_2 - h \cdot r_1 - m \cdot r - \frac{(f + F) \cdot r}{Q_m} \qquad \text{(EQ 4.3a)}$$

Likewise, if the mill imposes a limit on the rate at which ore is processed, $t = r_1/Q_h$, where Q_h is the maximum mill capacity that matches variable average cost *h* in the processing cost function. In this case, the capacity is expressed in units of ore per unit of time, such as tonnes of ore per year. In this case Equation (4.3) can be rewritten as

$$v_h = p \cdot r_2 - h \cdot r_1 - m \cdot r - \frac{(f + F) \cdot r_1}{Q_h} \qquad \text{(EQ 4.3b)}$$

It is worth noticing that in this case the energy consumed in the mill is given and fixed for a certain configuration. This cost, therefore, is a fixed cost that should be included in *f*, not in *h*.

For each pair of cutoffs—a cutoff grade at the mine and cutoff particle size at the mill—the previous equations should be compared to choose the lowest value, which is the one that could be attainable with the defined capacities. This could be done for successive incremental cutoffs pairs to thus find the highest value added for that particular fraction of material. This must be repeated for the remaining pit increments (fractions), until reaching the final pit. Table 4.3 displays an intermediate iteration for the first year of the base case mine plan, when the present value of the operation was still being increased to around $3.0 billion (before taxes).

The Year 1 increment in the base case—or the first fraction *r* from the open pit mine that corresponds to about 62.5 Mt of material—produces a value added of only $26.9 million when it is cut at 0.7% Cu at the mine and 137 μm at the grinding circuit in the mill (92.5% recovery). In contrast, when the cutoff grade at the mine and the primary grind size P_{80} at the mill are set at 0.6% Cu and 300 μm (85.1% recovery), respectively; the valued added is increased to $107.7 million. In this case, time *t* decreases from 1.0 to 0.71 years and mill throughput increases from 85,000 t/d (31 Mt/yr) to 131,000 t/d (47.8 Mt/yr).

TABLE 4.3 Value added for Year 1 fraction in the base case (M$)

	Recovery (%)/Capacity (Mt/yr)				
Grades (% Cu) Cutoff–Average	**93.58 28.5**	**92.50 31.0**	**90.91 34.5**	**88.43 40.2**	**85.05 47.8**
>0.00–0.59	–342.7	–289.5	–230.9	–161.6	–98.9
>0.10–0.86	–66.2	–32.1	5.0	47.7	84.3
>0.20–0.87	–58.8	–25.3	11.1	52.9	88.7
>0.30–0.88	–50.4	–17.6	17.9	58.6	93.3
>0.40–0.90	–38.3	–6.9	27.2	66.1	99.2
>0.50–0.93	–24.1	5.3	37.1	73.4	104.0
>0.60–0.97	–7.3	19.3	48.0	80.6	107.7
>0.70–0.99	2.6	26.9	53.0	82.5	107.0
>0.80–1.03	10.9	31.8	54.4	79.7	100.5
>0.90–1.08	13.6	29.3	46.1	61.1	49.0

Max v = 107.7

t = 0.71 years
V = \$3,000 million
C = \$320.5 million
W = \$2,889.3 million

The remaining present value W, which is the present value of the deposit after mining fraction r, can be calculated using Equation 3.5. In this case, however, time t is not a complete year but rather a fraction (0.71 years).

The same procedure should be repeated for the following fractions until the mine is exhausted. As in the coal mine example, iterations cease when the present value stabilizes. In this case, it stabilized at \$3.17 billion (before taxes). The final iteration gives rise to the optimum cutoff policy for both, the grades at the mine and the grinding size or overall recovery at the mill. If the mine restricts the operation in certain periods, different mining configurations could be studied to select the best one—the one that gives the highest NPV. Table 4.4 presents the optimized mine plan.[5]

As the optimized mine plan shows, the cutoff grade policy at the mine is reduced compared to the base case, and the declining policy honors the fact that the present value decreases, as does the opportunity cost, as the deposit is consumed. The same premise is valid for the primary grind size, which in the optimized mine plan varies from 300 μm in the first years to around 100 μm toward the end of the mine life. This allows mill recoveries ranging from 85.1% to 93.6% and mill throughputs from 131,000 to 81,000 t/d for the same period. The mining rate 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.

If the investments required at the mine-mill configuration designed at feasibility were roughly estimated at \$100 million, the gain in NPV resulting from the optimization would be about \$610 million (before taxes). Table 4.5 summarizes these economic results.

5. The optimization considered a maximum capacity of 131,000 t/d at the plant. This figure corresponds to a limit established because of a physical restriction in the underground conveyor-belt system that joins the open pit mine and the plant.

TABLE 4.4 Optimized mine plan

Year	Cutoff Grade (% Cu)	Mill Recovery (%)	Ore to Concentrator (t/d)	Ore to Concentrator (% Cu)	Mining Rate (t/d)
PP	0.70	91.7	8,000	1.04	160,000
1	0.60	85.1	131,000	0.96	263,000
2	0.60	85.1	131,000	1.03	314,000
3	0.60	85.1	131,000	0.90	248,000
4	0.60	85.1	131,000	0.88	240,000
5	0.58	85.1	131,000	0.84	221,000
6–7	0.54	85.1	131,000	0.75	228,000
8–10	0.51	86.3	131,000	0.72	230,000
11–15	0.43	85.1	131,000	0.67	192,000
16–20	0.34	85.6	128,000	0.67	168,000
21–30	0.25	92.9	82,000	0.62	133,000
31–51	0.25	93.6	81,000	0.62	131,000

TABLE 4.5 Economic indicators

	Investment (M$)	Present Value, *V* (M$)	NPV (M$)
Base case	1,360	2,460	1,100
Optimized	1,460	3,170	1,710
Difference	100	710	610

It is important to reiterate that these results gave rise to numerous internal studies that were developed in parallel with the construction. Among these were metallurgical tests carried out in Chile and in Canada, a thorough analysis of the main bottlenecks in the concentrator, a detailed study on cost classification, and studies on market forecasts, to name the most relevant.

These studies, along with the methodology presented here, enabled the company's management to improve the mine plan and create substantial shareholder value. It can also be argued that this innovative way of managing this mineral deposit could be partly responsible for the outstanding equity performance of the controlling corporation. The price of its shares, which are listed at the London Stock Exchange (LSE), was trading at a consistent value during the course of these studies. After these preliminary results were obtained and as the construction progressed the stock price began to climb, reaching a record high that almost tripled the initial value (from the end of 1999 when the operation started). At press time, the shares trade at about 3½ times this initial value despite depressed prices.

This case study is mainly the result of work done at Queen's University, Canada. The author acknowledges Sadan Kelebek for his contribution in the metallurgical aspect of the work.

CHAPTER 5

Organizational Design

Up to now, the discussion of mineral resource management has centered on its definition, on the scope of the concept within the mining business, and on formulating the business strategy for exploiting the mineral resource to maximize value. Along the way, a useful metric to gauge the true ongoing value added has emerged.

The approach has proven to be essentially dynamic because it involves the setting of key operational variables over the mine life, all of which should move in unison with market fluctuations. To put this function to work, two mine planning activities have been defined: strategic mine planning and tactical mine planning. Both advance in tandem, so while the former sets up the mining strategy, the latter transforms it into specific production targets whose realization serves as feedback for updating these strategic plans. This cycling gives birth to the continuous process of mine planning.

Having discussed the fundamentals underlying the business strategy, the focus now turns to designing the proper organization to achieve the organizational goals. This subject refers to the way people are organized in the mining firm to create the business strategy from scratch and later improve it continually during the mine life.

It is worth mentioning that the organizational issue is considered critical in the proposed framework, and the failure to recognize this seems to be a plausible explanation for the dysfunctional practices observed in many mining firms. Researchers and practitioners, in fact, increasingly associate the lack of understanding of this issue as the main cause of breakdown in strategy implementation. As Pfeffer (1998) emphasizes, "successful organizations understand the importance of [strategy] implementation, and, moreover, recognize the crucial role of their people in this process."

If the organization were conceived according to the Taylorian spirit reviewed in Chapter 2, the job of creating and implementing the business strategy would be much easier. Unfortunately, organizations are more complex entities and the understanding of their functioning appears to lie outside the rational and normative confines viewed by Taylor (1911). As Karl Weick (1979) points out, "organizations keep people busy, occasionally entertain them, give them a variety of experiences, keep them off the street, provide a pretext for storytelling, and allow socializing. They haven't anything else to give." Underlying this peculiar insight is a subtle message about the complex social structure of organizations, which has to be acknowledged and understood if organizational problems are to be successfully addressed.

The aim of this chapter, therefore, is to formulate some general propositions about how mining organizations should be built or changed to incorporate the function of mineral resource management. This is done by using developments of organization theory, a branch of administrative science devoted to the study of organizations. As with all social disciplines, this is not a homogeneous science based on generally accepted principles. Various theories of organizations have been and continue to be evolved as empirical work and knowledge in the area expand.

The overall proposition suggested 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 critical aspects: the organizational structure; the reward and penalty system; the technical and control systems; and finally the selection, training, and development of people.

The following sections examine each of these aspects. At the beginning of each section, a brief analysis of the theories and research in the field is presented. Their applications to mineral resource management are then outlined at the end of each section. The last section presents a case illustration that gives some insights about how some of the ideas presented here were successfully applied in a large mining corporation.

ORGANIZATIONAL STRUCTURE

The search for more effective approaches to organizing business enterprises has been a recurrent subject in the field of administrative science. The most serious attempt to understand organizations starts at the outset of the twentieth century with Weber's (1924) studies on bureaucracy. From a very wide perspective, he tried to assess the impact of large-scale bureaucracies on the power structure of modern society. Weber's classical writings on the ideal type of bureaucracy have become the basis of subsequent theories of bureaucracy and organizations.

The other major tradition of organizational writings starts with Taylor's (1911) work on scientific management and Fayol's (1916) classical approach to management, although both focused on the individual and the firm rather than on society. After World War II, when the influential works of Max Weber and Henri Fayol crossed the Atlantic and penetrated the massive North American market, the subject gained momentum and the volume of the literature began to increase at an impressive rate.[6] Today the subject of organization theory is still growing considerably and it is expected that this trend will continue over the years, as organizations become ever more complex entities.

Despite the angles from which business organizations are studied, the critical features to examine when creating more effective organizations seem to have converged. In effect, questions such as how organizations are structured, how people are paid, how performance is measured, and how individuals are trained and developed, are increasingly proving to be areas in which innovation can lead to improved performance and sustained competitive advantage.

Some General Definitions

In this study, "organization theory" refers to the body of knowledge that addresses itself to the problem of how to organize. More specifically, organization theory is defined here as the study of the structure, functioning, and performance of business organizations and the behavior of groups and individuals within the firm.

In organization theory, an organization is formally defined as a collection of people working together in a planned manner, with a division of labor and a hierarchy of authority, to achieve a common objective. For study purposes, organizations are generally depicted as open systems made up of interrelated and interdependent parts that produce a unified whole that interacts with its environment. This point of view also serves as a useful framework for understanding both the internal parts of the organization and the organization's relationship to its environment.

6. Weber's main writings, *The Protestant Ethic and the Spirit of Capitalism* and *The Theory of Social and Economic Organization,* were written in German in the early 1900s and later translated into English by Talcott Parsons in 1930 and 1947, respectively. Fayol's major contribution, *General and Industrial Management,* was originally published in a French mining bulletin in 1916 and then translated into English in 1929, but in a limited European edition. A widely available English translation, however, was published in 1949.

Organizations exist because individuals are limited in their physical and mental capabilities. By working together in a planned and organized way the combined effort of people is more effective than working individually or collectively but in a disorganized manner. The synergy achieved is actually the result of an "organizational structure," which interweaves two components—division of labor and hierarchy of authority. The first term refers to specialization, or the breakdown of jobs or activities into sets of tasks that are allocated among people. The second term relates to the formal reporting relationships, including the number of levels the hierarchy has or should have and the number of people supervised by managers.

The determinants of structure have been a recurrent concern in organization theory, although the ones defined in the business model of Chapter 2 have found consensus among researchers and practitioners as being the most important. These are the business strategy and the business environment, which in turn is defined by technology, mineral resource features, markets, and the legal framework.

The power control is another key variable that was examined in Chapter 2, although not included explicitly in the model. It refers to the power struggle by internal constituencies who constantly seek to further their interest, which plays an important role in the organization's *informal* structure.

"Organizational design," which emphasizes the management side of organization theory, is another term used in the field. It is defined as the act of constructing or changing an organization's structure to achieve the organization's goals in the most effective way. Design configurations range over a continuum from classic bureaucracy to more adaptive and innovative forms of organizations known as "adhocracies." Given the various structural types that lie in between these extremes and their respective strengths and weaknesses, the questions are when such forms would be preferred and how this decision can be assessed. This questioning inevitably calls to mind the term organizational effectiveness, already discussed in Chapter 2, which is the central theme in organization theory.

Informal Aspects of Organizational Structure

The definition of an organization includes the terms division of labor and hierarchy of authority. They constitute the pillars of what is called organizational structure—that is, how people are grouped together, who reports to whom, how tasks are assigned, and what types of jobs need to be performed within the organization. To most people, organizational structure is an intricate wiring diagram known as the organizational chart, which contains several levels of employees and reflects the established pattern of relationships among the parts of the organization. In some way this is a correct view, but it corresponds to what is known as the formal organization; that is, the organization designed by senior management to achieve the organization's goals and promote efficiency and effectiveness.

Within every organization, however, an informal structure exists alongside the formal structure. Based on relations between individuals and groups, the informal structure is much more dynamic and harder to define than the more rigid formal structure.

Most of the research described in the cumulative literature has focused on the formal type of organization, but in many respects the informal structures have important repercussions on the organization's effectiveness. This is especially valid in organizations functioning in mature and established industries, such as the mining industry. In effect, to function properly, the mining business requires specialization in key technical areas such as geology, drilling, blasting, leaching, flotation, and administration. This leads to many subunits within the organization, often with different goals, which may make accomplishing the broader organizational goals difficult.

For instance, from the pure geologic viewpoint it could be very interesting to know the continuity of deep mineralization in a certain deposit. From the business standpoint, however, achieving that knowledge could become contentious if, for example, it delayed the project start-up or distracted resources that might be used to better delineate zones for likely earlier extraction.

For some researchers, the business strategy and the business environment explain only a part of the organizational structure (Child 1972). The remainder, often the larger part, may be attributed to the twilight zone of organizational politics or more specifically to the power-control view of structure, which in some way shapes both the formal and informal structures mentioned earlier. As Bacharach and Lawler (1980) pointed out, "organizational structures are emergent activities; that is, they are the result of conscious political decisions of particular actors and interest groups."

The term "power" as used here should not be confused with "authority." Authority goes with the job whereas power is the capacity of individuals to influence decisions. Administrative assistants for high-ranking executives, for example, typically have a great deal of power but very little authority.

Power is the central theme in the power-control perspective. Those who hold power will make structural choices. Although this is usually senior management, it need not be. Power can be acquired by controlling resources that are scarce and vital in the organization or by reducing uncertainties that may interfere with the organization's performance. As both technical systems and the environment are given, but may be chosen in some respect, those in power will select technical systems and manage the environment in such a way as to maintain their control. Under this perspective, organizations are characterized by routine technical systems and environments where uncertainties are relatively low. To enhance control even further, those in power will choose the simplest structures that are high in both formalization and centralization.

The previous points can be clarified with an illustration. It deals with a porphyry copper deposit located in the Andes Mountains in central Chile, which began its exploitation in the early 1970s. Despite its favorable emplacement for exploitation by open pit mining—it actually outcropped—the U.S. mining company that owned the deposit at that time chose an underground method and even an underground concentrator, built in a huge man-made cavern. The apparent reason for supporting that costly decision was the hostile weather conditions of the area, which is very snowy in wintertime.

In retrospect, however, the real reason seems to have been the company's lack of open pit experience and the uncertainties posed by the snowfall in the winter. In fact, at almost the same time, a French mining company was exploiting a similar outcrop, from the same geologic formation, but using open pit mining on the other side of the hill.

Ten years later, in the early 1980s, the U.S. mining company, now with different ownership, decided to exploit another ore body located in the vicinity, in a more unfavorable area and with even more overburden, but this time using open pit mining. It is worth mentioning that when this decision was made, the company had a chief mining engineer in charge of that project with both underground and open pit experience.

In the early 1990s, the firm attempted to rectify the old decision and create a large open pit mine by eventually merging both mines. By then, however, it was too late. The underground method had already caved a 250-m column, and the instability of the crater presented an additional concern. Today, the company still operates the underground mine and one open pit mine, both feeding the underground concentrator. The money wasted and the profit unrealized as a result of the first decision is gone forever, for the opportunity to develop a deposit from its original state occurs only once (as pointed out in Chapter 4).

Structural Forms of Organizations

For grouping people in an organization, two fundamental structural forms exist: “functional form” and “divisional form.”

The functional form comprises the *means*—the techniques and activities—that people in the organization employ to do their tasks. Its major distinguishing feature is the grouping together of similar and related occupational specialties. In a mining company, for instance, routine operational activities such as drilling, blasting, loading, transportation, and the like are typically grouped under line functional structures that report to a higher authority, say a superintendent of operations. This person, in turn, reports to a mine manager who also exerts control over other superintendencies, such as geology, planning, and maintenance. The mine manager usually reports to the general manager, as do other managers at the same level, such as the mill manager, the finance manager, and the administration manager, among others.

Figure 5.1 illustrates the typical hierarchical form of a functional structure. At the top is the general manager, and immediately below are the functional managers. Below the functional managers are found other more specific superintendencies, and so on.

The divisional form focuses on the *ends*—such as particular customers, products, or end services. This form comprises self-contained and autonomous units that behave like little companies, each having its own organizational form, almost always of the functional variety described earlier. In the previous example, the mine is no longer a functional unit but a business unit that, in theory, can interchange products and services beyond the firm’s confines. Within the firm’s units these transactions occur at market prices or certain established transfer prices when a market does not exist.

Under this organizational form, the mine is in fact a separate business unit whose end is to sell ore to the plant. The organizational chart would be almost of the same form as displayed in Figure 5.1; however, small businesses or autonomous business units would take the place of functions.

The advantages and disadvantages of the forms, as well as the use of one or the other, have been a subject of continued debate. Despite these controversies, functional grouping is recognized as the best form for handling a single product or set of services. Its strength, in fact, lies in the advantages that accrue from specialization because it can yield clear task assignments consistent with an individual’s training. However, it encourages narrow perspectives and a focus on means rather than ends. Consequently, no one functional group is totally responsible for end results, and job coordination must finally lie with top management because this is the only group that can see the whole picture.

Divisional grouping, on the other hand, lends itself to managing workflow interdependencies and allows the organization to better meet the market needs. The divisional

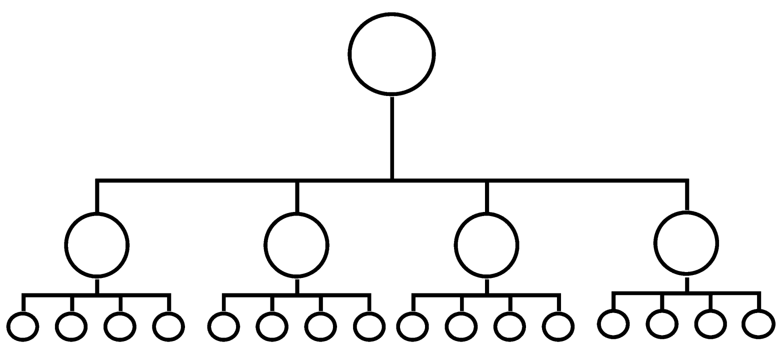

FIGURE 5.1 Functional form in organizational design

structure frees headquarters staff from concerns about day-to-day operating details, allowing them to pay attention to more strategic decision making. This form of grouping, however, is less appropriate for doing repetitive and specialized tasks well. It also may be more wasteful because it does not take advantage of economies of scale and often duplicates resources.

In the mining business, the controversies on which types of grouping are more appropriate come mainly from the divisional form's ability to better manage the interdependencies among the mine and the plants—for instance, the planning problem that extends across all the technical functions of mining. However, as will be examined later, to cope with the mine-plant relationship it may not be necessary to sacrifice all the advantages of the functional form in organizing the more routine and specific activities of mining.

In medium and large mining concerns, combining functional and divisional forms is common. For instance, the need to coordinate ongoing projects in a mining firm may require that the operating units be grouped by function even though a centralized project unit within the same organization is grouped divisionally and has authority over the way all projects are executed. This type of structure is usually known as a "hybrid form." Indeed, this is the principle behind the designation of line (command) and staff (advisory) units, where the former units conduct the core business and the latter are set up to assist the line units by supplying specialized expertise and services. Figure 5.2 shows this hybrid form, in which some divisional, nonline units are attached to the organizational chart.

The other basic type of organizational structure is called the "matrix form," which also combines functional and divisional grouping, but in a very different way. In brief, where a hybrid form groups functional and divisional units in different areas of an organization, a matrix form overlaps functional and divisional structures. For example, a metallurgical engineer working for an operating unit may also be assigned to a project group to participate in designing a new process.

Coordinating Mechanisms

Grouping people into units is only one aspect of organizational design. Those people and units must communicate with one another, and they must coordinate their efforts. These linkages must be in two directions: vertical and horizontal.

Basically, there are four vertical coordinating mechanisms. In an increasing degree of efficiency, the first is hierarchical referral, which means that problems are sent one

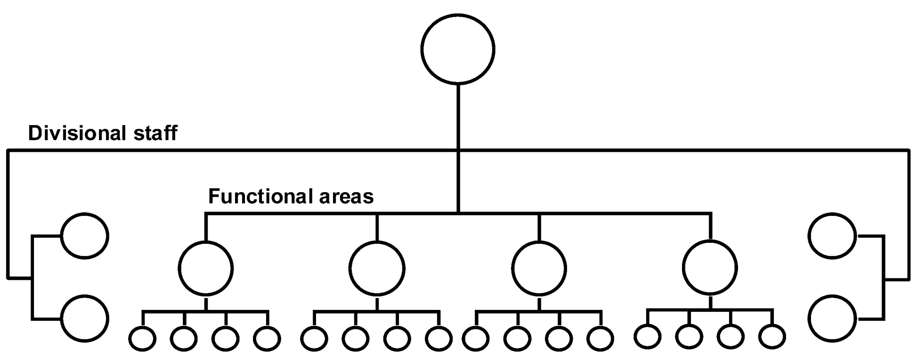

FIGURE 5.2 Hybrid form in organizational design

level up in the organization. The second is by means of rules and plans, which are used when coordination problems recur. A third way is to add positions or levels to the hierarchy so that the span of control is more manageable. Finally, instead of adding referral, rules, or people, the organization can add vertical information systems to move information to decision makers.

Organizations must also ease communication and coordination among units at the same level of the hierarchy, or horizontally. The most direct way to do this is with paperwork, such as the familiar memoranda or reports. Another way is with direct contact or face-to-face meetings among people who need to coordinate. Both methods have some shortcomings and become inefficient if many people or units must coordinate.

When two units must coordinate over time but on a limited basis, an organization may use liaison roles. This task may rest in a single individual with the responsibility of coordinating both units on matters of ongoing concern. If several units must coordinate the liaison, people need to meet as a group. On the other hand, if the coordination is for a limited time, members of each unit can meet as a "task force," which is a committee that exists for a specified time only. If the coordination is more or less permanent, they may use either a full-time integrator or a standing committee. Figure 5.3 illustrates a liaison overlay structure.

Full-time integrators in mining firms are typically operation or production managers who coordinate all the technical functions relevant to their output. Standing committees, in contrast, are institutionalized forms, where members of different units are brought together to discuss issues of common interest on a regular basis. For instance, a standing committee may be the typical occupational health and safety group, which usually dictates health policies and security measures for the whole mining company. A standing committee almost always oversees the jobs of people that may belong to different functional groups and, as such, is not itself a functional unit.

The Mining Organization

So far, discussion on structure has been focused on some general aspects that must be considered when designing the mining organization as a whole. These ideas now become useful in addressing the essential question, which is how to integrate the function of mineral resource management within the mining organization.

As pointed out in Chapter 2, mineral resource management involves virtually all the units that make up the mining organization. The traditional way of organizing a mining enterprise usually overlooks this integrative notion given here to the mining business.

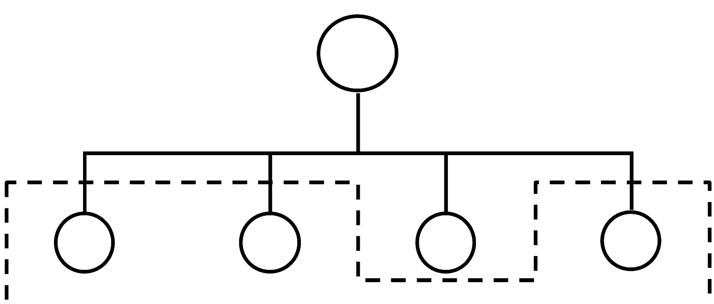

FIGURE 5.3 Liaison overlay structure

The resulting structure, therefore, is often of the hybrid form—with core technical functions that are related to the types of mining and processing methods and some divisional groups that support these technical functions.

Among the technical functions, the first is typically the mine unit. It is often made up of various subunits such as geology, operations, mine planning or engineering, and maintenance. Downstream units usually comprise the many processing plants, which also consist of various subunits according to the type of metallurgical process. For example, a whole mining company may comprise an open pit mine together with a mill concentrator, a smelting facility, and a refining unit, which ultimately delivers the salable product. These technical functional units may receive support from central units in aspects such as environmental management, legal advice, human resources management, external affairs, finance and administration, and the like.

In this traditional organization, preparing short- and long-term mine plans is often the responsibility of the mining unit. This work is typically done through a planning or engineering subunit. The predominant skills of these people are rather technical and related to their ability to understand the mineral deposit features well, along with specific knowledge in mining engineering. Commercial and financial aspects of the business, as well as the technical features of the downstream operations, are usually an input for this process. Such information from the other units is often collected either verbally or taken from memoranda and reports. These economic and technical data are then fed into economic models that, in conjunction with the geologic and block models, serve as the basis for mine planning.

Because routine work often drives out nonroutine work, strategic mine planning as presented here is generally overlooked in the traditional mining organization. When it is recognized, it is often a sporadic activity, usually consisting of a long-term plan that serves as a guideline for developing short-term and day-to-day plans as well as yearly budgets. Figure 5.4 depicts the traditional structure in mining concerns and the level at which mine planning occurs in this type of organization.

To carry out mine planning activities, the proposition here is that the standardized and more routine activities involved in tactical mine planning should continue being the responsibility of the functional units. In this way, strategic mine planning can be executed by a special unit, placed at a higher level in the hierarchy and circumscribed in an overlay structure above the traditional structure. This overlay structure is in fact a standing committee aimed at ensuring the liaison of this new unit with the other functional and staff units (see Figure 5.5).

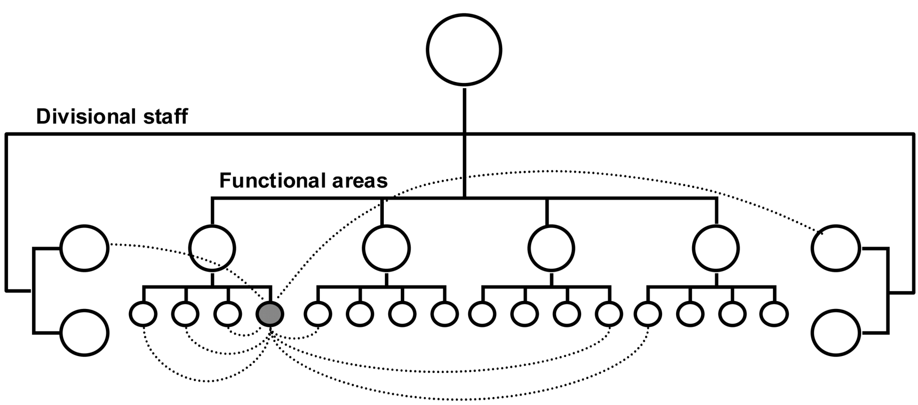

FIGURE 5.4 Mine planning in the traditional mining organization

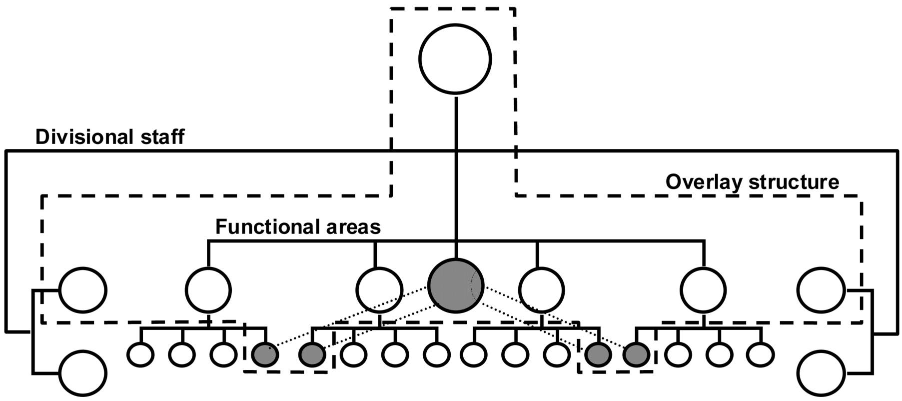

FIGURE 5.5 Mineral resource management and the mine organization

This new form of organization should not be seen as an attempt to bureaucratize and make strategic mine planning more rigid. Instead, the objective is to emphasize the importance of this crucial activity and raise it to a proper level in the organization. The main contention here is actually that mineral resource management is rarely performed in the mining industry, at least in the way prescribed here, because the traditional mining organization is not able to cope with the problem.

Perhaps a clearer way of envisioning the previous organization is by imagining a mining company where all the functional activities are fully externalized and executed by contractors operating in a competitive market. In such a case, the owner's only controllable activities to create value will be those concerned with the formulation and monitoring of the strategy to exploit the deposit. This is, in fact, the very heart of the mining business because the expertise to dig material out from the earth's crust and to later crush and grind it can be seen as a mere commodity under this approach.

In terms of organizational design, this imaginary mining company would require a rather small team with the specific knowledge to cover all the aspects of the business. Part of this team would be in charge of perfecting the holistic strategy and obtaining the resources to implement it efficiently. Another would transform these guidelines into day-to-day plans for the contractors to follow. And finally, another part would be responsible for monitoring and controlling the operations to ensure that the strategy is being executed correctly. This is exactly the kind of organization to superimpose on the traditional mining organization where functional operations are typically executed internally, with company-owned resources.

Because of the interdisciplinary character of mineral resource management and to ensure its effectiveness, this unit should be created as a divisional entity. The standing committee, which is aimed at coordinating and overseeing the functioning of this unit, must be chaired by the top executive officer and integrated by the leaders of the functional areas plus the appropriate staff. This committee will furnish the forum for discussing the tactical and strategic responses needed to steer the operation through the myriad changes and uncertainties that characterize the mining business.

Depending on the company's size, kind of operation, and circumstances it is highly advisable that the whole mine strategy should be completely and thoroughly reviewed at least every other year. Most of this work can be performed either in house, with internal resources, or with the help of outside consultants. Making use of consultants may be advantageous for mining companies that, for whatever reason, cannot have a permanent team for this effort. In addition, the external support may also enrich the work quality if it contributes new knowledge and fresh ideas. Moreover, for mining companies to receive the full benefit of diversity and competition, it could be advisable that in certain circumstances—especially at the outset of any major revision—the work could be executed in parallel, with more than one team.

Some mining corporations may opt for developing in-house, centralized capabilities in these matters so that their divisions can use them as required. This is also a good alternative, but it should be used carefully as this function is essentially nonroutine and in some respects risky. These aspects, however, are not always ascribed to corporate staff whose commitment to a particular division is rather weak. As Kanter (1979) pointed out when he examined the benefit of exerting productive power in the corporation: "Management consider them [staff specialists] fine for routine work, but the minute the activities involve risk or something problematic, they bring in outside experts. This treatment says something not only about their expertise but also about the status of their function."

In any case, this divisional unit should have a core permanent position—the manager of mineral resources. This individual's overall responsibility is to bring about the liaison of the market with the mining strategy and the operation. These tasks should be done in compliance with the organizational goals as well as in harmony with the state of the operation and the available resources. The idea is to oversee the economic side of the mining business and keep the mining operation in tune with the changing market conditions. Simply put, the manager of mineral resources should be a "money manager" for the mining operation.

The overall goal is to steer the consumption of the mineral resource so that the exploitation strategy does not just keep in step with the current market condition but more importantly, keeps up with the market forecast. This leads to an additional duty—evaluating the state of the economy in general and the specific market in particular, which includes the ability to predict fluctuations in the prices of inputs and outputs, interest rates, and the like. As discussed in previous chapters, assertive predictions in this respect are key to ensuring a good financial performance in the mining business.

In conclusion, the mining game is to anticipate market fluctuations and try to sell more output when the market is tight but expected to loosen (higher spot prices) and less when the market is depressed but expected to revive. This game, however, must be played considering that the deposit itself is a sort of buffer that can be squeezed in times of bonanza and slackened during downturns.

The importance of this new unit within the mining firm should be comparable to the one that the boards of central banks exert in their countries. In the United States, for instance, this body is known as the Board of Governors of the Federal Reserve Bank. Its primary responsibility is to make monetary policy; that is, key decisions affecting the cost and availability of money and credit in the economy. In addition, the board plays a key role in assuring the smooth functioning and continued development of the nation's vast payments system. The board usually meets informally several times a week, but it schedules eight regular official meetings each year. The authority entrusted to this board, particularly in the chairperson, as well as the power it wields on the functioning of markets, is remarkable. Perhaps the apex of its power and authority is seen during regular meetings, when the board members evaluate the economic climate and discuss objectives for the nation's economy.

This is exactly the kind of influence that the mineral resource management group should exert over the fate of mining endeavors. However, to serve its mission appropriately, this managerial function should also be entrusted with the corresponding authority.

REWARD AND PENALTY SYSTEM

The reward and penalty system—which includes nonmonetary rewards and promotions as well as salary changes and bonuses—is a critical component in the organization's design. To mitigate the sterile debate that usually surrounds this subject it may be pertinent to assert that particular pay practices are neither good nor bad in themselves. They must be evaluated in relation to the other components of the model, particularly with regard to the business strategy. This is because the business strategy indicates what the organization is supposed to accomplish, the competencies that are needed, and the kind of performance measurements that are required for effective performance.

The organization structure, on the other hand, specifies how the organization is supposed to divide the work and assign decision rights.[7] All these aspects should be consistent with the pay system if the organization is expected to succeed in achieving its goals. It is worth noticing that the pay system drives performance not only because it influences people's behavior in the organization but also because it conditions the type of people who stay in the organization and join it in the future. Therefore, reward and penalty schemes must be designed to support the business strategy and the needed organizational behaviors.

One of the most thoughtful ways to integrate the pay system with organizational design comes from the seminal works developed over the years by Michael C. Jensen and William H. Meckling. The basic postulate of this work, which is condensed in Jensen (1998), is that organizational problems rest on three fundamental aspects:

1. The partition and assignment of decision rights within the firm
2. The performance measurement of both individuals and business units
3. The methods of rewarding individuals.

The three early dimensions, which Jensen and Meckling termed the "organizational rules of the game," are obviously related. The reward and penalty system must coordinate rewards with performance if the performance measures are to have desirable effects on the behavior of an organization's members. Moreover, the performance measures are related to the ways in which decision rights are partitioned and allocated in an organization. The theory underlying these postulates has been nurtured from the outstanding works of two Nobel laureates, Ronald Coase and Friedrich von Hayek. A brief examination of both lines of thought may be useful to support the propositions given here about the way of rewarding people.

Property Rights and Transaction Costs

Until Coase (1937), the traditional economic analysis of the firm was characterized by a simple "black box" that transformed inputs into outputs. Coase was one of the first economists who tried to understand the institutional structure of the economy and the existence of organizations of the type known as firms. He showed that traditional basic microeconomic theory was incomplete because it included only production and transportation costs and neglected the costs of entering into and executing contracts and of managing organizations. Commonly known as transaction costs, these costs account for a considerable share of the total use of resources in the economy.

Thus, traditional economic theory had not embodied all the restrictions that bind the allocations of economic agents. When transaction costs are taken into account, it turns out that the existence of firms, different corporate forms, variations in contract

7. Decision rights mean the rights to decide and take actions. This includes not only sole and complete control over a given decision but also a range of possibilities for influencing the decision.

arrangements, the structure of the financial system, and even fundamental features of the legal system can be given relatively simple explanations. By incorporating different types of transaction costs, Coase paved the way for a systematic analysis of institutions in the economic system and their significance.

Coase also demonstrated that the power and precision of analysis might be enhanced if it were carried out in terms of rights to use goods and factors of production instead of the goods and factors themselves. These rights, which came to be called "property rights" in economic analysis, may comprise full ownership, different kinds of rights to use, or specific and limited decision and disposal rights that are defined by clauses in contracts or by internal rules in organizations. The definition of property rights and their distribution among individuals by law, contract clauses, and other rules determine economic decisions and their outcome. Coase showed that every given distribution of property rights among individuals tends to be reallocated through contracts if it is to the mutual advantage of the parties and not prevented by transaction costs. He also demonstrated that institutional arrangements other than contracts emerge if they imply lower transaction costs. Modifications of legal rules by courts and legislators are also encompassed by these arrangements. Property rights thus constitute a basic component in analyses of the institutional structure of the economy.

The preceding framework is the basis of mining legislation in most countries around the world. Indeed, it constitutes the core argument that supports the nature of the mining firm as depicted in Chapter 2.

In his theory of the firm, Coase posed two fundamental questions about the very nature of the firm—why organizations of the type represented by firms exist and why each firm is of a certain size. A key result in traditional theory was to demonstrate the ability of the price system to coordinate the use of resources. The applicability of this theory was diminished by the fact that a large proportion of the total use of resources was deliberately withheld from the price mechanism, to be coordinated administratively within firms. At this point, Coase introduced transaction costs and illustrated their crucial importance. Alongside production costs, there are costs for preparing, entering into, and monitoring the execution of all kinds of contracts, as well as costs for implementing allocatable activities within firms in a corresponding way. If these circumstances are taken into account, it may be concluded that a firm originates contract and administrative costs within the firm other than by means of purchases and sales on the market. Similarly, a firm expands to the point where an additional allocatable activity costs more internally than it would through a contract in a market. If transaction costs were zero, no firms would arise. All allocation would take place through simple contracts between individuals.

An important element in the model is that there are two types of contracts: those that stipulate the parties' total obligations and those that are deliberately made incomplete by not specifying all obligations, but intentionally allow a free margin for unilateral decisions by one of the parties. Such open agreements may be exemplified by employment contracts, which usually leave room for direction and giving orders. According to Coase, the firm is characterized by the leeway for decisions created by a particular cluster of such open contracts. The firm actually consists of this array of contracts and is related to the rest of the world by other fully specified contracts covering purchases of inputs, sales of products, and loans under prescribed terms.

Coase's formulation has proved to be extremely practical and has given rise to profuse examination of the contract relations that characterize firms. It is now clear that every type of firm comprises a distinctive contract structure and thereby a specific distribution of rights and obligations. His work on the theory of the firm has become the basis for rapidly expanding research, such as Jensen and Meckling's agency theory, on principal-agent relations.

The Use of Knowledge in Organization

The other current of thought for Jensen and Meckling's works comes from Hayek's seminal essay (1945) on the use of knowledge in society. In a masterpiece, Hayek extended his field of study—philosophy, economics, and politics—to embrace issues arising from the way individuals, organizations, and various social systems use what he calls scientific and particular knowledge. Hayek's main insight in this respect was that an organization's performance depends on the collocation of decision-making authority with the knowledge important to those decisions. He argued that the distribution of knowledge in society calls for decentralization.

Jensen and Meckling use this idea as a point of departure for analyzing how the distribution of knowledge affects organizational structure and its critical role in the development of a theory of organization. They used the labels "specific and general knowledge," instead of "scientific and particular knowledge," and asserted that the cost of acquiring and transferring knowledge among decision agents is key to organizational analysis. Specific knowledge, by its very nature, is costly to transfer among agents and cannot be easily observed by other agents in the organization's hierarchy. The knowledge required for devising an exploitation strategy for a mineral deposit, which is very specific and gained over a long period of time by certain agents, is an example of this type of knowledge. General knowledge, on the other hand, is transferable among agents at low cost and can be readily observed by other agents. An example is production data in a mining firm, which is simply aggregated and inexpensive to transmit among agents.

Agency Theory

Making effective use of knowledge in decision making is a major problem in an organization. The literature in this respect centers on finding ways to transfer knowledge relevant to a decision to the agents involved in the decision. This makes sense when the knowledge is general and thus transmittable at a low cost, but when it is specific, this approach tends to fail. The alternative to moving knowledge is to move the decision rights to those agents who possess the relevant specific knowledge. The cost incurred in this approach is engendered by the fact that people are self-interested. Therefore, as the decision rights are partitioned out among agents in the organization, self-interested agents will be inclined to use the decision rights to benefit themselves—sometimes at the expense of the organization's performance. This makes it necessary to expend resources to control the costs associated with inconsistent objectives of agents in the organization. Jensen and Meckling called these expenditures "agency costs," which are part of what Coase termed transaction costs.

Agency costs, then, include the costs of devising and enforcing contracts with agents; the costs of monitoring the agents' behavior; the bonding costs incurred by the agent to help assure the principal that he or she will not engage in opportunistic behavior; and the residual loss, which is the cost incurred because it is uneconomic to define contracts perfectly. The residual loss arises because it pays to incur additional monitoring, bonding and contracting costs only to the point where the improvements just pay for themselves. This means that not all counterproductive behavior is eliminated.

It is worth mentioning that the self-interested behavior and the opportunistic problems underlying agency theory is not a new concept. Indeed, Adam Smith (1776:800) put his finger squarely on the problem more than two centuries ago when he wrote:

> *The directors of such [joint stock] companies, however, being the managers rather of other people's money than their own, it cannot well be expected, that they should watch over it with the same anxious vigilance with which the partners in a private copartnery frequently watch over their own. Like the stewards of a rich man, they are apt to consider attention to small matters as not for their master's honour, and*

very easily give themselves a dispensation from having it. Negligence and profusion, therefore, must always prevail, more or less, in the management of the affairs of such a company.

Agency theory postulates that because people pursue their own best interests, conflicts of interests inevitably arise over at least some issues when they engage in cooperative endeavors. Jensen (1998) argued that such activities not only refer to business trade, but also to the interaction among members of families and other social organizations. To safeguard value, the theory provides a structure within which to understand and model a broad array of human organizational actions, including incentive compensation, auditing, and bonding arrangements of all kinds.

Overall, the central proposition of agency theory is not that people are self-interested or that conflicts abound, but that rational self-interested people involved in cooperative endeavors always have incentives to reduce or control conflicts of interests and thus decrease the losses resulting from them. The benefit of this action is that some or all the parties can then share the gains. In business organizations, particularly in mining, one way to confront agency problems is through tailored reward systems. In business circles, they have come to be known as pay-for-performance schemes. Basically, they consist of incentive compensation contracts tied to performance measurements.

A Reward System in Mining

A basic proposition of this study is that the value of the mining firm is enhanced when the agency problems are recognized and confronted with ingenious reward systems. The idea is to make managers behave as if they were owners—with a sense of urgency in the short term but also with a sense of vision for the longer term. This long-term view, as discussed earlier, is crucial when the mining strategy is being devised.

Converting managers into owners, though, is not a straightforward activity. It implies the design of a reward scheme that balances four simple, although conflicting, objectives:

1. *Alignment*—giving management an incentive to think and act like owners so that they can choose strategies and investment opportunities that add value.
2. *Leverage*—giving management an incentive to seize opportunities while keeping an eye on the long term, to take the necessary risks to explore the roads less traveled, and to make unpleasant decisions such as closing an operation and laying off staff to maximize shareholder value.
3. *Retention*—giving managers sufficient total compensation to retain them in the firm, particularly during periods of poor financial performance caused by downturns.
4. *Shareholder cost*—limiting the cost of management compensation to levels within market ranges to maximize the wealth of current shareholders.

Alignment and leverage are intended to deal with the agency problems already discussed. However, balancing each of these four conflicting objectives is the crucial role of a total compensation strategy. A sound package must make trade-offs between leverage, retention risk, and shareholder cost. For instance, a strategy that relies on a high proportion of guaranteed compensation can achieve limited retention risk and shareholder cost, but at the expense of a modest leverage. On the other hand, a strategy with substantial leverage and minimal retention risk—one that relies on the large firm's stock grants, for instance—can be achieved, but at the expense of excessive shareholder cost. Likewise, a strategy that relies on the large firm's stock option grants can achieve extremely high leverage with minimal shareholder cost, but only by accepting greater retention risk than a strategy that relies on firm's stock grants.

Having discussed some general ideas about agency costs and how they could be managed through reward systems, and having defined the way in which a mineral deposit should be exploited, along with the metric to gauge the ongoing value created and the structure to accomplish such a venture, the next question is how to compensate the people who effectively do the mining as prescribed here. One way to deal with this problem is by first looking critically at the four conflicting objectives, then relating them to mining, and finally drawing some conclusions.

At first glance and regardless of the business type, an initial conclusion is that to cope with the alignment and leverage factors, the total compensation must be variable. Another general conclusion is that the retention risk necessarily implies a base salary if shareholder costs need to be limited.

On the other hand, by analyzing the finite character of mineral deposits, it can be concluded that wealth can be created when exploiting a mineral deposit by either managing the exploitation strategy, reducing the cost of inputs, or improving the quality and quantity of the reserves (i.e., via reconnaissance). Prospecting for new discoveries in other areas might also create wealth, but this activity is outside the scope of this study. In this last respect, it is important to reiterate that the focus here is on the business level; this study is not aimed at prospecting for new deposits, but at devising an exploitation strategy for maximizing the expected economic value of a certain known deposit. This value is indissolubly tied to decision rights and actions taken on the mineral deposit. Thus, if the owner of the deposit were a public mining firm with no assets other than the deposit, the market value of its shares would have internalized the value of this asset in some way.

This clarification is crucial because the incentive schemes mentioned earlier must focus on the aspects of the business that managers can influence most directly. This is exactly the case of the exploitation strategy whose design rests entirely on this new entity created to perform the function of mineral resource management. To cope with the alignment and leverage factors, the variable compensation for this group may be a percentage of the economic value created by the exploitation. The fraction should be a matter of negotiation. However, once the deposit is more or less defined in terms of size and value, simulating various scenarios can help to decide this issue.

Estimating the true economic value created when mining a deposit could be straightforward if the company that owns the deposit were public and its only asset were the deposit along with the associated installations. In this case, the company's market value would provide a straight indication to estimate the value of the deposit. The true economic value created in a certain period would be the net cash flow generated in that period minus the cost of capital times the value of the deposit at the beginning of that period.[8]

On the other hand, if the company had additional mining assets or was engaged in other businesses, beyond the exploitation of the deposit, the firm's market value would not be a proper source for estimating the value of the deposit. In such a case—or if the company were not public—the value of the deposit could be estimated as the present value of its future cash flows, which in turn are taken from the mining strategy. Thus, the true ongoing economic value generated in a certain period would be the net cash flow generated in that period minus the cost of capital times the present value at the beginning of that period.

Needless to say, this last way of estimating the deposit's value and its true ongoing economic value will be somewhat controversial. In these circumstances, discussion will

8. The value of a mineral deposit does not necessarily coincide with the market value of the company that owns the deposit because it surely has short- and long-term obligations that have to be deducted to make that estimate.

be necessary on the many variables that affect the present value, including the projected prices for the commodities involved in the business. This situation will certainly introduce a great deal of subjectivity to the analysis, but in any case it must be overcome. To avoid tortuous discussion in these respects, including some sort of arbitration, may be useful. In any case, arbitration is always an option that should be considered in the design of mechanisms for solving controversies.

The Bonus Account Reserve

The ultimate goal of the unit in charge of mineral resource management is to deal with a dual-track problem—to maximize both the ongoing economic profit and the present value resulting from the mining operation. The compensation system, therefore, should be planned to deter any intertemporal gaming that may harm long-term shareholder value. An example of this gaming is the so-called high-grading practice, which consists of accelerating the exhaustion of a deposit in a rational and deliberate manner, although in a totally uneconomic way—at least from the shareholder's viewpoint. Another example is the premeditated postponement of mine developments with the sole purpose of improving the very short-term cash flows.

It is important to point out that the two previous examples are uncommon in the traditional mining organization. They could be the result of an ill-designed reward system, such as one based only on short-term profits. In the traditional mining organization, where pay systems are generally fixed, the gaming occurs in exactly the opposite direction; that is, to extend the mine life, uneconomic material is often mined and processed. On the other hand, to show competitive costs and avoid unnecessary risks mine developments are usually brought forward and not postponed, especially when these expenditures can be capitalized (set up as assets).

If a persuasive package based on the firm's stocks or stock options were not a feasible alternative for employees, the long-term perspective can be encouraged via a bonus account reserve. This is an individual's notional bank account, managed by the firm and 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 profits (or losses), before being withdrawn according to a prearranged payment schedule. The purpose is to filter large bonus swings and defer the impact of short-term improvement until it has been determined that the bonuses are associated with permanent changes in shareholder wealth.

A simple design could be to pay just a portion of the bonus, say one-third, during the first year of the plan. The remaining two-thirds could be carried forward in the individual's bank account, but at risk of future performance. In the second year, the payment could correspond to the one-third yearly bonus, plus a fraction, say one-fifth, of any net positive bank balance. The cumulative balance in the bonus account is again carried forward and the same procedure is repeated in subsequent years. Negative bonuses, if incurred, are withdrawn from the bonus account.

An additional feature of the bonus account system, essential in the cyclical mining business, is that it limits the retention risk by smoothing out the bonus payments. Effectively, in the high part of the cycle, managers can build up a hefty account balance, which could be drawn down during the lean years. Also, the bonus account may act as "golden handcuffs" for highly successful managers if the uncollected account balance is forfeited when the manager resigns. Although properly designing a comprehensive reward system and calibrating all the parameters involved is a complex undertaking, converting managers into owners and reaping the dividends more than justifies the effort.

An anecdote may reinforce the effect that pecuniary incentives have on people and ultimately on performance. It deals with the small mining operation that immediately preceded the case study presented in Chapter 4. At the beginning of 1998, because this small underground operation was interfering with the construction of the large project and also because of proprietorship considerations, the owner decided that the smaller operation should be shut down by mid-year. Along with that decision, the owner offered a monetary reward to the work force, which was tied to the production of copper concentrates during that period. In the intervening months, before closure, the first action taken by the metallurgists was to increase the particle size at the primary grinding stage. This change allowed the plant to gradually increase the throughput to a peak of about 40% more than the previous average throughput. According to a metallurgical engineer who was involved in that operation, they could not increase tonnage further because the underground mine was working at full capacity and without possibility of new developments.

Why this was not done at the beginning, around 1990, when the operation was commissioned, and why they did react in that way in response to such an incentive are questions that certainly invite meditation. At any rate, it is important to highlight that this fact was essential to configure the arguments for optimizing the large project as presented in Chapter 4. Moreover, that experience and the metallurgical data obtained from that stratagem served as reference to support the first relationship between the metallurgical recovery and plant throughput in that case study (Figure 4.10).

It is important to stress that the message here is not 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 likely 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 which 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.*[9]

TECHNICAL AND CONTROL SYSTEMS

The term "system" is used here to denote the mechanisms for monitoring and controlling activities, mechanisms that any organization must have to be effective. The term also includes the specific tools required to facilitate the adoption of mineral resource management. In this last respect, it is worth mentioning that part of the problem in devising competing mine plans has been associated with the lack of tools for analyzing the numerous options that appear when the exploitation of a mineral deposit is being planned. For instance, the definition of the final limit of exploitation for a large deposit—this problem is called the "ultimate pit limit" in surface mining—took almost a year in the early 1960s, mainly because of the manual character of the task and the lack of computer programs.

Today, with powerful information systems and the assistance of graphic-oriented computer applications, the same problem can be handled within a day, if not an hour, once all the data are properly assembled. In the future, this type of problem will be likely solved almost instantaneously, as mining data and market variables change.

On the other hand, traditional systems designed to make the organization work day by day and year by year, such as operating and capital budgeting systems, training systems, and accounting procedures, have increasingly proved to indeed be helpful

9. This is the introductory paragraph of an Andrew Carnegie's speech before the British Iron and Steel Institute, printed as *The Secret of Business is the Management of Men.*

mechanisms for the functioning of organizations. They have also proven to be invaluable tools for avoiding disruptions in business organizations. In fact, the troubles experienced by many mining organizations in the recent past have all been associated with poorly designed or antiquated control systems. The Canadian Bre-X saga and the Japanese Sumitomo "unauthorized copper trading" scandals—both taking place around 1997—are examples that confirm the previous assertion.

Traditional control systems and computer development tools must both be considered vital for the appropriate functioning of mining organizations. They are also essential components for the proper functioning of mineral resource management. Actually, it would be difficult if not impossible to carry out this task without the assistance of appropriate systems. The goal of this section, then, is to describe the tools considered critical to implementing the function of mineral resource management.

Technical Systems

The first systems judged to be useful in mine planning are the technical ones aimed at gathering, editing, and working the ongoing geologic information. In the recent past, a number of worldwide suppliers of computer tools have appeared on the market and there are now many good options in this respect, especially in terms of graphic applications for statistic analysis, geologic modeling, reserve estimation, geostatistics, and the like, all of which call for fairly standard procedures. Even for the intricate optimizing procedures described in Chapters 3 and 4, it is now possible to find some incipient computer applications. Although these developments are not intended to solve all the multifaceted problems that usually appear in complex operations, they are quite helpful for preparing preliminary mine plans.

Another set of technical systems is becoming common in the operation of mines and processing plants—systems for control and dispatch. These computerized systems, based on technologies such as programmable logic controllers (PLC) or global positioning systems (GPS), monitor the whole sequence of operations from control consoles that keep tabs on activities in various sections of the operation. Such systems not only reduce the number of people at the work sites but also improve operational efficiency and data collection.

The opportunity and reliability with which the operating data are gathered is relevant to the effectiveness of mineral resource management. As discussed previously, intentionally changing some technical parameters—such as the cutoff grade at the mine or the grind size at the mill—because of changes in economic circumstances is not a common practice in mining operations. Although making people partners in the operation is a good way to motivate such behavior, appropriate information systems that can quickly predict the outcome and monitor its realization must also be in place. Once people become accustomed to these tools, they become essential for ensuring that the planned changes are working properly and value is being created.

Administrative Systems

The other group of systems critical to mineral resource management is related to the ongoing financial information of the business and the bonus accounts of the individual employees. As shown in Chapter 3, almost all mining decisions included in strategic mine planning consider an opportunity cost, which is often estimated from the present value of future cash flows and the cost of capital. Both estimates must be at the planner's fingertips at any moment during mining. As these concepts depart from the GAAP, some adjustments to common practices must be made. In effect, 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 will do in the future.

Turning to bonus accounts for individuals within the company, people should be able to estimate their own bonuses based on company performance. That means that financial information of the company, as required here, should be updated regularly. In this way people are encouraged to push forward, even in good times, and are discouraged from making a difficult time even worse.

Systems and collected data, however, must be used for specific purposes. Mining operations may routinely collect a great deal of information on geologic properties of the ore body, operating parameters, production costs, and the like, without a precise objective. The effort becomes meaningless when companies do not have an integrated approach to using such information. Simply put, if information is to mean something and be useful, it must be turned into knowledge—productive knowledge as advocated here. In this perspective, the goal of information systems is not just to bring together information but also to present it in a comprehensive way so that it can be used efficiently in mineral resource management.

Finally, it is important to remember that although systems and the information they provide are useful for the functioning of mines, they can never hope to be a proper substitute for common sense and good judgment on the part of the management. This aspect and other "people" considerations are the subjects of the next section.

SELECTION, TRAINING, AND DEVELOPMENT OF PEOPLE

The proper selection, training, and development of people to perform the function of mineral resource management are critical aspects in organizational design. In fact, under the framework presented here, it follows that mining goes beyond the mineral resource. Because the deposit has an intrinsic value that depends on a devised strategy for its exploitation, what really matters in this approach is the knowledge and creativity of talented people. A good deposit is still important, but making use of the talent of individuals is the only way to add value to that inert asset.

Selecting the Right People

Many corporate managers wish to believe that if there is a problem in part of the organization, with a manager making the wrong decisions, it must be caused by having the wrong person in the job. The solution is to sack that manager and look for a new one. In contrast to this view, the business model discussed here would predict that if the manager has the proper talent and training, it is the business strategy, the organizational structure, or even the reward system that may be at the root of the problem. The solution would not be to fire the manager, but to reexamine the many components of the business model to ensure that they fit together properly. In other words, the only way to assess the real capability of people in business organizations is to critically scrutinize the other components of the business model first. The preceding example, where a small mining operation had to put certain incentives in place because of particular circumstances, clearly corroborates this assertion.

In seeking the right individuals with the proper talent to execute mineral resource management, the level of authority and responsibility that will be delegated to such individuals must be taken into account. The chief of this unit, for instance, is managing the asset that is at the core of the mining business. The weight of his or her decisions is usually measured not in hundreds or thousands but in millions of dollars. In the case of large deposits, it may easily jump to a couple of billions of dollars. It may be concluded, therefore, that first, this person must be a good manager. On the other hand, the individual cannot be competent on all matters. He or she must base many decisions on the advice given by the other members of the team. However, lack of competence in the fundamentals of mining is inadmissible. It follows then that this person must possess a fair competence in the specialized aspects of the business.

Training Activities

Turning to training activities for mineral resource management within mining companies, nontechnical people should be given the opportunity to acquire a general knowledge about the technicalities of the business. Conversely, specialized mining professionals, working in technical areas of the business, should enhance their skills in economics, finance, and business management. This is necessary because the mining business as presented here is much easier to understand when an economic way of thinking has already been nurtured.

Although the need for training and development of people appears clear, many mining organizations significantly underestimate the training requirements of work redesign and fail to put appropriate systems and practices in place to support the higher training demands. Mining firms, therefore, should recognize that training needs extend beyond the start-up phase and that people need to be taught skills on an ongoing basis to help the group develop over time.

In this respect, many companies engage in team-building training to enhance team cohesiveness and functioning. Ultimately, however, such practices are valuable only if proper mechanisms are put in place to ensure that new knowledge, skills, or attitudes are transferred back to the workplace (Parker and Wall 1998).

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

Development of People

As already mentioned, the pay system drives performance not only because it influences people's behavior in the organization but also because it conditions the type of people who remain in and are attracted to the organization. But it is not just money that counts when attracting and retaining talented people; success in this area definitely requires more imaginative work on the part of employers and recruiters. People are motivated by various factors other than money—they want to do well, make a difference, be recognized, interact with exciting and challenging peers, enjoy flexible work arrangements, and have the opportunity for continuous learning.

ILLUSTRATIVE CASE

Because of the contingent nature of these organizational ideas and their novelty, it is difficult to relate all of them to a single case. However, the following examples may illustrate how their essence worked successfully in a mining corporation. In fact, this experience is in many ways what ignited and shed light on several of the propositions outlined here.

The case is related to Codelco, Chile's state-owned corporation that is currently the world's largest copper producer and one of the few state-run mining companies that can exhibit a balance sheet in the black over the years. It was formally created in 1976 to group the four copper mines nationalized in the early 1970s—Chuquicamata, El Teniente, El Salvador, and Andina.

The initial corporate model featured the four mines operating as divisions, each with its own structure of the hybrid form described earlier; that is, with functional units to perform the core technical activities plus the support of specialized staffs for the other divisional services. These autonomous divisions, in turn, received centralized support from headquarters in aspects such as commercialization, finance, human resource management, capital investment, and development, among others. Since the beginning, this basic structure remained relatively unaltered although some minor variations were made in the intervening years.

In the early 1990s, with the reestablishment of democratic order in Chile, the new Codelco administration had a specific mission—to reinvigorate the financial position of the corporation, which with the passage of time had began to suffer the typical problems of almost all state-owned companies such as lack of investment and overstaffing.

During that period, a small mining consulting group was introducing a different approach to the planning and exploitation of mines in Chile. The group's partners were all mining engineers, who had departed Codelco's operating divisions in the mid-1980s to offer their specialized services independently.

These innovative concepts enjoyed a good reception among some of Codelco's executives, especially those in charge of the most problematic divisions. This helped build a tacit alliance that later was extended to eventually encompass all the other divisions. In retrospect, it can now be argued that this association genuinely fulfilled the role of the special structure encouraged here to oversee the nonroutine aspects of the mining business. As will be become clear in recounting the facts, this alliance was essentially concerned with issues within the scope of strategic mine planning.

The following examples relate how this liaison started and developed. In so doing, they describe the technical challenges of two important Codelco divisions and the way they were managed to create value.

The Andina Case

The Andina operations are located in the central Andean range of Chile, about 80 km northeast of Santiago, at an altitude between 3,000 and 4,200 m above sea level. The current mining is underground for the resources located in the Rio Blanco sector and open pit for the nearby resources in the Sur-Sur and Don Luis sectors. Because of the snowy winter, the ore is transported and treated in an underground concentrator. The tailings are sent to a disposal dam, which was built recently in the lower part of the valley.

The Andina mine was commissioned in the early 1970s when the Cerro Corporation, a U.S. mining company, developed a block caving mine in the Rio Blanco sector. This mine was coupled with a mill concentrator to treat around 10,000 t/d of fresh ore. The original exploitation was conceived so that the Rio Blanco deposit was gradually exploited by means of vertical layers called "panels." The First Panel was the initial 120-m layer that allowed the mining of the enriched zone located in the upper part of the deposit.

The Sur-Sur open pit operation is located about 2 km south of the Rio Blanco sector. It started in 1982 with the sole purpose of exploiting a small high-grade zone of a deposit discovered in 1980, under a 40-m-thick glacier. At the time, the Andina operation was being expanded to 26,000 t/d with the simultaneous inclusion of the Second Panel. Figure 5.6 is a sketch of the Rio Blanco and Sur-Sur/Don Luis sectors of the Andina ore bodies.

The open pit operation was opened with the intention of temporarily replacing some of the hard ore coming from the extreme south of the First Panel, which at the time was close to exhaustion. It also coincided with a prolonged downswing in the business cycle and a corresponding very depressed copper price. This short-lived conception for the Sur-Sur operation and the downturn led management to reduce the initial capital

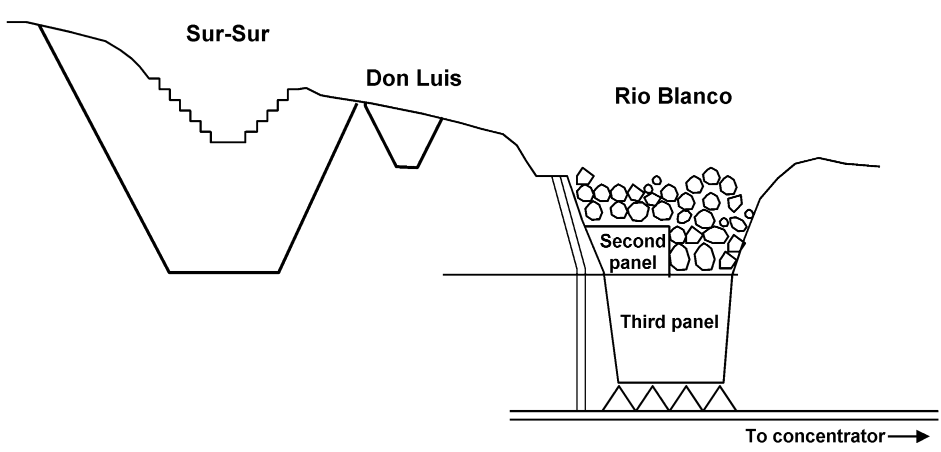

FIGURE 5.6 Mining at the Andina division

investment. In practice, it meant externalizing the prestripping activities and using reconditioned equipment from a sister division to operate the mine.

Luckily, an infill drilling campaign executed in the early years of the Sur-Sur pit and an exploration/drainage tunnel built under that mine revealed additional resources that could be mined by open pit. At the same time and under a cloud of controversy, the concentrator gradually increased the tonnage by intuitively using the trade-off between throughput and mill recovery. It rapidly achieved a higher production rate that stabilized at about 34,000 t/d. Hence, the Sur-Sur open pit mine was formally included in the long-term plan at 16,000 t/d, with the First and Second Panels supplying the remaining tonnage.

The preliminary engineering studies for the inclusion of the Third Panel into the long-term plan started by 1985. The mining concept considered a block caving operation at 20,000 t/d so that the open pit mines would yield the remaining 14,000 t/d. In this new scenario, some additional investments were approved to enhance the performance of the open pit operation at Sur-Sur, which at the time was deficient because of inappropriate infrastructure. New equipment was acquired to replace the reconditioned tools, new maintenance facilities were built, and several optimization studies were performed in areas such as geomechanics, geology, and mine planning.

In the early 1990s, when the basic engineering of the Third Panel project was complete and the new Codelco authorities took over, a divisional assessment found that the different projects needed to sustain production at the current level were not so profitable as a whole. If this division were to continue operating, it would require a capital injection that was estimated at more than $300 million. In effect, the up-front capital estimates for the Third Panel had been increased from $73 million to nearly $100 million and the new tailings disposal called for an additional investment of around $200 million. The divisional NPV of the 1991 mine plan—which considered the Third Panel at 20,000 t/d and the Sur-Sur mine at 14,000 t/d—was estimated at $16 million before taxes, for a copper price of $0.85/lb and an annual discount rate of 12%.

To improve the financial performance of the division and bring it back from a perilous track, management set up a task force. Two external consulting groups were invited to separately participate in this challenge. This presented itself as a propitious occasion for one of the groups to test the strength of the methodology advocated here.

The strategy developed by one of the groups to improve profitability was rooted in the premise that mining is essentially a cost-based business. In fact, its mantra was to position Andina as a low-cost producer—ideally in the first or second quartile of cash costs. This group's proposed answer was mainly based on an expansion project to increase the capacity of the plant, improving Andina's income statement by distributing the high proportion of fixed costs over a larger tonnage. This solution, however, would have an adverse impact on the company's balance sheet, requiring an additional capital injection of around $350 million. Moreover, it would barely add value because a considerable amount of time would be needed for implementation and, in the interim, almost nothing would be done.

The other group, not so inclined to the cost-based approach, used this innovative mine planning process to optimally deplete Andina's vast mineral resources. New options were generated and evaluated and eventually a new life-of-mine plan was released to use the in-place plant capacity. It demonstrated the economic advantage of radically changing the mining sequence and the cutoff grade policy in the existing mine plan.

The major change in the new mining strategy related to the Third Panel project. The various planning exercises carried out over the whole of the Andina resources found that the economics could be significantly improved if this project could fulfill the total capacity of the mill on a stand-alone basis. This meant increasing the Third Panel production rate from 20,000 to 34,000 t/d so that the open pit operation at Sur-Sur ceased when the Third Panel reached a steady-state production by mid-1998. The strategy implied that during the Third Panel development and ramping up, the concentrator would have to be fed with the best ore from the Second Panel and Sur-Sur sectors. In turn, it would require a redefinition of the mine plan for the 6-year period from 1993 to 1998. In practice, it meant a better selection of the minable reserves from both sectors and, accordingly, a higher production of copper during that period.

The Third Panel project was then reformulated to accommodate the higher tonnage. A new sequence and cutoff grade policy was defined—without the interference of the open pit operation, which in the previous case had severely restricted the Third Panel sequence. Minable reserves were even reduced from 300 Mt at 1.01% Cu to 250 Mt at 1.08% Cu, but this drop improved substantially the copper grade profile of the Third Panel project. This was mainly the effect of introducing the opportunity cost concept into the definition of the mining sequence and draw-point cutoff grade policy.

Overall, the new mining strategy enabled the Andina division to increase its NPV tenfold—from $16 million (before taxes) to almost $160 million, considering the copper price at $0.85/lb and annual discount rate at 12%.

By the middle of 1992, both groups had the opportunity to put forward their strategies to the company's management. These novel ideas were presented in one afternoon, after the other group had expressed theirs in the morning. When the second presentation concluded, the chief executive exclaimed, "This is the best thing that I've listened to in these two years." After the meeting, the winning strategy began to be executed and the Andina division began rushing back to its developing path.

The higher copper production resulting from the new mining strategy happened to occur during an upswing in the business cycle. This fact was beneficial not only because of the better cash flows achieved, but also because company morale was considerably stimulated. In effect, as the short-term actions were being successfully implemented and as the Third Panel construction progressed, Andina's management again raised the idea of an expansion. This time, however, the proposed expansion received a much better reception at Codelco's headquarters because it could now be compared with a more robust base case and led by a more confident team.

The previous studies also shed light on the crucial concept to be used in analyzing expanded options. The concept was to drive the extraction rate from the Third Panel project to its maximum and reopen the open pit mining in the nearby area to result in the additional tonnage required. Several capacities were assessed and the most promising was found to be in the range of 65,000 t/d. As the maximum capacity for the Third Panel was estimated as 45,000 t/d, the remaining 20,000 t/d would come from the Sur-Sur and Don Luis pits.

In March of 1995, Codelco's authorities approved the expansion project along with an up-front capital expenditure of $370 million. By the end of 1998, the project was commissioned. Since that time, the idea of another expansion has been in the air. This larger project is currently under examination and it is likely that more profitable copper can come to light in the near future from this world-class deposit. Figure 5.7 displays Andina's real copper production during the 1990s and contrasts it with the production projected in the 1991 mine plan and the London Metal Exchange (LME) copper price.

As seen in Figure 5.7, the copper production over the 6 years to 1998 was considerably higher than that projected in the 1991 mine plan, as the result of the radical change in Andina's mining strategy. After that period came the expansion project, which from 1999 forward increased the copper production even more. Perhaps the words of the newly appointed chief executive in 1994—who was the second in command during these changes—best sum up these facts: "In the past, we were doing things right, but it seems that now we are doing the right things."

The Chuquicamata Case

Chuquicamata is Codelco's largest division, comprising many production units, with the sulfide line being the most relevant. It is made up of a large open pit operation, coupled with a mill concentrator and a smelting and a refining facility. The division also operates Mina Sur, which comprises a medium-size open pit mine, along with an LX-SX-EW process. A dump leaching line, operating with an SX-EW plant, processes the low-grade sulfide ore coming from the Chuquicamata mine.

At the beginning of 1994, a new management team arrived at this division. Its mission was to carry out an in-depth modernization program focused mainly on restructuring its business operations, downsizing, and introducing a mine planning process consistent with the now-explicit company goal of maximizing value.

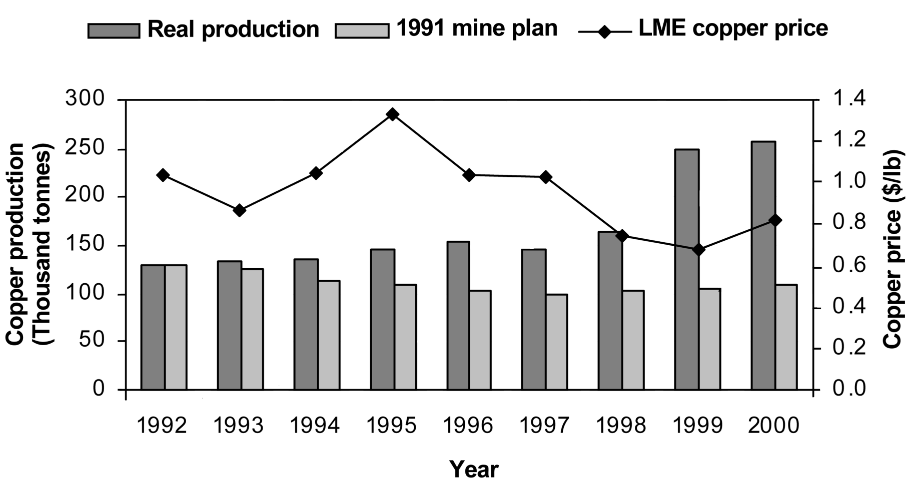

FIGURE 5.7 Copper production at the Andina division

Almost all the managerial efforts centered on the Chuquicamata mine, which at the time was considered the division's cash cow. This almost centenary operation had begun to experience the typical problems of an aged open pit mine—declining grades and increasing haul distances.

To tackle these problems and try to improve the profitability of this operation, the new management created a task force. To provide some expertise but also to separate the day-to-day work from this effort, the same external consulting group that had helped in Andina was part of this team.

At the time, the run of mine material at the Chuquicamata sulfide line was 640,000 t/d. Of this, 155,000 t/d corresponded to ore, which yielded about 4,200 t/d of concentrate. This implied an annual movement of around 230 Mt at the mine, of which 56 Mt were treated in the concentrator. This resulted in a stripping ratio of around 3:1.

The exploitation scheme considered an "open scheme," which meant that every bench in the mine was designed with enough roadway space (berm width) to allow the traffic of large trucks. This feature allowed the operation a great flexibility, but the consequences were flat slope angles—much flatter than those recommended by the geomechanics experts. One of the arguments for using this operating practice was the grade variability demanded by the plant, which to the understanding of the mining people had to remain stable between certain limits. Thus, long-term schedules at the mine were always designed to keep head grades relatively constant and short-term schedules formulated to meet such grade targets accurately. This practice led the mine to operate with a great deal of independent push-backs to produce the desired blending, which in turn required the corresponding flexibility in the traffic system.

The cutoff grade policy at the mine considered a fixed figure of 0.5% Cu. It had been unaltered for a long time and, in fact, was the reason that the capacities at the mine and concentrator always matched. The mine operated principally on benches of 26-m height, although the upper benches were of 30-m height. The mining fleet included electric shovels ranging in size from 28 to 34 yd^3 along with trucks from 200 to 240 short tons (st).

Two in-pit crushing systems were used—one for waste and one for ore. Both kept a significant area of the pit captive, so the actual mine plan considered relocating them to other positions within the pit. The ore crusher would be relocated back to its previous position in the southeast sector, although a couple of benches down; the waste crusher would be moved up to a bench closer to the surface to allow the same existing conveyor system to be used. It is worth noticing that these systems were always conceived with the purpose of reducing operating costs, as was the usage. Figure 5.8 displays the crushing systems at the Chuquicamata mine and the options for relocation.

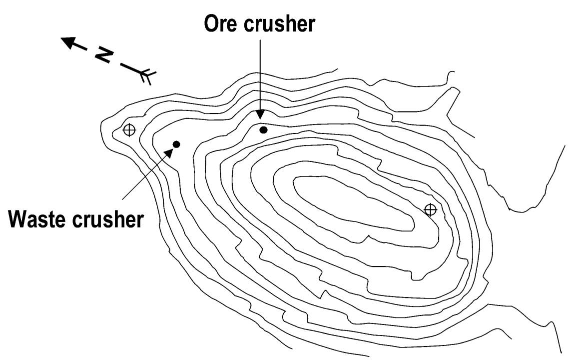

FIGURE 5.8 Crushing systems at Chuquicamata (⊕: options for relocation)

Scrutinizing the open scheme was perhaps the most critical activity. Each of the arguments underlying this old practice was thoroughly examined with planners and operators along the productive chain. None of them had enough merit to justify such an expensive practice as was demonstrated with a challenging mine plan that adopted a closed scheme instead. It allowed steeper working slopes, resulting in less waste removal, to expose the same amount of ore. The total extraction at the mine was reduced from 640,000 to 480,000 t/d for the same 0.5% Cu cutoff grade. However, the most significant impact of the steeper slopes was the delay of the low-grade ore located in the pit ribs to concentrate the exploitation on the bottom of the pit, where the better-quality ore usually comes from.

The closed scheme represented a fundamental change for the Chuquicamata mine. In fact, it required a different push-back design, with autonomous haulage routes to access each push-back independently. The demystification of the stable copper grade to the mill enabled the mine to operate with fewer working faces in the pit, which in turn paved the way to the gradual incorporation of larger equipment. The economic impact of this change was estimated at about $500 million, in terms of before-tax present value now using a copper price of $1.0/lb and a 10% discount rate.

The mine sequence at Chuquicamata was a complex problem aggravated by the two in-pit crushing facilities. The solution to this problem considered not only the savings in transportation costs but also the implications in revenues because of a more constrained mine plan. In addition to the relocations shown in Figure 5.8, various other positions were studied. The most relevant were those that put the crushing facilities outside the pit rim because they required much less time and capital investment. One of these options considered a semimobile ore crusher in the pit edge, which would be then relocated within the pit when economic; the time schedule for this project was estimated to be 2 years. Another option was adapting the waste crusher within the pit to operate it dually with waste and ore; the estimated time for this change was also 2 years.

Each alternative originated a life-of-mine plan along with particular operating and capital cost estimates. This exercise showed a surprising result: the advantages of any in-pit crushing options were far outweighed by the advantages of relocating them temporarily in the pit rim. The greater pit flexibility and the possibility of liberating better-quality ore earlier improved the before-tax present value by another $100 million, for the same copper price and discount rate.

Because of the closed scheme, the mine entered into a stage where less waste removal was needed. In effect, the mine capacity and the fleet had been calculated to extract more than 650,000 t/d; in the new mine plan, it had declined to around 450,000 t/d. This was the propitious occasion to review the cutoff grade policy. The exercise showed the advantage of using a variable cutoff policy, which would be higher in the initial years to reach a break-even point toward the end of the mine life. For a price of $1.0/lb Cu and an annual discount rate of 10%, the declining cutoff grade policy varied between 0.65%–0.45% Cu. This new strategy added another $200 million to the before-tax present value.

Overall, the changes enabled the Chuquicamata division to increase its economic value by more than $800 million, in terms of before-tax present value. In reality, this value was even higher because the first additional production of copper achieved with these changes was sold in a favorable market, when the copper price was higher than the $1.0/lb used in the evaluation. Figure 5.9 shows the copper content in concentrates predicted in the 1992 mine plan over the 8 years to 2000. This is contrasted with the real copper production for the same period. The same figure also displays the yearly ratio between the total ROM material extracted from the pit (real ROM tonnes) and that forecasted in the 1992 mine plan (1992 ROM tonnes).

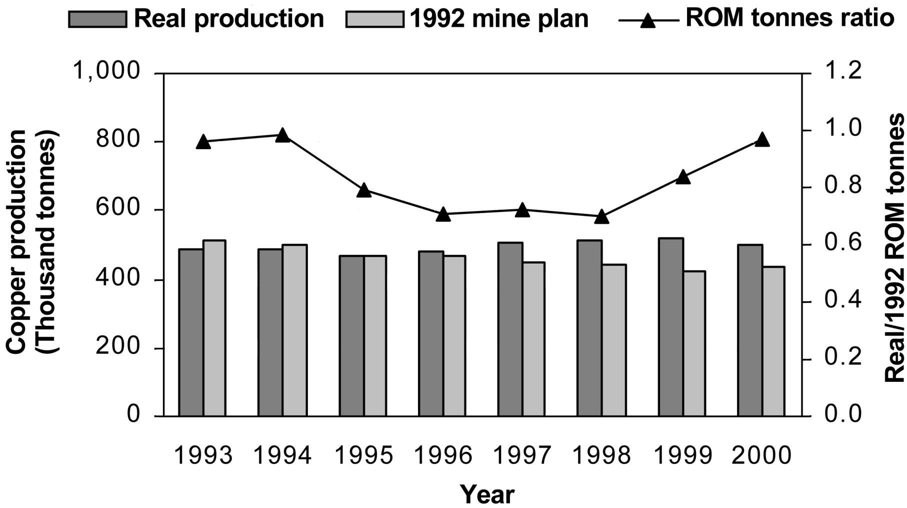

FIGURE 5.9 Copper production in concentrates at Chuquicamata

Complementary Discussion

These achievements were not just a consequence of grouping together the right people to deal with the activities involved in strategic mine planning. They were also the result of many deliberate actions taken to overcome the many difficulties and complications encountered during the course of the work. Some fortuitous circumstances also made a contribution.

This discussion is aimed at drawing additional evidence from these cases so that the achievements may be linked with the other organizational variables mentioned in this chapter.

It is worth commenting that Codelco's ownership was an incidental factor that in many respects facilitated the favorable reception to these ideas. In effect, state-owned firms often encounter political difficulties to rationalize and downsize their operations. The new management, therefore, could not rely entirely on the most common tool used by troubled companies, which is to reduce the labor force. Instead, it put the emphasis on a special particular strategy: to technically optimize the exploitation of its vast resources with the objective of enhancing the company's value. This was clearly identified in the new mission statement, which for the first time made an explicit reference to the pecuniary objective of the corporation.

Another factor that certainly helped the undertaking to take wing and finally succeed was the proactive role that senior management played in this process—particularly the chief executives. It materialized in the decisive and continuous support from the top, which became visible not only by raising the team activities to the proper level in the organization but also by articulating the actions necessary for many of these ideas to be implemented. This is exactly the role assigned here to the overlay structure (standing committee) that must keep watch over the management of mines.

Although compensation was never an explicit issue in this alliance, the lessons from the experience might help to illustrate this aspect of the subject.

A first observation in this respect is that an external consulting firm was involved in the company's strategic planning. This would have gone unnoticed had the people not been former Codelco employees. A pertinent question arises: Why did they not perform any part of this function before? An answer may be found in the way mining companies are organized and the way they reward their employees.

The more visible people in the mining business, who move up quicker on the company's ladder, are usually those who engage in line responsibilities. This means that the most talented people orient their career toward those more rewarding functions that generally focus on operational, day-to-day tasks. In turn, this means that those ambitious people with other interests or aptitudes, do not always find the appropriate path in the traditional mining organization. They adapt and accept the tacit rules or they simply leave. If they leave, though, it is not because the grass is greener on the other side of the fence; rather, it is because the grass is brown on their own side. This may be another way of looking at Gresham's law of planning, which asserts that routine drives away nonroutine activities.

Another observation about this alliance is that it was in essence a pay-for-performance relationship. In effect, success is the only way for a consulting firm to make money and, ultimately, to survive. In addition, once the scope of certain work has been defined and its value agreed on, the service firm has a powerful incentive to be effective. This is seldom the case in the traditional mining organization where individual rewards are usually fixed and there is no direct incentive for taking risks. Actually the incentive is to take the greatest risk of all, which is taking none.

As a final thought on compensation, this agreement was built on a base-to-base case and in no way was competition absent. On the contrary, the principles underlying the methodology had to be defended constantly because many domestic and international consulting firms were always hovering in the wings.

Most of the technical systems used in these assignments were commercially available. However, the same consulting group had to develop the systems used to determine the strategic mining variables in house. Because this type of knowledge had been less dispersed, it was not always possible to find off-the-shelf tools for the various specific problems that were found. For example, the mining sequence as well as the cutoff grade optimization problems at Andina—which involve simultaneous open pit and underground mining— called for very specific, customized applications. Fortunately, the same routines were later used successfully in other block caving mines within Codelco. Today, improved versions of some these tools are becoming increasingly common in commercial mining applications.

Most of the members of the consulting group who conducted these strategic studies were senior, well-educated engineers with considerable field experience and good economic acumen. Although this proved to be a tremendous advantage for interacting with Codelco's engineers, it was also a difficulty in a buoyant and competitive market lacking experienced professionals. To keep cohesion in the consulting group and keep the "grass green," many organizational changes were implemented, including an ingenious reward system. Although this did not operate in exactly the same way as proposed here, as the circumstances were rather different, it worked out well in practice.

But having skilled, motivated consultants on one's side is not enough. Their counterparts, in this case Codelco's professionals, also had to come to understand the basis of the proposed methodology. For this reason, many seminars and workshops were organized along the way. Leading worldwide professionals, accustomed to this approach and even in some cases original advocates, were also invited to present their points of view and relate their experience. In retrospect, these training activities seem to have been essential for the success of the alliance, as they supported the dialogue that was needed to move ahead.

The same approach was later replicated in the other Codelco divisions, unlocking substantial economic value from these operations. All these achievements were reflected in Codelco's production costs, which during that period declined by 17¢/lb of copper. For the layperson, this is simply a great cost reduction. For the more inquisitive, though, this is mainly the result of skillfully managed mine plans that enabled Codelco to accelerate its copper production with almost the same installations. In either case, the end result was about $1.5 billion added to the company's cash flows over the last decade and an almost twofold increase in present value.

With the benefit of hindsight, it now seems fair to relate this whole process to the Codelco image in its host country. Currently, Codelco is among Chile's top ten most admired companies, according to a ranking prepared by *El Diario,* a local financial newspaper, and PricewaterhouseCoopers, an international consulting firm.[10] It considers the opinion of about 4,500 senior executives on matters such as business strategy, financial strength, quality of people, innovation, and the like. In addition, this process may also confirm the assertion that mining companies that focus only on reducing costs seldom get significant results, whereas those that concentrate on improving business performance succeed more frequently and, along the way, obtain lower costs.

In conclusion, it can be argued that the methodology presented here has been crucial for enhancing Codelco's profitability. Although the organizational issue was not addressed as indicated in the business model, there is indeed a resemblance allowing some lessons to be learned from these cases. Coincidentally, the company is now engaged in a core reorganization aimed at underpinning this process to unlock the potential value that surely is still trapped in its various businesses.

10. This survey is similar to the worldwide research on the world's most respected companies produced every year by PricewaterhouseCoopers and *Financial Times,* the British newspaper. In 2001, Codelco was ranked third in Chile, as it was published by Chile's *El Diario* newspaper on August 20, 2001.

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CHAPTER 6

Challenges to the Mining Industry

One of the concerns of this study is the low profitability of the mining business. The brief analysis presented in the introductory chapter illustrates how the mining industry consistently and substantially underperforms other sectors of the economy in providing returns to shareholders. The thesis here is that among the various factors that may explain this situation, one is fundamental: the little attention that practical mining 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 the importance of the subject into more prominence, a core managerial function is suggested—the management of mineral resources.

Mineral resource management can be conceived as a tool aimed at improving the financial performance of the mining business. As with any idea that intends to solve a problem, however, it requires actions. These actions, in turn, mean change, in this case a profound change in the way of doing things. Because mining is an established, mature industry, with entrenched rules of thumb and rituals, this is likely the most difficult barrier to overcome. But the mining industry not only comprises mining companies of varying sizes and ages. It also encompasses educational institutions that prepare the professionals the industry needs; government agencies that define the rules and regulations of the sector; metal and stock exchanges that allow the transaction of commodities and firm's shares; suppliers that produce the goods and services the industry demands; nonprofit mining organizations that create the linkages and professional bonds that the industry calls for; and nongovernmental organizations.

One way or another, each industry's constituent is affected by the propositions outlined here. The purpose of this last chapter, therefore, is to provide some final remarks aimed at enhancing policy formulation in some of these institutions and, at the same time, to pose some challenges to the mining industry in general.

CHALLENGES TO THE MINING FIRM

The concept that flows from the arguments presented here is that the mining firm is the main focus for this transformation. The types of changes that must be implemented to reap the benefits of mineral resource management, however, go beyond a mere reorganization to put these principles in practice. The fundamental change is structural, and deals with the firm's attitude toward market forces; for example, to what extent the mining firm is open to the market or to what degree the mining firm is willing to explicitly compete for the rights to exploit its mineral resources.

In general, the market is blind to what mining companies are doing with their deposits because detailed information about mineral resources is either unavailable or incomplete. If this information were available and if mining companies were listed in stock exchanges individually, it would be difficult for them to consistently underperform the market because they would rapidly become potential targets for takeover.

These days, a common way to reject this fundamental market premise is to discourage the disclosure of information. This attitude is pernicious and may be counterproductive for value creation. An open attitude toward market forces, with all the difficulties that might be encountered, will always benefit shareholders and the industry as this is the best way to foster a healthy competition. It is also the fairest approach for assessing the performance of teams in charge of mineral resources management, because takeovers ultimately exist to enable the transfer of resources to those who can manage them best. As the saying goes, markets are like parachutes—they work properly only when they are fully open.

The mining firm, however, operates within an industry that is considered mature. Most of the individual firms are very formalized organizations that follow standard procedures and use widely accepted practices in their operations. All these characteristics imply that the structural change proposed here must come from the top down, which contrasts with more entrepreneurial forms of organization, where change usually comes from the ground up.

In planning the organizational change for the mining firm, it is useful to bear in mind that structural changes are seldom the result of planned actions needed to ensure high performance. In fact, those in power have little reason to initiate change unless they are confronted with a real threat. Instead, change is most likely a response to pressing demands created by internal or external parties interested in the business. This is the ultimate reason to advocate openness toward market forces. Only in this way will high-caliber people and wise investors be enticed to continue mining and bring about change.

If organizations evolved like natural species do in Darwin's evolutionary theory, one of his reflections on the subject is quite appropriate to the grand challenge of the mining firm: "It is not the strongest species that survive; nor the most intelligent, but the ones most responsive to change."

CHALLENGES TO EDUCATIONAL INSTITUTIONS

As already highlighted, individuals and organizations, by their very nature, are conservative. They instinctively resist change. Even educational institutions, which exist to open minds and challenge doctrines, are themselves extremely resistant to change.

The truth and importance of this assertion was recognized in the writings of Henri Fayol, a prominent mining engineer, who is considered the real father of modern management. At the turn of the twentieth century he already emphasized the necessity of introducing core courses of administration and management into the mining engineering curriculum. However, during that century and at the outset of a new one, mining education—with just a few exceptions—has continued to focus on the specific technicalities in the field.

The formation of new leaders and the creation of ad hoc mining and research programs for the industry should be based on the fact that activities in the sector require cross-functional tasks that are beyond the mining engineering field. This combination of disciplines involves complex interactions of many factors that are not technical, but call for special managerial skills. Mining educational programs and research activities, therefore, should assist mining professionals in decision making and provide integrating skills in the fields of management, economics, finance, and mining, among others. The result of this effort should be the development of broad-based professionals with wide perspectives, who are capable of improving the business performance of mining and lead the change proposed here.

Achieving these goals is ultimately the responsibility of mining firms and corporations because they are the main employers of mining professionals and the major beneficiaries of high-skilled individuals. Thus, if mining firms also demanded mining professionals for performing mineral resource management as well as for advancement into other management positions, the educational institutions would necessarily have to modify their programs to cope with this additional request.

Those educational institutions that are ahead of these changing needs will have a tremendous advantage over those that overlook or simply dismiss the change. The latter institutions will likely not be in the race, as is already happening with many of the once-leading mining schools throughout the world.

CHALLENGES TO GOVERNMENT ORGANIZATIONS

If it is accepted that the general role of government organizations is to look after the well being of the societies they represent, the mandate of government agencies that deal with mining should be proactive toward value creation. The role of government agencies with respect to the production of mineral products should be seen as collaborative, as this is an important way to ensure that the immense amounts of resources the industry requires are utilized effectively and efficiently. Thus, if the mining industry creates wealth, it is the whole society that receives the benefit. Conversely, if it destroys wealth, which seems to be the present case, everybody loses.

Because it identifies the sources of wealth creation in the mining business, mineral resource management seems a useful tool for government agencies to use in designing and formulating mining policies. For instance, when governments put in place policies that demand resource maximization and employment rather than increased profitability, they only contribute to the destruction of wealth, since as has been concluded here, the economic size of a mineral deposit and the scale of operation are variables that must be determined according to a company's market expectations rather than being imposed by government regulations.

Ideally, government rules and regulations should be encouraging to mining, although this is not always possible because restrictions and certain limits must sometimes be established. This is the case of some environmental policies, which generally call for additional expenditures. Despite this fact, expediency by government agencies in granting authorization and permits is of the utmost importance for the mining industry to reduce the opportunity cost of delays in the start-up of mining projects. The Voisey's Bay nickel project in Canada is a good example of what should be avoided in this respect. The provincial government of Newfoundland and Inco, a Canadian mining firm, have been unsuccessful in reaching an agreement to proceed with this venture, and other non-Canadian producers have become the major beneficiaries of this impasse.

In other instances, government intervention could be managed so that optimum mining strategies do not deviate from the right track. Taxation is a good subject to illustrate this point. As governments also share the economic profit generated by mining companies, the taxation system should be designed to support the creation of wealth as prescribed here. Although it is not the purpose to advocate any particular tax regime, the message is that certain systems are less harmful than others in terms of value creation. A tax system that does not recognize the finite character of mineral deposit, for instance, does not lead to a socially optimum exploitation track.

CONCLUDING REMARKS

This book 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 for revealing the value that is inherent in mining, but that is unseen under the current paradigms. The cases and illustrations presented throughout the text are just a glimpse of what can be achieved by doing things differently.

Perhaps the most significant fact that unfolds in this book is the proper concept of profit in mining. As shown, profit or economic value added is not the value attributable to an in situ mineral resource, which the owner can realize even without mining. Instead, it is the value that miners add to the in situ resource value by using their ingenuity and intelligence. This undertaking calls for competent people, or "knowledge workers" as Peter Drucker labeled them in the early 1960s. Incidentally, they are now coming to be referred to as golden-collar workers. Whatever their name, the answers for the mining industry are in their minds, waiting to be triggered. To succeed in this task, mining leaders will have to realize that mining is a peculiar business that requires an extra managerial function—the management of the mineral resources. The market will certainly reward those companies that not only work harder, but above all, that mine smarter.

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Note: *f*. indicates figure; *t*. indicates table.

About the Author

Juan P. Camus, member of the Society for Mining, Metallurgy, and Exploration, Inc., is a mining engineer graduated from the University of Santiago, Chile in 1979. He began his professional career in Exxon Minerals during the development of its first mining operation in Chile—the Los Bronces project. In 1981, he joined Codelco as a shift boss at the Chuquicamata mine, which at the time was the world's largest open pit copper-mining operation. In 1985, after receiving a master's degree in applied economics from the Catholic University of Chile, he was appointed project engineer and then chief planning engineer at the Andina mine, another Codelco division. In 1987, Camus left Codelco and with other partners he founded Metálica Consultores S.A., a mining consulting firm that became one of the most respected in Chile. As the managing partner of this group, he was involved in many of the large-scale projects and operations in Chile such as Collahuasi, Chuquicamata, Los Pelambres, Andacollo, and Candelaria. Camus also advised domestic and international lending institutions about arranging and structuring loans for the development of important mining projects in Chile.

During his career in Chile, Camus also served as director and later vice president of the Chilean Institute of Mining Engineers. He taught several courses on mine planning and design at the Mining Engineering Department of the University of Chile.

In the fall of 1997, Camus enrolled in the PhD program in mining engineering at Queen's University in Canada, and began writing this book about mineral resource management. During his stay at Queen's, he served as an adjunct professor in open pit mining, and gave numerous seminars on the topics of his research. In the fall of 2000, Camus completed his doctoral program and one year later joined Codelco in Santiago, Chile as managing assistant to the vice president of operations. In 2002 he was appointed corporate manager, mine planning and development. Camus can be reached via email at jcamus@stgo.codelco.cl.

Mining is fundamental to modern civilization, yet the industry that produces such riches is not as lucrative as it may seem. The mining industry's strategy for coping with low profitability has focused primarily on controlling production costs. Despite mechanization, automation, and other technical improvements, the aggregate profitability of mining still falls far short of that realized by most other industries.

Author Juan Camus contends that what is required is not additional technical knowledge, but rather sound management practices that utilize the existing knowledge base more productively. *Management of Mineral Resources: Creating Value in the Mining Business* explores mining *management*—the process of generating plans and supervising their implementation.

This book is concerned with the analysis of some of the internal, controllable factors that influence mining production effectiveness. It combines the best thinking in mining and management so practitioners can devise a concrete strategy for generating maximum shareholder value. Ideas in both of these areas have rapidly evolved in recent years, and this insightful text presents an authoritative review of the current state of the art.

Overall, the book puts forward a systematic approach for conducting the mining business, which challenges the many paradigms and rules of thumb that have been used in mining over the years.

The Society for Mining, Metallurgy, and Exploration, Inc. (SME), advances the worldwide mining and minerals community through information exchange and professional development.

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